VOL. 14, NO. 19, OCTOBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SUBSTANTIATION OF DREDGING TECHNOLOGY OF WATER-BEARING DEPOSITS AT SUBZERO AIR TEMPERATURES

Victor Evgenievich Kislyakov, Ravil Zinnurovich Nafikov, Aleksandr Konstantinovich Kirsanov, Pavel Viktorovich Katyshev, Natalya Aleksandrovna Shkaruba and Ekaterina Vasilevna Zaitseva
Siberian Federal University, Rabochiy Avenue, Krasnoyarsk, Russia
E-Mail: ve.kislyakov@mail.ru

ABSTRACT

The article deals with the problem of reducing dredge performance when operating at subzero air temperatures. This problem is particularly relevant for deposits located in the Far North, where the dredging season is limited by climatic conditions. During the period of subzero air temperatures dredge performance decreases significantly due to the icing of dredge structure. In consequence, dredging operations are terminated until the occurrence of favorable conditions for work. The article presents the review of the existing methods aimed at extending the dredging season, providing their systematization, which is based on the methods of water lanes' maintenance and formation in the open-pit dredging. The authors propose a method to isolate the open-pit mine with artificial materials, as well as consider the application of similar structures in the dredging industry. Existing structures are used to store mineral dumps, protect the environment from dust, as well as for other purposes. It was revealed that the most perspective material to isolate dredges was polycarbonate, possessing a number of advantages. An experiment was conducted to confirm the effectiveness of this method by creating a facility in the form of a hangar model. The hangar model was performed on a scale in compliance with geometric similarity. Thermal sensors and an infrared camera were used to record the results. This allowed obtaining the distribution of thermal fields in the constructed experimental hangar. The developed mathematical model allows determining the temperature inside the isolated space of the open-pit dredging depending on the water temperature of the open-pit and the ambient air temperature. It is revealed that the application of the proposed method will extend the dredging season, or even make it year-round. The authors have calculated hangar sizes while all sizes were accepted minimum for reducing the cost of construction and keeping the heat inside it. The application of the proposed method for straight and oblique dredging was considered. The hangar area was determined for the development of mines with dredges of different standard size. The optimal method of rock excavation was revealed. The authors offer the scope of application, as well as the technology aimed at extending dredging season.

Keywords: placer deposit, dredge, dredging season, systematization, insulating structures, polycarbonate, winter period, productivity.

INTRODUCTION

Currently, one promising area in the dredging industry is the extraction of precious stones and metals, which are contained in placer deposits in significant amounts. The conditions of placer deposit occurrence allow their effective development using relatively simple technology. When developing placer deposits, dredge development method is characterized by high technical and economic indicators. This method can be used to develop water-bearing continental deposits, as well as technogenic accumulations of gold, platinum, and other minerals (Lorey III, 2002; Van-Van-E, 2010; Belov, 2011; Talgamer, Chemezov, 2012; Chemezov, Dementiev, Talgamer, 1990). This method has a number of advantages, such as the ability to be implemented in complex hydrogeological conditions, high efficiency, etc. However, in severe climatic conditions of placer deposits' localization, this method has a significant drawback, which is seasonality of works.

The duration of the dredging season is largely determined by the climatic conditions of the area. Works' seasonality is due to the difficulty of dredge maneuvering in case of ice cover formation in the open-pit, the icing of the rocks in digging buckets and elevator ladder, increasing the degree of wear of the dredging mechanisms that lead to increased downtime for repair and cleaning of ice (Figure-1).

ARPN Journal of Engineering and Applied Sciences

Figure-1. Dredging of placer deposits in Northern latitudes (November).

In the Northern latitudes, the subzero air temperature remains for a long time that reduces the duration of dredge operation and leads to a significant decrease in annual productivity (Kostromin, Yurgenson, Pozlutko, 2007; Bazuin, 2003). In the Northern regions, the duration of the dredging season can be only 160-180 days.

The extension of the dredging season does not always allow achieving the desired economic effect. In the period of subzero air temperature, operating costs increase sharply, while the performance of the dredge falls. Due to decreased performance, the average daily metal alluvium decreases, while its cost increases.

In most cases, when developing water-bearing deposits by dredge method, one limits dredging season without the most reliable feasibility studies. In this regard, the intense development of deposits located in the Far North is hampered. Therefore, the extension of the dredging season in order to improve the efficiency of the use of dredge throughout the year is very relevant.

METHODS

The contemporary development level of equipment and technology allows conducting effective working of the water-bearing deposits in the winter period. Thus, at present, a number of methods are known that allow extending the dredging season during the development of water-bearing fields (Kislyakov, Nafikov, 2016; Garnett, Bassett, 2005; Grayson, 2008; Grayson, 2009; Spence, 1996). These include the development of fields with and without drainage. In the case of drainage, working off deposits is conducted openly or underground. When developing without drainage, underwater dredging is necessary. In this case, the dredging equipment is placed in the coastal zone, under water, above water, or under ice. The extension of the dredging season can be achieved using methods without drainage through the arrangement of equipment above water. At that, these methods can be divided into two main groups: water lanes' maintenance and their formation.

The first set of methods to extend the dredging season is based on the maintenance of water lane (i.e. artificially created in the winter nonfreezing wide channel of water in a field of ice of the quarry water surface, designed to provide technological movements of the dredge in the face).

There are different ways to maintain the water lane. One method is the installation of *propeller pumps* attached to the dredge structure, providing vertical water circulation from the bottom of the reservoir to its surface. Bottom water has higher temperature, so no ice is formed around the dredge. Also, the lane can be effectively preserved by using axial *flow generators*.

The vertical circulation of water and preservation of the water lane can be achieved by creating an underwater *pneumatic curtain*, which can be created by pumping air under pressure from the holes of the collector lowered deep in water or laid on the bottom. The air is supplied to the collector from the compressor attached to the dredge or installed on the ice surface if it is mounted on a trolley or sled.

A *chemical method* is another possibility to preserve the nonfreezing lane. For example, in France, water areas were kept in a nonfreezing condition during the winter by sprinkling water with sodium alginate and zinc stearate. These substances contribute to the creation of soft spongy snow on the water surface instead of ice cover. However, due to the negative impact on the environment, this method has not been widely used.

Attention is drawn also to the idea of using *groundwater*. The implementation of this idea in the highlands of Colorado (Canada) for water supply has had a significant economic effect. It is assumed that the use of water from groundwater wells will be effective to extend the dredging season.

The method of preserving nonfreezing water areas using *hot water* or *steam*, taken from the boiler plants of the dredges, is also widely used in dredge operation in the winter.

The use of *floating foams* is known as well. The isolation of the water surface of the open-pit against the impact of subzero ambient temperature prevents the formation of ice.

One method of water lane maintenance is the isolation of open-pit by natural materials, such as ice, against the impact of subzero temperatures. This method is

ARPN Journal of Engineering and Applied Sciences

implemented as follows. Before the onset of subzero temperatures, the water level is raised above the dredge, and reserves are prepared, while fixings are installed at the height of the increased water level. After ice formation, water is discharged to the previous level, while dredging and processing work, as well as dumping during the winter period, are carried out under the ice cover.

However, in practice, for greater efficiency, *combined methods* are usually used, combining several ways of water lane preservation.

The second group is based on the processes of water lane formation (opening of the ice cover). This group includes the following methods.

Chemical method of breaking the ice; in this case, calcium chloride, sodium, ammonium, potassium, as well as sodium sulfide, sodium fluoride, and potassium bicarbonate are used as reagents. The rate of ice thawing depends on the selected chemical, ice structure, ambient temperature, and other factors. In consequence of the application of this method, the ice thaws in form of a uniform layer along the height from top to bottom.

One main advantage of this method is the high rate of chemical reactions that affect the ice. Under natural conditions, salt lumps can penetrate into the ice to a depth of 20 to 70 cm per day.

The main disadvantages of this method are the high cost and negative impact on the chemical composition of natural watercourses, so in practice, this method is usually not used.

Mechanical methods of ice failure: mechanical methods include the break-up of ice by *ice-cutting machines*, which are designed to cut ice up to 1.2 m thick. These methods have advantages such as the possibility to transport the dredge from one reservoir to another by land that can significantly reduce their fleet, concentrating equipment in the most dangerous area. They are characterized by the reliable operation, the independence of the results on the operating conditions, as well as harmless effect on the environment.

Along with the advantages of using ice-cutting machines, there are a number of disadvantages. These include the inability to use machines to eliminate congestion formed during the spring ice drift. Basically, these machines are suitable only for preventive measures.

Another effective method of mechanical treatment of *ice cover* in the course of water lane formation is cutting ice with *steam, water, or electric thermal cutters*.

Steam cutter: according to the practical experience in using steam cutters when forming water lanes in the Far North, the ice cutting speed using these cutters is 50-200 m/h for ice with a thickness of about 1 m.

It may be advisable to form a water lane using *thermal water cutters* consisting of a copper tube with hot water flowing inside. The cutting speed of 40 cm ice is about 30 m/h.

Electro-thermal cutting of ice is carried out by heating nichrome wire through an underwater cable. The cutting speed of one-meter thick ice is about 20-30 m/h.

Icebreaker consoles: to implement this method, an icebreaker, made in the form of a plate, should be attached to the dredge structure. In the course of dredge movement, the plate approaches the lower base of the ice due to the crank mechanism and breaks the ice.

Manual ice cutting: this method in most cases is auxiliary. Usually, the use of manual work is associated with the cleaning the elevator ladder, pile machine, or other components of the dredge against ice frozen over. In the absence of other means for water lane formation, manual cutting of ice is the main method of ice cover break-up. However, these works are very inefficient, because they are associated with high costs of labor and money.

Excavating method when forming water lane is rarely used in hydraulic excavation practice. This method can be recommended to break-up the ice cover with a thickness no more than one meter. In this case, the excavator is alternately equipped with a wedge and a mesh ladle. The main drawback of this method is large energy intensity and cost.

One of the directions of water lane formation is the *use of blasting*. This method is most effective when other methods of ice break-up do not give successful results. Also, the advantages of the method include relatively rapid use of measures to combat congestion. The method is usually used when the thickness of the ice exceeds one meter. In addition to ice break-up, blasting is used for rock breakage to facilitate the excavation of rocks by the dredge.

In practice, for the more effective break-up of the ice cover, in most cases, *combined methods* of water lane formation are used.

RESULTS

The considered methods of the dredging season prolongation, the main elements of which were water lane maintenance and formation, made it possible to develop their systematization (Figure-2). Also, in the course of the conducted review of existing methods to extend the dredging season during the development of deposits, it was revealed that none of them was widespread. This is primarily due to the high economic and energy costs, labor intensity, as well as environmental damage.

ARPN Journal of Engineering and Applied Sciences

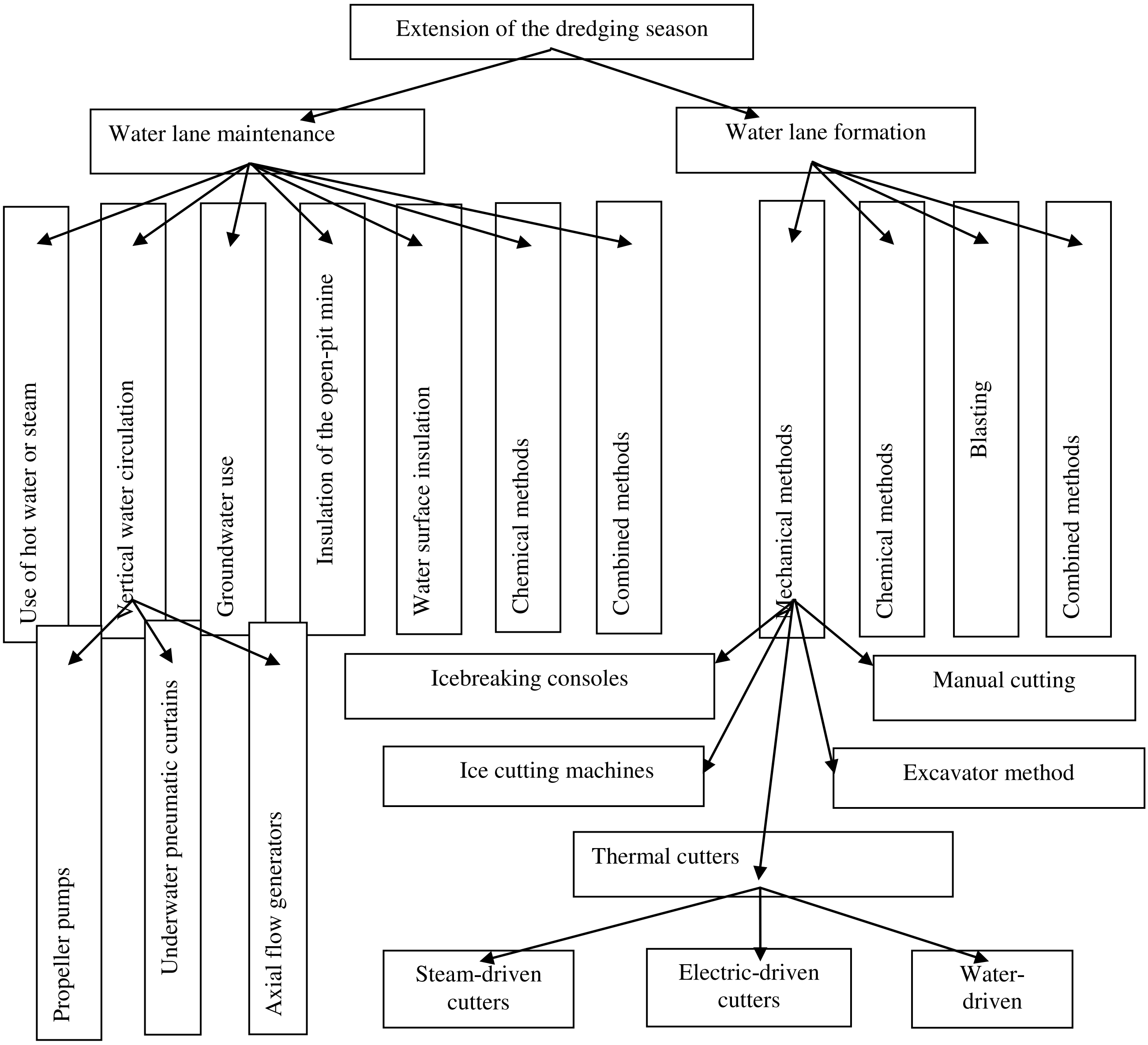


Figure-2. Systematization of methods to extend the dredging season under subzero air temperatures.

In order to eliminate all the above shortcomings, new technical solutions are needed. The most promising way to extend the dredging season is a method based on isolation of the dredging open-pit from exposure to subzero air temperatures. However, the existing method based on the use of ice has a number of disadvantages, such as the high risk of caving of the ice mass, the complexity of the technology, large downtime during the freezing of the required water layer, as well as the annual need to create water-raising dams with subsequent flooding of the inter-dam space.

Consider the possibility of replacing the ice with artificial materials to exclude the above disadvantages. Today, the construction of this type structures for industrial needs can be carried out by many companies around the world. In the dredging industry, actively using similar technology, one can distinguish the Geometrica construction company, which designs industrial buildings that do not contain columns, for the unrestricted arrangement of the equipment. These structures are designed to protect the environment from dust, to store dumps of minerals, fuel, hazardous materials, and other purposes. These designs of spherical and longitudinal shape are presented in Figure-3.

VOL. 14, NO. 19, OCTOBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Figure-3. Insulating structures produced by Geometrica used in the dredging industry.

The above-noted designs are made of materials that do not transmit sunlight. For the proposed method, light-transmitting materials should be used, since in this case, it would be possible to exclude the cost of artificial lighting, as well as increase the temperature of the air inside the hangar due to natural insolation (irradiation with direct sunlight). Organic glass, as well as cellular or monolithic polycarbonate, having low thermal conductivity, can be used as such materials. Besides, these materials have advantages such as ease of operation and safety. Having studied the technical specifications, as well as the cost of the materials presented, polycarbonate was chosen as the most promising material for the proposed method. The advantages of polycarbonate include low specific gravity, low thermal conductivity, resistance to the rapid temperature drop, durability, and high light transmission capacity.

To confirm the effectiveness of the proposed method, an experiment was conducted. For this purpose, the experimental setup was designed in the form of a hangar model. Its schematic diagram is shown in Figure-4.

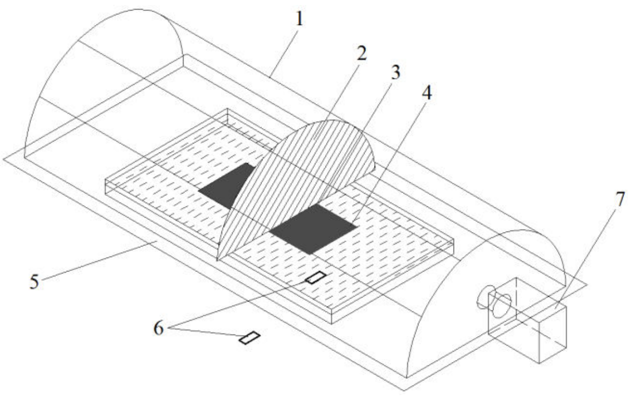


Figure-4. Schematic diagram of the experimental setup: 1- hangar; 2 - foil screen; 3 - dredge model; 4 - water tank; 5 - base; 6 - temperature sensors; 7 - infrared camera.

The setup is designed on a scale of 1: 100 for the 250-liter dredge. It is 270 mm high, 520 mm wide and 1,250 mm long. The hangar walls are made of cellular polycarbonate. The thickness of the polycarbonate chosen for the experiment was 3.5 mm, and the light transmittance was equal to 0.92. The hangar is installed on a solid base and all gaps are sealed in such a way as to exclude free circulation of air between the hangar and open air. The abutting end has a hole to install the infrared camera of IR928+ model. The camera is designed to measure the distribution of temperature fields inside the hangar that is required to determine the average temperature. The infrared camera is designed to measure temperatures within the range from -20 to 500°C with an accuracy of 2°C.

In the central part of the hangar model, a foil screen is installed to record the distribution of thermal fields. A container of 0.01 m^3 in volume filled with water is placed under the screen. Temperature sensors are installed both in the water container and outside the hangar to measure the water and air temperature.

The experiment was carried out in five stages at an ambient temperature ranged from -11 to -3°C. During each stage, a water tank was placed in the hangar. The initial water temperature at which the thermal fields in the hangar were taken was 20°C. Further, the measurements were carried out when the water temperature decreased to 18, 16, 14 and 12°C. In order to eliminate errors in the measurements, the initial water temperature was taken at 5°C higher than that required in the experiment. This was done to ensure that at the beginning of the measurements of the air, temperature in the hangar was distributed naturally.

The Guide IrAnalyser software was used to visualize the images of an infrared camera. The temperature field distributions in the experimental setup are shown in Figure-5.

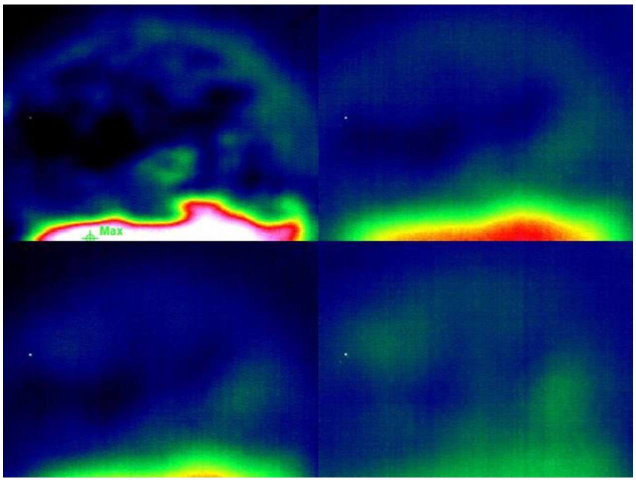


Figure-5. Examples of temperature field distributions in a dredge hangar.

To determine the average temperature in the hangar, images of the thermal field distributions were divided by means of Guide IrAnalyser software into isotherms limiting the fields with the same temperature.

The number of areas with the uniform temperatures was determined depending on the maximum temperature difference in the hangar. Thus, for images with temperature differences of 18°C, 6-7 thermal areas were distinguished, while for images with differences equal to 5°C, this number was reduced to 3-4.

Next, the photographs with isotherms were exported to AutoCAD software environment to digitize and determine the areas of temperature fields. The results obtained were used to calculate the weighted average temperature of the air inside the hangar using the formula:

$$T_a = \frac{T_i \cdot S_i + ... + T_n \cdot S_n}{\sum_{i=1}^{n} S}, \text{°C}, \quad (1)$$

where T_i was the temperature of the i-th thermal field, °C; S_i was the area of the i-th thermal region, cm^2.

Based on the data obtained, a graph was plotted to represent the dependence of the air temperature in the hangar on the water temperature and the ambient air temperature. These dependencies had a linear character:

$$T_a = a \cdot T_{вод} + b, \text{°C}, \quad (2)$$

where T_{water} was the water temperature, °C; *a* and *b* were the empirical coefficients.

Using multiple correlation method, a mathematical model was obtained, which allowed determining the temperature of the air inside the hangar, depending on the temperature of water and ambient air with an error not exceeding 10%:

$$T_a = (0.04 \cdot T_{air} + 0.38) \cdot T_{water} + (1.72 \cdot T_{air} + 8.19), \text{°C}, \quad (3)$$

where T_{air} was the ambient temperature, °C.

In consequence of the conducted experiment, it was revealed that the temperature inside the hangar was higher than the ambient temperature that allowed extending the dredging season.

DISCUSSIONS

When using the proposed method, the compliance of the size of the hangar with the dredge parameters should be taken into account. The main dimensions of the hangar include height, length, and width. Overall dimensions of the hangar should ensure the safe maneuvering of the dredge at all stages of field development. At the same time, the hangar dimensions should be as small as possible to reduce the cost of hangar construction and keep the warmth inside it.

The minimum permissible hangar height depends on the dredge type, its characteristics, as well as the technological parameters of the field development, and is determined by the formula:

$$H_h = H_{dr} - H_{draft} - H_{fb} + \varepsilon, \text{ m}, \quad (4)$$

where H_{dr} is the overall height of the dredge, m; H_{draft} is the draft height of the dredge, m; H_{fb} is the height of the freeboard worked placer deposit, m; ε is the safe gap between the hangar and the dredge, equal to 0.5 m.

The calculated heights of the hangar for dredges of different models are presented in Table-1 for the maximum freeboard height.

Table-1. Calculated values of the minimum allowable height of the hangar structure.

The volumetric capacity of digging buckets, l	The overall height of the dredge, m	The draft height of the dredge, m	The height of the freeboard of declining placer deposit, m	The minimum permissible hangar height, m
50	9.2	1.4	1	7.3
80	17	1.7	1	14.8
150	21.6	1.8	2	18.3
250	25.7	2	3,5	20.7
380	39	2.7	4	32.8

The length of the hangar depends on the dredge model and technical specifications, and is determined by the formula:

$$L_H = L_{dr} - a_{dr} \cdot n + L_{cv} + 2 \cdot \delta, \text{ m}, \quad (5)$$

where L_{dr} is the overall length of the dredge, m; a_{dr} is the dredge stepping, m; n is the number of stepping within the hangar; L_{cv} is the caving length of the front bank, m; δ is the width of the prism of possible caving, m.

The results of the hangar length calculations (n=1) are presented in Table-2.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-2. The estimated values of the minimum allowable hangar length.

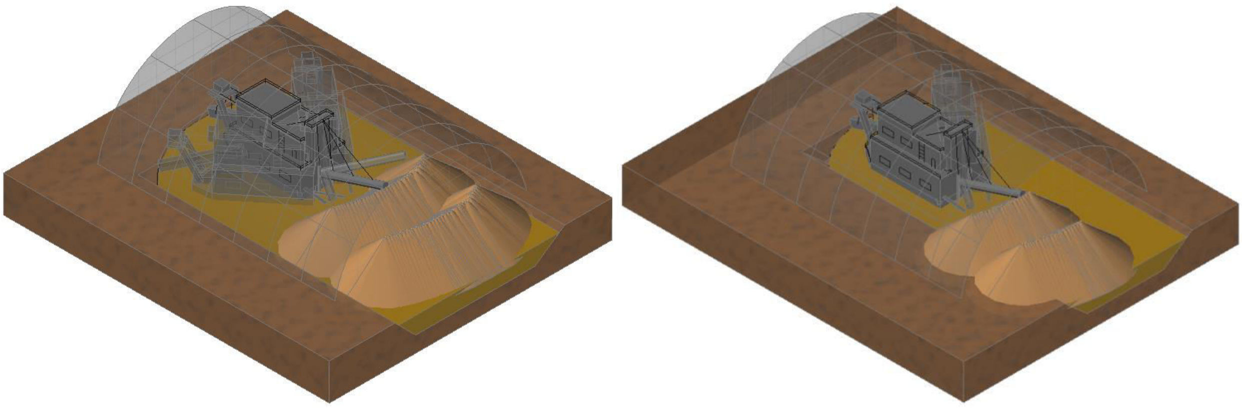
The volumetric capacity of digging buckets, l	The overall dredge height, m	Optimal stepping providing most complete excavating, m	Minimum allowable hangar length, m
50	34,5	2	45
80	50	2,5	61
150	74.6	3.25	87
250	92	4	106,5
380	156.2	5	174.7

The hangar width at the base is determined by the following expression:

$$B_{\text{k}} = B_{\text{m}} + 2 \cdot L_{\text{cv}} + 2 \cdot \delta \text{, m,} \quad (6)$$

where B_k is the width of the dredge maneuvering, m.

According to the obtained formulas, we determine the necessary dimensions of the hangar when continue field development by straight and oblique dredging. Noted dredge development schemes of deposits using the proposed method are shown in Figure-6.



(a) (b)

Figure-6. Schematic diagrams of the open-pit dredging when developing the deposit in the winter by straight (a) and oblique (b) dredging.

For these methods, the hangar area was calculated for different size dredges. At that, safe distances were taken into account for maneuvering the dredge at all development stages of the placer deposit.

According to the results obtained, it was revealed that the hangar area in case of straight dredging was greater than that at the oblique dredging by an average of 18%. However, since the width of the approach at straight dredging was much larger, this led to a decrease in the number of dredge stepping, the length of the section to be worked out in the winter, and the volume of preparatory work in the spring. In consequence of the conducted research, it was established that it was economically more viable to build the hangar allowing dredge to maneuver safely at the field development by straight dredging with periodic field development by oblique dredging.

This method is recommended for the development of long narrow and medium placer deposits (terrestrial and key placer deposits) according to a single-longitudinal scheme. At single-transverse, adjacent-longitudinal, and adjacent-transverse schemes designed for wide and very wide placer deposits (floodplain, channel, and bench placer), the use of this method is impractical due to the complexity and the significant cost of hangar construction. Also, when working out several adjacent faces, the installation of a hangar on a pontoon or an air cushion was discussed, however, the implementation of these methods in practice was very labor-intensive due to the freezing of the reservoir in the winter.

The proposed method assumes that, when dredging operations are carried out in the summer, the stripping of polygons intended for working out in the winter should be conducted, and bedrock cuts should be made. In the early autumn, insulation of exposed sands should be carried out by laying insulating coatings on them, flooding of prepared reserves, preliminary loosening of the soil, etc. In the late autumn with the onset of frost, the dredge starts working out the prepared reserves. At the same time, the hangar assembling is carried out. During this period, it is recommended to carry out repairs. After completion of the construction, dredging and processing work, as well as stacking for the winter period, are carried

ARPN Journal of Engineering and Applied Sciences

out inside the hangar. In all cases, a layout of work should be conducted in such a way as to ensure continuous production of a single working area throughout the winter period.

CONCLUSIONS

Based on data resulting from the performed calculations, it was found that the application of the proposed method with respect to placer deposits located in the area of 63 degrees north latitude allowed extending dredging season from 180 days to 240 (Figure-7). When developing fields located southward, it is possible to produce their development year-round due to the maintenance of the open-pit dredging in the nonfreezing condition. As a result, the annual productivity of dredge increases by 20-35%.

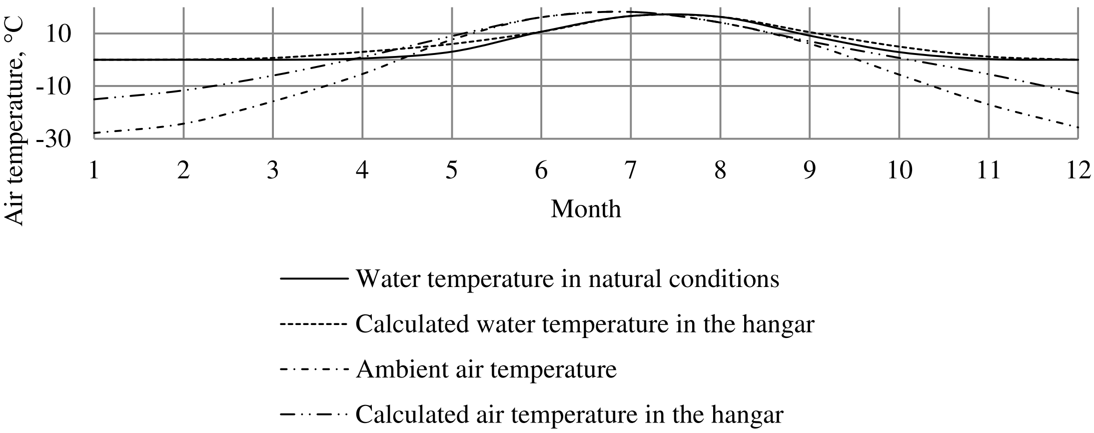


Figure-7. Air and water temperature dynamics in the hangar.

The payback period of the hangar will be 1-3 years, depending on the dredge model, its technical specifications, as well as the dredging and geological conditions of the deposits. At that, it should be noted that in most cases the warranty period of polycarbonate is 10 years, although in practice this figure can reach 25 years.

REFERENCES

Bazuin G. 2003. Successful gold dredging in severe winters: Abstract. World Placer Journal. 3.

Belov S. V. 2011. Tekhnogennye mestorozhdeniya zolota: sostoyanie i perspektivy osvoeniya [Technogenic gold deposits: Development state and prospects]. Gold Mining Industry. 4.

Chemezov V. V., Dementiev S. A., Talgamer B. L. 1990. Sokrashchenie poter' poleznogo iskopaemogo pri povtornoj razrabotke glinistyh rossypej dragami [Reduction of mineral losses when redeveloping clay deposits with dredges]. Yakutsk, Resource-saving technologies in the open dredging of minerals of the North. pp. 57-60.

Garnett R. H. T., Bassett N. C. 2005. Placer deposits. Economic Geology. 100, 813-843.

Grayson R. 2008. Bucket-line gold dredges: A review of world techniques. World Placer Journal. 8, 1-41.

Grayson R. 2009. The Gold Miners Book - BAT for Placer Gold Miners. Pilot edition, CD published by Eco-Minex International Ltd. pp. 1700.

Kislyakov V. E., Nafikov R. Z. 2016. Parametry izoliruyushchej konstrukcii pri drazhnoj razrabotke v usloviyah otricatel'nyh temperatur [The parameters of the insulating structure during dredging at subzero temperatures]. Bulletin of Tula State University, Earth Sciences. 2, 95-101.

Kostromin M. V., Yurgenson G. A., Pozlutko S. G. 2007. Problemy drazhnoj razrabotki kontinental'nyh rossypej [Development problems of dredging continental placer deposits]. Novosibirsk, Nauka. pp. 180.

Lorey III F. 2002. The golden age of gold dredges. International California Mining Journal. 71(10).

Spence C. C. 1996. The northern gold fleet: Twentieth-century gold dredging in Alaska. Urbana Illinois, University of Illinois Press. p. 302.

Talgamer B. L., Chemezov V. V. 2012. Ocenka tekhnogennyh rossypej i metodov opredeleniya ih zapasov [Assessment of technogenic placer deposits and methods to determine their reserves]. Bulletin of the National Research Irkutsk State Technical University. 12(71): 126-130.

Van-Van-E A. P. 2010. Resursnaya baza prirodno-tekhnogennyh zolotorossypnyh mestorozhdenij [Resource base of natural and man-made gold deposits]. Moscow, Publishing House of Moscow State Mining University.