Design analysis of the mining ship to the extraction of Fe-Mn

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Abstract

In the last years, in the area of mining polymetallic nodules has been made a lot of progress in their search, assessment of the marine environment, the development of mining technology, was developed a framework for political and legal and made economic analysis.

Therefore, is increasingly becoming a feasible mining of Fe-Mn on an industrial scale. One of the basic elements of the whole system of mining is mining ship, hence the article presents a scheme the determination of its size depending on the initial parameters, i.e.: the annual efficiency of mining and storage period of excavated material in the holds of the ship. Determined dependence of regression to the preliminary forecasting ship size by using the information from drill ships – deemed similar in terms of functional and architectural. As a result of analyzing the main compartments of the vessel was estimated the percentage of volume in the hull of the vessel. Performed visualization of spatial design concept of mining ship.

Introduction

At the turn of the last decades can be observed changes in supply and increasing in raw materials demand. As a results may be more and more difficult sourcing certain raw materials, i.e. iron, copper, nickel, chrome or gold.

Depletion of resources, as well as energy resources and other mineral resources is forcing humanity to explore new sources which are found in the seabed and oceanbed.

Ocean polymetallic nodules fields are an excellent opportunity to obtain already deficit strategic metals and rare earths.

The value of industrial have a especially nodules fields sulfide and oxide-iron-manganese [1].

Poland holds great potential when it comes to exploitation of Fe-Mn due to the right to the parcels in one of the richest in raw materials oceanic zones – Clarion – Clipperton, situated in the eastern part of Pacific Ocean.

In the last years in the area of mining polymetallic nodules has been made a lot of progress in their search, assessment of the marine environment, the development of mining technology and developed a framework for political and legal and made economic analysis.

One of the basic elements of the whole system of extraction is mining ship. Due to the missing of built ships – up till now, ships such a purpose as well as the missing of design concepts and space distribution of the main compartments of the unit, elaborated scheme of determining size of the ship and its main compartments.

The performed research aim to find the relationship between the rate of mining and the main parameters of the vessel which can be useful for system optimization e.g. costs of mining nodules from seabed.

Characteristics of the ship – the main element of the system of mining nodules

The mining process of Fe-Mn nodules – as the main task of the mining system – will be implemented by three basic appliances such as: bottom vehicle collector, vertical mining pipe line and conventional single-hull mining ship. The basic function of the mining ship will provide:

– the relevant volume of the hold on the mining mixture: nodules with water which is strictly the result of the rate of mining the nodules of mining pipe line and the time interval of storing the nodules in mining ship holds;
– the relevant volume for mining shaft with specialized assistive devices, process mining, the stabilized hoist tower and mining casing fitted with mining pipe line;
– maintenance of several kilometers mining pipe installation;
– the relevant volume of the magazine for the reserve pipes mining, transport mining vehicle collector (main and spare) and workshops onboard;
– the relevant volume of the engine room which results from large power demand for numerous power consumers;
– the volume of the superstructure, providing adequate domestic and social conditions of crew;
– the relevant volume storage tanks and ballast, ensuring stability and good maneuverability characteristics.

Assumption and input date

Analysis of the project of the mining ship has been carried out for the following input data (Table 1) and assumptions about the assumed properties of nodules in the area of extracting (Table 2).

Determination of main dimensions of mining ship

Estimation of the main dimensions of the ship has been developed on the basis of:
– statistical analysis of vessels (architecturally and functionally), similar vessels such as drilling vessels [2, 3], due to the lack of built mining ship;
– initially estimated parametric functions to determine the main dimensions according to [2];
– the range of variation of parameters, first of all, i.e.: L/B, B/T (with drilling vessels [2, 3]) which have a decisive effect on the maintenance of good seakeeping.

Dimensional analysis began from the foundation of the breadth $B = 32.24$ m – due to the limitations of the Panama Canal.

Schema the designation of the main parameters and dimensions of the mining ship at the preliminary design is shown in figure 1.

The weight load was calculated from the following formula:

$$M_L = \frac{Q_{mk}}{T_e} \qquad (1)$$

The volume load was calculated from the following formula:
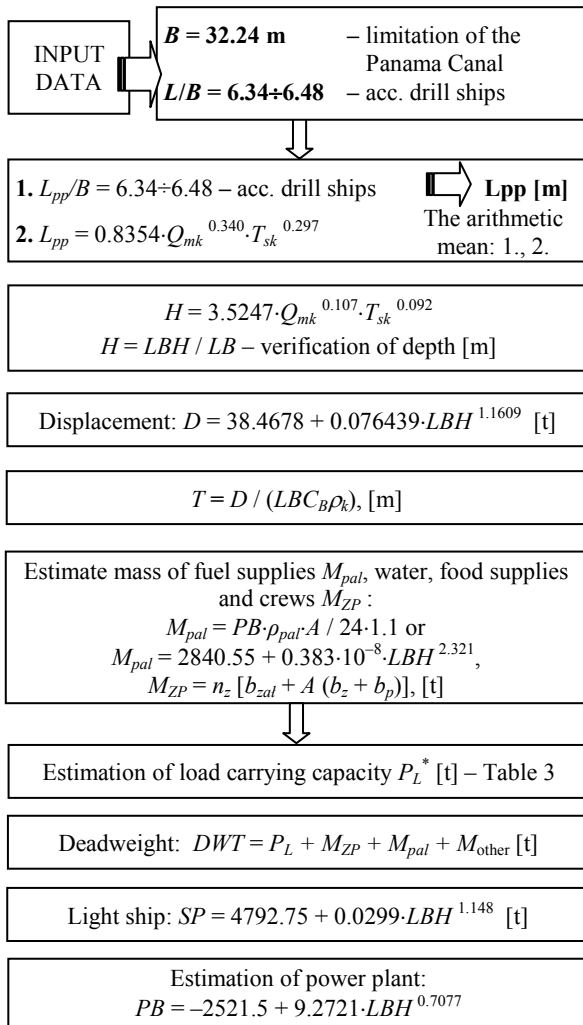
$$V_l = \frac{M_L}{\rho_k} \qquad (2)$$

Table 1. Input date

No.	Parameters / Unit	Variant 1	Variant 2	Variant 3
1	Yearly rate of mining the wet nodules Q_{MK} [t/year]	1,400,000	1,750,000	2,100,000
2	Theoretical rate of mining the nodules Q_{theor} [t/h]	200	250	300
3	Theoretical rate of mining the nodules Q_{theor} [t/days]	4795	5993	7192
4	Operation time interval [days/year]	292	292	292
5	The water depth of mining h_w [m]	4600	4600	4600
6	System of the mining nodules	vertical mining pipe line		
7	Time interval of storing the nodules T_{sk} [days]	8, 10, 12 + reserve 1		
8	The autonomy of the ship A [days]	15		
9	Number of crew n_z [perons]	145	148	150
10	Hull block coefficient C_B [–]	0.835	0.840	0.845
11.	Fuel consumption ρ_{pal} [g/kWh]	210		

Table 2. Input date – properties nodules Fe-Mn [6]

No.	Characteristic deposits of polymetallic nodules	Value	Unit
1	Mining of area	Clarion-Clipperton	–
2	Deep of mining	4500 – 5500	[m]
3	Shape, form	Irregular lumps, fragile	
4	The contents of minerals	Approx. 50 metallic and non-metallic components (important are: nickel, cobalt, copper, iron, manganese, molybdenum, zinc)	–
5	The average unit area concentration	Approx. 10	[kg/m^2]
6	Average density of concretions	Approx. 2–3	[t/m^3]
7	The content of water	about 40 dry weight	[%]
8	Density – dry / wet of nodules	1.22–1.39 / 1.94	[g/cm^3]

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│  INPUT   │  │ B = 32.24 m    – limitation of the│
│  DATA    │  │                   Panama Canal    │
│          │  │ L/B = 6.34÷6.48 – acc. drill ships│
└──────────┘  └─────────────────────────────────┘
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1. $L_{pp}/B = 6.34÷6.48$ – acc. drill ships   ➡ **Lpp [m]**

2. $L_{pp} = 0.8354 \cdot Q_{mk}^{0.340} \cdot T_{sk}^{0.297}$ The arithmetic mean: 1., 2.

$H = 3.5247 \cdot Q_{mk}^{0.107} \cdot T_{sk}^{0.092}$

$H = LBH / LB$ – verification of depth [m]

Displacement: $D = 38.4678 + 0.076439 \cdot LBH^{1.1609}$ [t]

$T = D / (LBC_B\rho_k)$, [m]

Estimate mass of fuel supplies M_{pal}, water, food supplies and crews M_{ZP} :

$M_{pal} = PB \cdot \rho_{pal} \cdot A / 24 \cdot 1.1$ or

$M_{pal} = 2840.55 + 0.383 \cdot 10^{-8} \cdot LBH^{2.321}$,

$M_{ZP} = n_z [b_{zal} + A (b_z + b_p)]$, [t]

Estimation of load carrying capacity P_L^* [t] – Table 3

Deadweight: $DWT = P_L + M_{ZP} + M_{pal} + M_{other}$ [t]

Light ship: $SP = 4792.75 + 0.0299 \cdot LBH^{1.148}$ [t]

Estimation of power plant:
$PB = -2521.5 + 9.2721 \cdot LBH^{0.7077}$

Fig. 1. Schematic estimate dimensions and the main design parameters of mining ship

On figure 1 * for purposes of determining vessel capacity, mass and volume loads calculated (for the assumed yearly rate of mining the nodules) – results of calculations are shown in table 3, and then by determining the hold concept (Fig. 2), the calculated volume of the compartment. Hold dimensional parameters for mining ship are shown in table 3.

Table 3. The results of calculations of vessel capacity and dimensions of cargo holds

| No.	The calculated parameter	$T_{sk} = 10$ [days]		
1	Q_{mk} [t/m³]	140,0000	175,0000	210,0000
2	Operation time interval T_e [days/year]	292	292	292
3	Weight load M_L [t]	4795	5993	7192
4	Density of nodules ρ_k [t/m³]	2.00	2.00	2.00
5	Volume of holds V_l [m³]	2397	2997	3596
6	Volume of holds + reserve 1 day [m³]	26,370	32,962	39,555
7	The volume of cargo holds in 96% [m³]	25,315	31,644	37,973
8	Load capacity P_L [t]	**52,740**	**65,925**	**79,110**
9	Breadth B [m]	32.2	32.2	32.2
10	Depth H [m]	18.9	19.3	19.7
11	Breadth of cargo holds B_{load} [m]	**26.2**	**26.2**	**26.2**
12	Depth of cargo holds H_{load} [m]	**14.6**	**15.0**	**15.4**
13	Length of cargo holds L_{load} [m]	**68.8**	**83.5**	**97.8**
14	Volume module of cargo holds $(LBH)_{load}$ [m]	26,317	32,816	39,460

The stabilized hoist tower mining
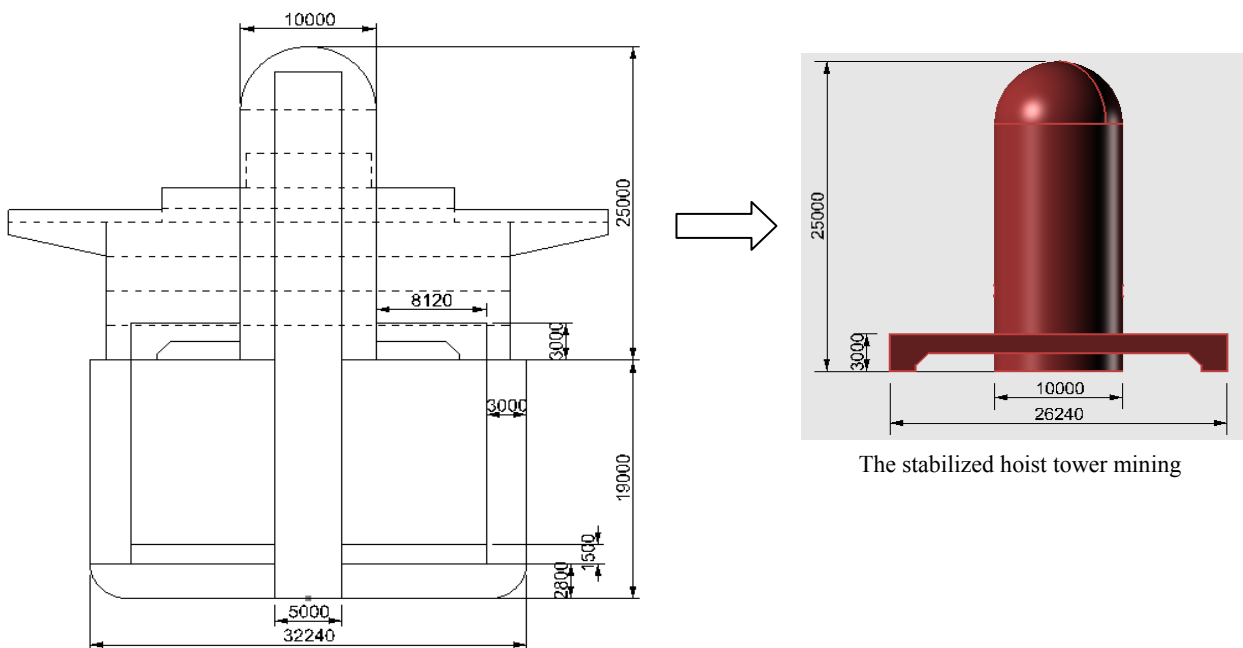
Fig. 2. Section of the mining ship – view of the hold ($Q_{MK} = 1,400,000$ [t/year], $T_{sk} = 10$ [days])

Under the holds of the ship, provided for additionally compartment (height 1.5 m) for various types of piping, related to the function of the main system extracting nodules, etc.

Verification of the basic design equation

Verification of dimensions consists in pre check the basic equation of buoyancy, connecting with the main dimensions of the masses, i.e.:

– displacement in function of the main dimensions [t]

$$D = L \cdot B \cdot T \cdot C_B \cdot \rho_w \cdot k \qquad (3)$$

– displacement in function of the masses [t]

$$D = DWT + SP \qquad (4)$$

then:

$$L \cdot B \cdot T \cdot C_B \cdot \rho_w \cdot k \geq DWT + SP + \\ + \text{possible reserve } SP \qquad (5)$$

Determination of modulus of volume for the main compartment of mining ship

Determination of the weight of the mining pipe line

Input data mining pipe line:
- Outer diameter of the pipe $D_w = 0.27$ m;
- Internal diameter of the pipe $D_z = 0.25$ m;
- Wall thickness $t = 0.01$ m;
- Material: stainless steel with a density $\rho_s = 7.85$ t/m^3;
- The length of pipe $L_r = 9$ m;
- The surface area of the pipe $A_r = 0.00817$ [m^2].

The results of calculations of weight and volume of pipes depending on the depth mining – are shown in table 4.

According to the idea of the autor particular pipe line will be storage in the stock in forward part of hull the ship. The dimensions of the store are shown in figure 9.

The pipes will be stored in the modulus 6×6 pcs. and a lenght of 9 m. Dimensions of volume modulus with structure are shown in figures 3 and 4.

Table 4. The weight and volume of the pipes for the mining pipe line

h_w [m]	Volume of the pipes [m^3]	Weight of the pipes [t]	Quantity of pipe 9 m [pieces]	Reserve (20%) [pieces]	Weight of the pipes + reserve [t]
1000	8.17	64.0	111	12	83.0
2000	16.3	128.2	222	24	165.0
3000	24.5	192.4	333	36	250.0
4000	32.7	256.5	444	48	331.0
4600	**37.6**	**295.0**	**511**	**56**	**381.0**
5000	40.8	320.6	556	62	415.0
6000	49.0	384.7	667	74	496.0

Modulus of pipes will be transported on board the ship with a crane of suitable deadweight, and then transported in the aft part of ship. On board the vessel at the stern part provided for a gantry crane, providing particular pipes to the stabilized hoist tower mining , in which (on the working deck) will be assembled and lowered in the depths of the sea.

- Volume one module pipe 9 m, $V_{\text{module}} = 22.75$ m^3;
- For mining depth $h_w = 4600$ m are needed 16 modulus of pipes;
- Volume – to 16 modulus of pipes 9 m, $V_{\text{module 16}} = 364$ m^3.

The concept arrangement of mining pipes lines as well as internal transport the ship's hull was based on the solutions used on offshore ships, acc. to [4, 5, 6].
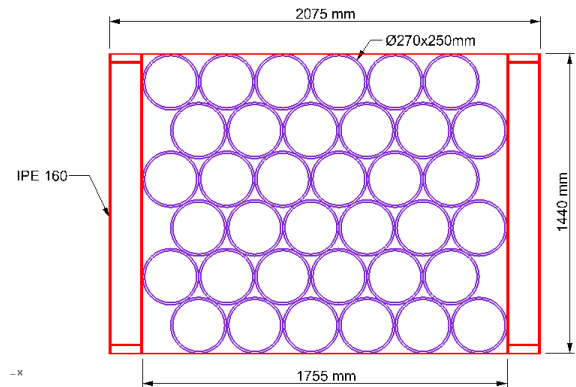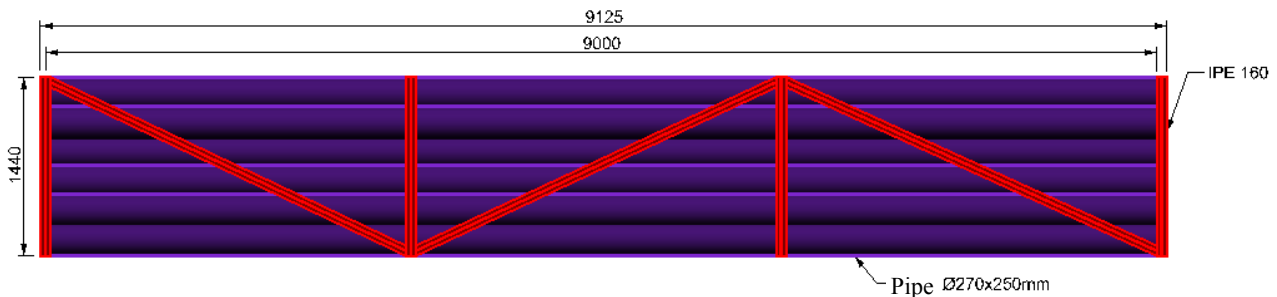

Fig. 3. The module of pipe – cross section

Fig. 4. A concept transport module of pipe – side view

The storage for mining pipes, spare parts and bottom vehicle collector

The dimensions of pipe lines storage on the mining ship:

$$L_m \cdot B_m \cdot H_m = 15 \cdot 26.2 \cdot 16.2 \ [m]$$

In hold for pipe lines on the platform provided for space for the bottom vehicles collector – 2 pieces (main and spare).

Figure 5 shows the view of arrangement of modulus of pipes and spare vehicles collector in hold of storage pipes lines.
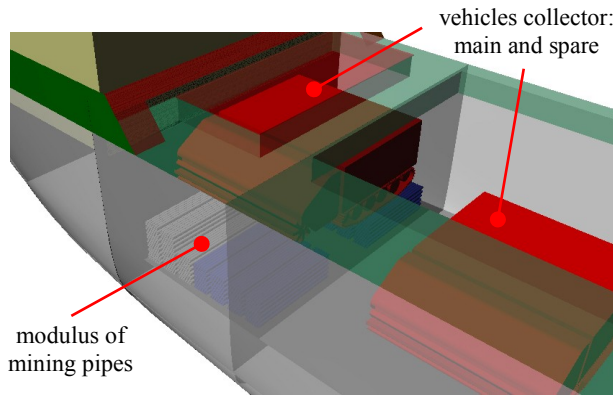

Fig. 5. 3D view on hold on pipes and a spare bottom vehicle collector on ship

The module transhipment installation

Calculations capacity of the transhipment installation on transport vessels were carried out for following assumptions:

– unloading time/transhipment time $T_{trans.} = 12$ [h];
– piping with zero buoyancy finished with ball connector.

Examples of calculation results transhipment capacity depending on the efficiency of mining of nodules presented graphically in figure 6.
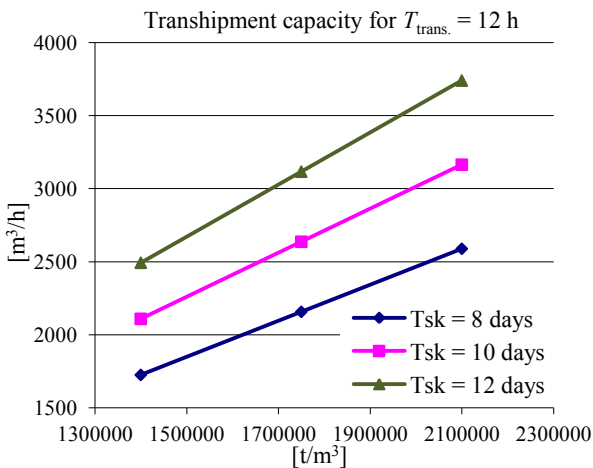

Fig. 6. Productivity reloading according to productivity mining

After estimating the capacity of transhipment shall be select pumps of suitable diameter and a correspondingly high the capacity, enabling the flow of nodules on ships.

Based on catalog data should also be estimate the power plant of transhipment installation.

On this stage is difficult to assess the volume module, how much space it will take the transhipment installation in the hull.

A module of residential – manned compartment (accommodation)

Surface area and volume module superstructure was determined depending on the number of crew n_z. For this purpose also used information from drilling ships and compiled on based their functional dependencies.

Assumption:

Width superstructure: $B_{sup.} = 29.74$ m;

Average height of the stories of the superstructure: 2.7 m.

• The surface area of the superstructure:

$$lb_{sup.} = 236.551 + 0.0741 \cdot n_z^{1.736} \qquad (6)$$

• Module volume of the superstructure:

$$Lbh_{sup.} = 1525.33 + 0.013372 \cdot n_z^{2.70417} \qquad (7)$$

• The length of the superstructure:

$$l_{sup.} = lbh_{sup.} / bh_{sup.} \qquad (8)$$

Mining ship will have 6 floors in superstructure.

A module of engine room

To determine module of volume of engine room on the mining the vessel shall be know total power for propulsion system.

Assumption:

Width engine room $b_{eng.} = B - 2 \cdot h = 26.24$ m (B – breadth, $h = 3.0$ m – double side).

Surface area and volume module engine room was determined depending on the total power engine room (based on drill ships). Developed on basis regression formulas to estimate the size of the engine room:

• The surface of the engine room $lb_{eng.}$:

$$lb_{eng.} = 69.635 + 0.023 \, PB \ [m^2] \qquad (9)$$

• Module volume of the engine room $lbh_{eng.}$:

$$lbh_{eng.} = -4203.9 + 20.8385 \, PB^{0.6442} \ [m^3] \quad (10)$$

• The length of the engine room $l_{eng.}$:

$$l_{eng.} = lb_{eng.} / b_{eng.} \ [m] \qquad (11)$$

Spatial arrangement of mining ship

Designed mining ship is a vessel with a single hull with a transom stern. The midship part is used to accommodate the following:

- the stabilized hoist tower and winning casing fitted with mining pipe line – dimensions are shown in figure 2;
- the compartment with devices supporting the mining nodules process and internal transport them to cargo hold (Fig. 9);
- the hold compartments (on aft and fore side of the stabilized hoist tower) (Fig. 9);
- reserve pipe mining systems – possible to location the pipes on the platform above the aft cargo holds and in the bow storage in hull of ship or only in the bow storage for pipes.

The ship is fitted with double bottom extending fore and aft as well as double side structure along the working space. The double bottom spreads from the after-peak bulkhead to the collision bulkhead. The double bottom height was assumed equal to 2800 mm (on the basis of drilling ships) over its full length, and the breadth of double sides equal to 3000 mm. The inner bottom is assumed flat over the whole breadth of hull, and the upper deck is of no sheer and camber.

The power plant with main and auxiliary generators, and supply devices are located in the aft part of ship. Wheelhouse with superstructure are located in forward part of ship. In the forward part also envisaged all systems and equipment related to the operation of the superstructure.

A concept of mining ship – 3D model

The concept of the mining ship with the main functional compartments are shown in figure 9, and by means of 3D model (Fig. 10).
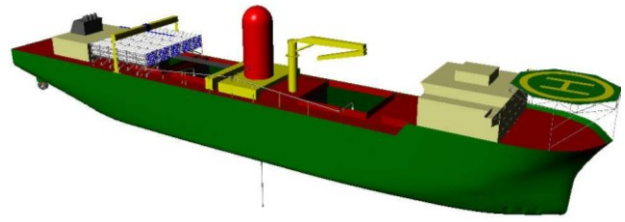

Fig. 10. A concept of the mining ship – 3D model

Conclusions

Developed, approximate scheme may be used for the purposes of the initial mining ship design, concepts arrangement of the main compartments of the ship and forecasting operating costs – resulting among others: from size of vessel.

In article included parameters which have a decisive impact on size of ship such as: yearly rate of mining the nodules and time interval of storing the nodules. Presented relations regression allows the estimation the size of the vessel in the preliminary design stage

Performed an analysis of main compartments of the mining vessel (i.e.: cargo holds for nodules, engine room, store for pipes and spare parts, together with the idea of transport theirs), determined in percentage terms their volume of participation in the hull of the ship and their space location.
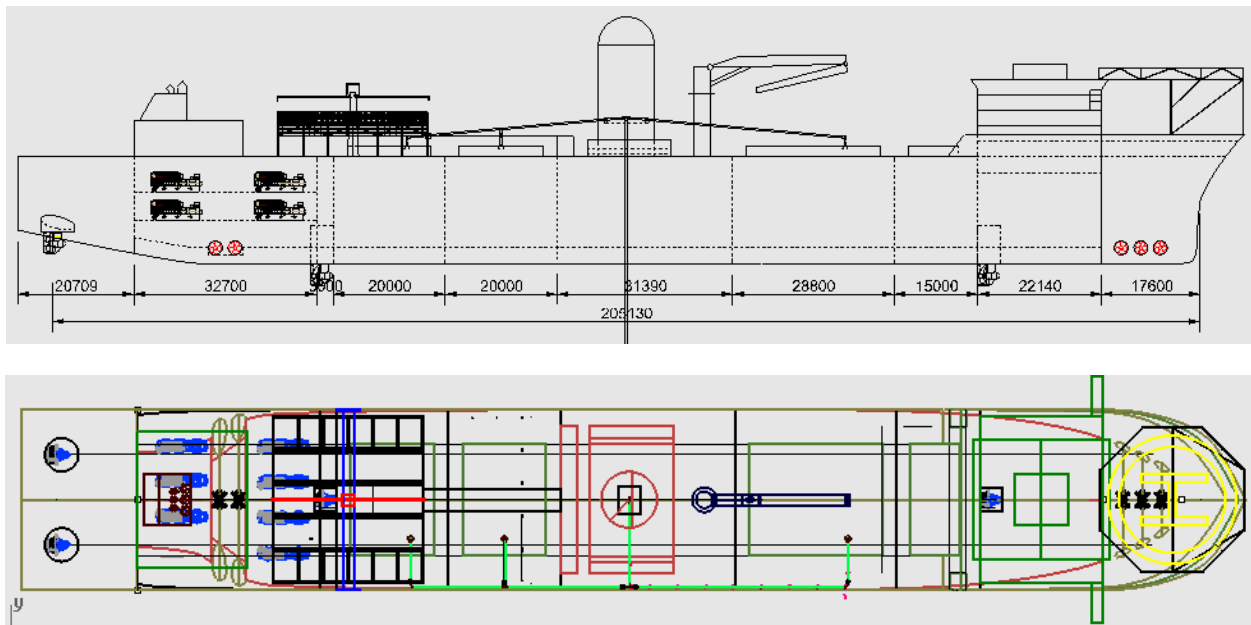

Fig. 9. A concept of mining ship (Q_{MK} = 1,400,000 [t/year] and T_{sk} = 10 [days])

In addition, 3D visualization has been carried out mining ship model.

Due to the still progressing development of technology of mining polymetallic nodules from sea bed and in view of still missing built ship for this specialist task as well as the concept of or certain guidelines (guidelines) project, presented the conceptual design of the mining the vessel is the vision of the author with the possibility of modification.

It is anticipated that the current state of development of mining technology, the first extraction of noduls on an industrial scale may occur in 2020.

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