SELF-CLEANING SYSTEM FILTER TREATING INSTALLATION OF THE BALLAST WATER FOR SHIPS

Nicuşor Baroiu[1], Georgiana-Alexandra Moroșanu[1], Sorin Ștefan Chislitschi[1], Viorel Păunoiu[1]

[1] *"Dunărea de Jos" University of Galaţi, Department of Manufacturing Engineering, Nicusor.Baroiu@ugal.ro, Alexandra.Costin@ugal.ro, sorin_chislitschi@yahoo.com, Viorel.Paunoiu@ugal.ro*

Abstract: *For the ballasting process, a ballast water treatment system requires a filter, with characteristics and working parameters in accordance with the monitoring rules of the IMO BWM Convention, in 2004. For the proper functioning and use of these filters, it is absolutely necessary to build a self-cleaning high-performance system, which can ensure a high operating efficiency. Therefore, it is important to make a calculation corresponding to the operation and use requirements when choosing the working components of the self-cleaning filter system, depending on the positioning and fixing of the pump in the intended space in the ship's pump room. The paper presents a model of a pumping system that performs the self-cleaning of the filters under the conditions imposed by certain control and safety parameters.*

Keywords: *ballast water, ships, filter, flow, delivery lift*

1. Introduction

Ships contain various systems and plants in their construction, which are designed and divided into various decks and compartments in order to ensure the functions and destinations provided by the shipwrights, pursuant to the effective regulations and certificates [1-3].

One of these systems, of great importance in the structure of a ship, is the ballast system, which has the role of correcting the position of the ship's center of mass using liquid ballast (seawater), by embarking, transferring or discharging this ballast overboard.

This mass of liquid ballast is used when the ship performs various general cargo loading and unloading manoeuvres, and the ship's metacentric height is altered and may endanger its stability and balance, as well as ensuring a safe voyage.

At the same time, a transverse stability is ensured, the ship's manoeuvrability and propulsion are improved, compensating for the weight losses due to fuel and water.

A ballast system, Figure 1, consists of a system of pipes that are connected to each other in various pull rod couplings, which can be provided with manual or automated valves to ensure a necessary direction to the ballast tanks, as well as to the inlet and outlet of the liquid ballast (seawater).

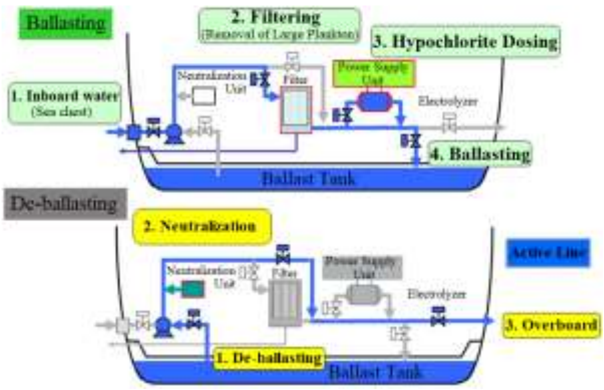

Figure 1: *Schematic Diagram of the Ballast System [7], [8].*

Usually, these pipes are installed in a tween deck under the double-bottom area/ceiling of ships, and water can flow inside the lines in both directions because the strainers in the ballast tanks are not provided with filters, and their block valves do not contain check valves [7].

Water is one of the most widely used chemical, which leads to its use in technological processes in various industries in an overwhelming percentage.

Therefore, it becomes very important for the world to be a continuous concern for the protection against water and ocean pollution. One solution proposed and approved at the IMO Convention in 2004 was the BWTS (Ballast Water Treatment System) for all new and operating merchant ships.

Ballast water treatment systems must be provided with two water sample collection points, one point before the treatment applied and the second after this treatment applied on the ballast water.

Generally, a ballast water treatment system is composed of the following parts:

- the part of particles, organisms and microorganisms filtering;
- the part of the UV radiation (ultraviolet) treatment or other types of physico-chemical treatment;
- the part of piping and manual and automatic valves;
- the control part;
- the high-energy part, Figure 2 and Figure 3.

Figure 2: *Unit 1 BWTS [7].*

Figure 3: *Unit 2 BWTS [7].*

The BWTS diagram is shown in Figure 4.

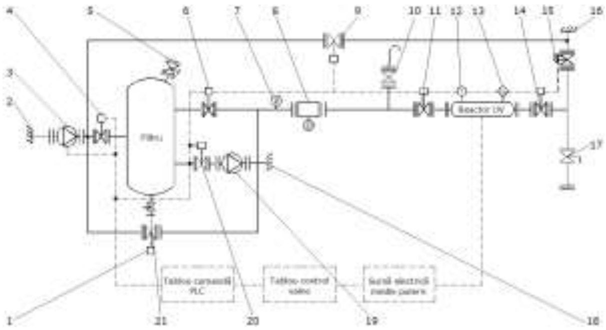

Figure 4: *BWTS diagram: 1 – bypass- valve of the filter; 2 – inlet valve; 3 – ballast pipe; 4 – input valve of the filter; 5 – ventilation valveof the filter; 6 – relief valve of the filter; 7 – pressure sensor; 8 - flowmeter; 9 – bypass-valve system; 10 – air release valve; 11 – inlet valve of the UV-reactor; 12 – temperature sensor; 13 - UV-radiation sensor; 14 – outlet valve of the UV-reactor; 15 – pressure-flow control valve; 16 – outlet valve; 17 – system-discharge valve; 18 – outlet valve; 19 – self-cleaning pump; 20 – self-cleaning valve system; 21 – discharge valve of the filter.*

2. The Control System of the Ballast Plant

In order to be controlled and operated, the treatment system is equipped with various receiving and transmitting sensors of the controlled specific parameters.

These sensors can measure the necessary parameters, such as: the ballast water pressure inside the line, the differential pressure between the inlet and outlet at the particle filter, the flow in the water treatment system, the *UV* radiation emitted in the chamber of the *UV*-lamp or the temperature recorded in the *UV*-lamp chamber. Thus, the values of the parameters recorded by the sensors are transmitted to a programmable controller for process control, for example a PLC (*Programmable Logic Controller*), as well as a *PC*, with the role of data acquisition and monitoring, Figure 5. Both the PLC and *PC* contain specific software for controlling and monitoring the ballast water treatment system. Thus, through this software, to which the parameter values for the normal working conditions are established, the PLC will control and operate the components of the ballast water treatment system.

Figure 5: *A Model of a PLC-type Programmable Controller [6].*

For example, such a system can be built according to Figure 6, promoted by one of the world leaders in this field, namely *Optimarin A.S.*

Figure 6: *Visual representation of a BWTS [6].*

The operating principle is sequential, being of the classic type, used in these types of systems. Thus, the operation stages begin by choosing the type of operation required (ballasting, de-ballasting or stripping), Figure 7.

Figure 7: *Representation of the BWTS bench [6].*

After selecting the operation, the *PLC*, a programmable controller, will selectively control the opening of the pneumatically or electrically-driven working valves, for the free passage of ballast water through the system.

The flow direction through the system is visually represented on the monitor, from left to right of the screen, also highlighted with a colour, different from the original stand-by image.

In the case of ballasting or stripping operation, in which the filter for mechanical particle separation is also used, the automatic start of the self-cleaning operation is highlighted on the control monitor by the "*Flushing*" sign, Figure 8.

This operation will start automatically in case of a lower pressure difference between the disposal and the input into the mechanical separation filter, an operation monitored by a hydraulic pressure differential.

Figure 8: *Representation of the self-cleaning - flushing [6].*

The self-cleaning system is represented by a geared engine at the top of the filter, an disposal pipe, separated from the main system, an automatic pneumatic controlled valve and a centrifugal pump, which creates a vacuuming-phenomenon on the system, releasing particle-contaminated water back into the sea using a ballast water outlet valve of the ship.

If the de-ballasting operation is used, the mechanical separation filter will be bypassed using another pneumatic or electrical valve, specially controlled by the PLC software for this operation in the water treatment system.

The water circuit in the *BWTS* system will continue with the passage through the *UV* (ultraviolet) radiation chambers or by the injection of chemicals into the ballast water from the reactor, if the chemical treatment variant used is similar to the one used by other shipbuilders who design this type of plants.

The flow and pressure adjustment in constant working mode, according to the minimum and maximum values set out in the main software, shall be made using a special hydraulic valve, visually represented on the flow output from the monitor display control image.

For the safety of other work and maintenance operations of the *BWTS* ballast water treatment plant, the system shall be equipped with a general pneumatic or electrically operated bypass valve which can be operated automatically by the *PLC* software or manually from the *PC*'s screen control.

The visualization and monitoring of the main working parameters is obtained automatically or selectively on the *PC*'s screen, e.g.: pressure, flow, *UV*-radiation, temperature, electrical power developed, running hours, warning or alarming, in case of technical failure, Figure 9.

Figure 9: UV-lamps *Monitoring, UV-radiation, electrical power, temperature [6].*

Depending on the basic values of these working parameters, established by the software, as well as the quality conditions of the ballast water, the operation ratio of the system will have a variation that must fall within the requirements of the *G2*-standard admitted at the *IMO Convention*. The B-2 provision of the *IMO* Convention for Ballast Water defines that all ballasting and de-ballasting operations should be recorded in a logbook and the software of the programmed PC of the *Ballast Water Treatment System (BWTS)* should contains records of operations conducted with location data (*GPS* data), the quantities of ballast with the degree of treatment applied (example: 0...100%), usage period etc. [8].

3. Choosing the Type of Filter and Pump

Water filters are intended to separate, to a certain degree of filtration, sediment particles, which are transported with water pumped through the pipes of a system used in the domestic or industrial environment, Figure 10.

Figure 10: *Filter with pneumatic valves.*

Depending on the purpose of the system used, the filters have various capacities and forms of construction and, at the same time, the materials from which they are manufactured are diverse, a first main condition being their resistance to corrosion and chemical attack. Generally, the separation of particles in a water filter is done mechanically by adjusting the sediments during force passage of the liquid (water) through a separator, which has a certain maximum capacity through the "*riddle*". These separators can be mounted individually or together in the body of a filter, having in this multiple form, either the same limit of passage (filtering) of all separators or a filtration sequence with different passage limits between the separators. The materials from which the filters are produced are different, depending on the purpose and role they play within the desired operating system, as well as the financial considerations taken into account.

Industrial filters are built to run by horizontal or vertical passage of the direction of the liquid's flow inside the filter, which, in the construction of a filtration system, is beneficial for choosing the filter model compatible with the storage and mounting on ships. At the same time, the calculation of the execution of a filter shall take into account the maximum working pressure capacity, as well as the maximum and minimum flow capacity required for the filtration plant. When choosing the filter model for mechanical separation, account shall be taken of the capacity of the plant's required flow so that, in general, there shall be chosen a filter which will have an input and output flow with a value at least equal to the flow rate of a ballast pump of the ship. Ships are usually equipped with two ballast pumps, and the ballast-piping system is calculated in order to bear a flow rate, at least equivalent to the flow rate of the two pumps, Figure 11 and Figure 12.

Figure 11: *Ballast Water Pump*

Figure 12: *Self-cleaning Filter Pump*

This calculation is a necessity in order to avoid system pressure overloads, as well as shortening running hours when filling or emptying the ballast tanks.

4. Pumping System

The pumping system for filter self-cleaning, Figure 13, consists of:
- disposal pipes:
- valve (tap) automatic lock;
- disposal pump;
- electromotor pump drive;
- differential input pressure
- output of liquid flow.

Components:
1. Manual stop valve for cleaning disposal;
2. Electrically-actuated pump;
3. Automatic stop valve for cleaning disposal-pipe
4. Airing filter;
5. Self-cleaning electrical reductor;
6. Filter;
7. Ballast water flow pipe;
8. Differential pressure sensor;
9. Pneumatic and electric actuated valve filter output;
10. Manual filter emptying tap;
11. Pneumatic and electric actuated valve filter input;
12. Ballast water flow pipe;
13. Self-cleaning disposal pipe.

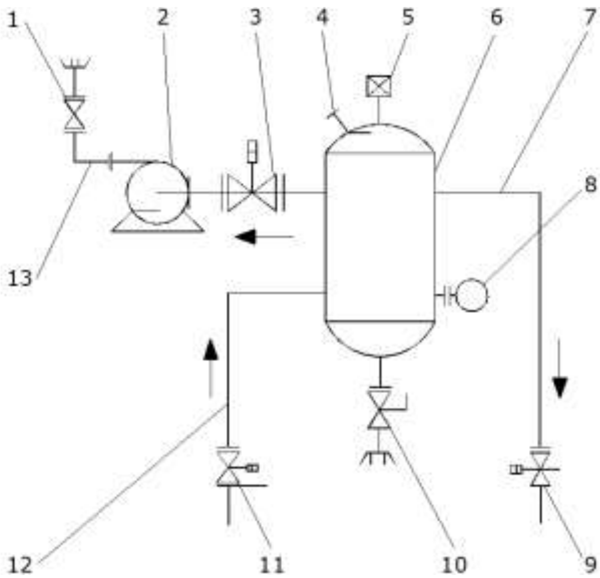

Figure 13: *Diagram of Self-Cleaning Filtration System [6].*

5. Choosing the type of pipe for the liquid discharge from the self-cleaning system

In general, for discharging the liquid from the self-cleaning system of a filter, single-stage centrifugal pumps are used for technical, economic and qualitative reasons. These types of pumps, Figure 14, can operate for flows ranging between 1 to 200 l/sec, and the pumping height varies between values of 3 to 120 m.

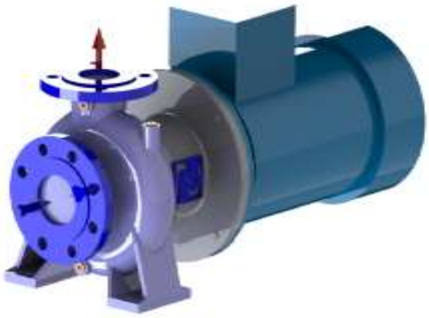

Figure 14: *Pump Model [6].*

The pumps used in a self-cleaning filter system may, as a rule, be surface, centrifugal water pumps, with axial input and radial disposal, motor-actuated, which ensure constant flow and pressure, if the basic rules for mounting are followed [6], [9], [10], [11]:

a. their mounting shall be made as low as possible from the filter system, in order to ensure constant absorption and discharge, without air gaps*;*

b. providing pumps on a rigid stand in order to avoid vibrations*;*

c. the actuation of the pumps by electromotors shall be in accordance with the diagram;

d. running intermittent revisions at a frequency corresponding to the manufacturer's technical indications. Centrifugal pumps contain the following main elements:

- the pump's body, which contains the coupling flanges (caps) for suction and discharge of the liquid, the suction tank, the volute chamber and the discharge diffuser;
- radial bladed-impeller, consisting of shaft (cap) and treetop;
- rotor support and fastening bearings consisting of bushings and bearings;
- sealing elements consisting of rings of graphite felt, rings (o-ring) and rubber oil-scal rings, klinkerite gasket;
- motor-actuated rotor.

5.1 Principle of Operation of Centrifugal Pumps

By the rotation of the electromotor in a spiral direction towards the disposal zone of the pump's body, the rotary flow is transmitted through the permanent coupling provided by a wedge on the rotor hub.

Thus, through the bearings, the shaft rests on the clamping bearings in the pump body, rotating together with the treetop and the radial blades at the speed printed by the electromotor.

Once the water reaches into the from the suction pipe attached to the coupling flange of the pump's body, it will move into the suction tank from where it is taken over by the impeller's treetop and the radial blades. By rotating this impeller, a vacuum is created at its entrance, and the atmospheric pressure acts inside the suction tank, which leads to a pressure difference that generates a continuous fluid flow.

On the margins of the treetop and the radial blades of the hub (tree), the liquid is collected in the volute chamber and directed to the exhaust diffuser and then to the discharge pipe, its fixing and holding being made by means of the exhaust flange of the pump's body.

As a result of this rotary flow, in the volute chamber and in the diffuser, a substantial quantity of kinetic energy of the liquid will turn into potential energy (PE).

Materials used in manufacturing of centrifugal pumps used in shipwork are generally made of grey cast iron, aluminium alloys or bronze-nickel alloys for housings and pump bodies.

The pump's impeller is made of stainless carbon steels, and the treetop and radial pallets can also be made of nickel-alloyed bronzes, in order to have increased mechanical strength, as well as against corrosion in contact with the sea's saline water [6], [7], [8].

It is recommended, when choosing a centrifugal pump for the self-cleaning system of a filter, that the nominal flow rate, *Q*, of the pump falls within a value of *8* to *12* % of the nominal flow rate of the ballast water treatment system filter. In general, pump types are chosen from representative tables of the manufacturers, which comply with the standards and marine registers in force. An example of a type of centrifugal pump attached to a filter with a self-cleaning system can be seen in Figure 15.

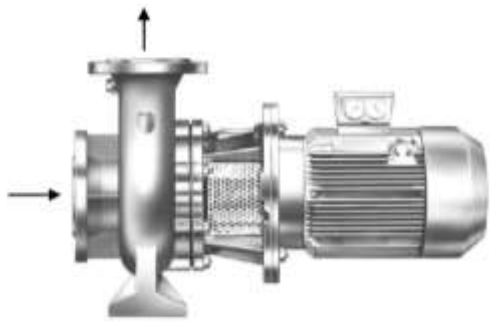

Figure 15: *Centrifugal Discharge-Pump [6].*

The types of electric motors used to operate centrifugal pumps for ships are asynchronous, triphase, *440V/60* Hz, with a power developed between *3.5...14* kW, depending on the pump's capacity, required for the self-cleaning circuit.

The engine's power is chosen at a value of 25...30% greater than the required power calculated on the pump shaft to ensure the pump's running at absorbed power rates, greater than the design rate [6], [8].

5.2 Description of the Functionality of a Self-Cleaning Filtration System

For example, we will consider a type of industrial filter, *BOLL KIRCH*-type with vertical actuation of the self-cleaning system, which has the following technical characteristics [6], [7]:

- maximum permissible pressure: $p_N=10$ *bar*;
- running pressure: $p_O=0.5 \rightarrow 3.5$ *bar*;
- running temperature: *T=(-2°C÷60°C);*
- running flow: $Q=83...370\ m^3/h$;
- differential actuation limit: $p_d=0.38$ *bar;*
- type of filter elements: *"Candela" (cd);*
- working environment: seawater;
- liquid for self-washing: its own environment.

The centrifugal pump for self-cleaning usage will have the following technical characteristics:

- running flow: $Q=38\ m^3/h$;
- impeller speed: *n=3500 rpm*;
- maximum height of the liquid column: *H=25 m*;
- maximum absorption depth: $H_a=-5\ m$;
- maximum permissible pressure: $p_N=10$ *bar*;
- operating temperature: *T=(-2°C÷60°C)*;
- framing and vortex wheel: alloy material Bz-Al-Ni.

The electromotor for pump actuation will have the following technical characteristics [6], [7], [8]:

- running voltage: *U=440* V;
- running frequency: *f=60 Hz*;
- power: *I=5.5-9.2* A (electrical connection type (type ⅄ sau Δ);
- input: *P=4.25 kW*;
- number of rotations: *n=3550 rpm*

The pipe construction diameter at the input and outlet of the filter is in accordance with the current standard DN150 PN10_16 [6], [7]. The construction diameter of the self-cleaning water disposal pipe, is in accordance with the current standard DN80 PN10_16.

6. Determination of Hydraulic Parameters in Impallers With Known Geometry

6.1 The Running Principle of Centrifugal Pumps

For $v_a=1.5$ *m/s* and the minimum flow ratio:

$$Q_{\min} = \frac{\pi}{4} \cdot \left(D_0^2 - d_n^2\right) \cdot v_a \ \ [\mathrm{m^3/h}], \qquad (1)$$

Results in:

$$Q_{min} = \left(0.102^2 - 0.04^2\right) \cdot 1.5 \cdot 3600 =$$

$$= 47.54\ \mathrm{m^3/h}.$$

The verification is made supposing that: $v_{1m}=v_{2m}=v_a=1.5$ m/s.

Thereby:

$$Q_{1min} = \pi \cdot D_1 \cdot b_1 \cdot v_{1m} = \pi \cdot 0.108 \cdot 0.021 \cdot$$
$$\cdot 1.5 \cdot 3600 = 38.48 \text{ m}^3/\text{h},$$

and:

$$Q_{2min} = \pi \cdot D_2 \cdot b_2 \cdot v_{2m} = \pi \cdot 0.204 \cdot 0.013 \cdot$$
$$\cdot 1.5 \cdot 3600 = 47.41 \text{ m}^3/\text{h}.$$

For $v_a=4$ m/s, is achieved:

$$Q_{\max} = \frac{\pi}{4} \cdot \left(D_0^2 - d_n^2\right) \cdot v_a = 99.57 \text{ m}^3/\text{h}.$$

Verification is made for: $v_{1m}=v_{2m}=v_a=4$ m/s:

$$Q_{1min} = \pi \cdot D_1 \cdot b_1 \cdot v_{1m} = 102.61 \text{ m}^3/\text{h}$$

and

$$Q_{2min} = \pi \cdot D_2 \cdot b_2 \cdot v_{2m} = 126.43 \text{ m}^3/\text{h}.$$

6.2 Calculation of the Pump Head for Known-Engine Speed

The height calculation ratio is:

$$H = k \cdot D_2{}^2 \cdot n^2 \text{ [m]}, \qquad (2)$$

For a single-stage pump:

$$H = i \cdot \Delta H \text{ [m]}, \qquad (3)$$

For a multiple-stage pump:

$$\Delta H = k \cdot D_2{}^2 \cdot n^2 \text{ [m]}, \qquad (4)$$

and i represents the number of impellers.

For $k=(1.3 \div 1.5) \cdot 10^{-4}$, for a paddle-bladded stator or $k=(1 \div 1.4) \cdot 10^{-4}$, for one without paddles, choose $k=1.4$

- a paddle-bladed stator and a single impeller, and $n=3500$ *rpm*.

Thus:

$$H = 1.4 \cdot 10^{-4} \cdot 0.204^2 \cdot 3500^2 = 71.37 \text{ m}.$$

6.3 The Determination of Characteristic Curves Depending on the Engine's Speed

For centrifugal pumps it is important to know the variation, in order to choose and exploit them correctly within a pumping system.

Variations can be determined using determined and established flow mathematical relations (Q), which vary in proportion to pump speed (n) and pump height (H), proportional to the square of the ratio of different speeds applied to pumps by experimental values.

The following relations shall be established [8]:

$$Q = Q' \cdot \frac{n_2}{n_1} \text{ [m}^3\text{/h]}; \qquad (5)$$

$$H = H' \cdot \left(\frac{n_2}{n_1}\right)^2 \text{ [m]}, \qquad (6)$$

Where Q' and H' represent the flow, respectively, the constant pumping height: Q'=38.48 m^3/h, H'=71.37 m.

Therefore, 6 variants for determining the flow rate and the pumping height are presented in Table 1, depending on the pump speed. The results are centralised in Table 2 and plotted in Figures 16÷21.

Table 1: *Speed Values for Centrifugal Pumps*

Variants	*I*	*II*	*III*
n_1 *[rpm]*	3500	3000	2500
n_2 *[rpm]*	1000	1000	1000
	1500	1500	1500
	2000	2000	2000
	2500	2500	3000
	3000	3500	3500
Variants	*IV*	*V*	*VI*
n_1 *[rpm]*	2000	1500	1000
n_2 *[rpm]*	1000	1000	1500
	1500	2000	2000
	2500	2500	2500
	3000	3000	3000
	3500	3500	3500

Table 2: *Flow and Height Pumping Values for Centrifugal Pumps*

I		*II*	
Q_1 *[m³/h]*	H_1 *[m]*	Q_2 *[m³/h]*	H_2 *[m]*
10.99	20.39	12.83	23.79
16.49	30.59	19.24	35.69
21.99	40.78	25.65	47.58
27.49	50.98	32.07	59.48
32.98	61.17	44.89	83.27

III		*IV*	
$Q_1\ [m^3/h]$	$H_1\ [m]$	$Q_2\ [m^3/h]$	$H_2\ [m]$
15.39	28.55	19.24	35.69
23.09	42.82	28.86	53.53
30.78	57.10	48.10	89.21
46.18	85.64	57.72	107.06
53.87	99.92	67.34	124.90
V		*VI*	
$Q_5\ [m^3/h]$	$H_5\ [m]$	$Q_6\ [m^3/h]$	$H_6\ [m]$
25.65	57.58	57.72	107.06
51.31	95.16	76.96	142.74
64.13	118.95	96.20	178.43
79.96	142.74	115.44	214.11
89.79	166.53	134.68	249.80

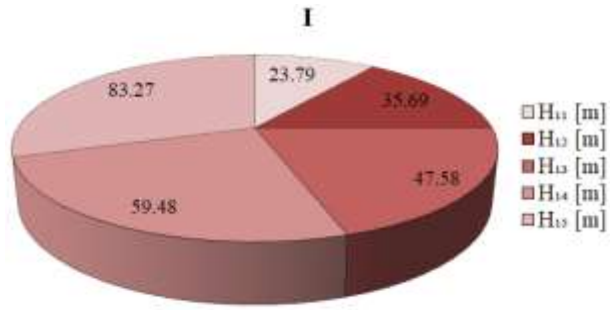

Figure 16: *Centrifugal Pumps' Flow pompelor in Case I.*

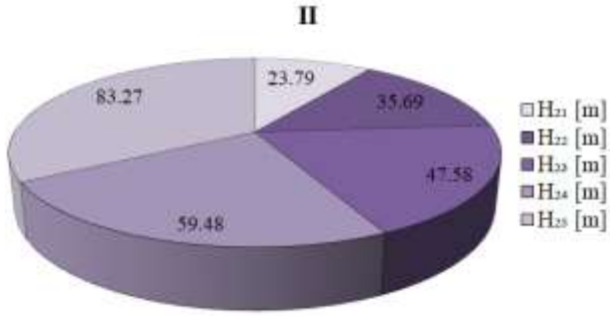

Figure 17: *Centrifugal Pumps' Flow in Case II.*

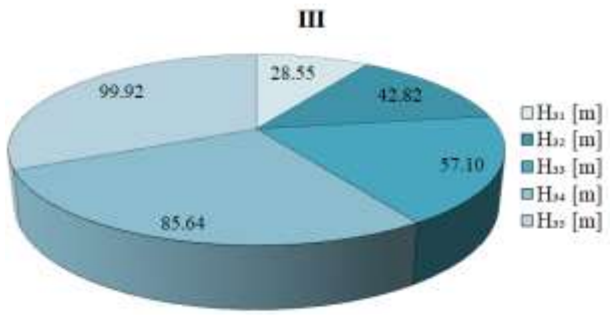

Figure 18: *Centrifugal Pumps' Flow in Case III.*

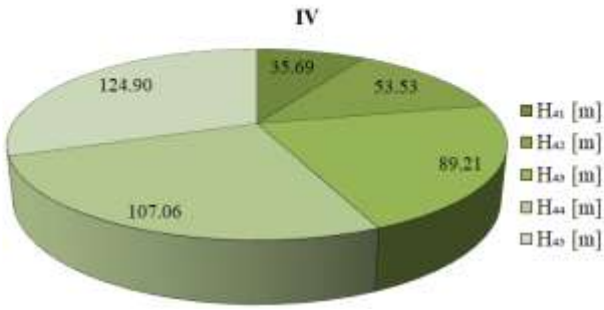

Figure 19: *Centrifugal Pumps' Flow in Case IV.*

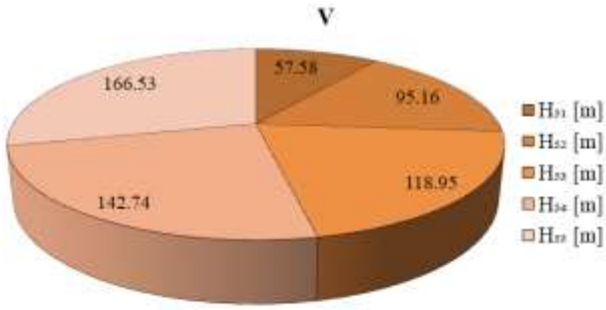

Figure 20: *Centrifugal Pumps' Flow in Case V.*

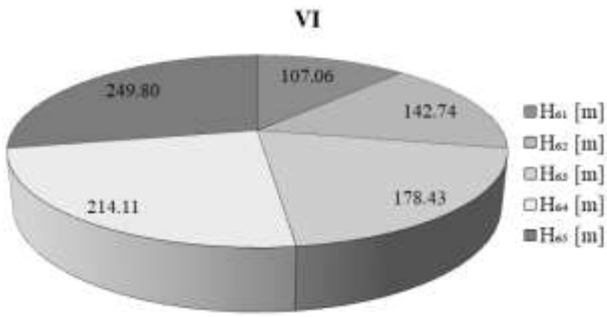

Figure 21: *Centrifugal Pumps' Flow in Case VI.*

The hydraulic control is run by the *PLC* software, through data provided by the flowmeter's sensors and pressure sensors in the system. Hydraulic losses in a pipe system with grids and fittings can be calculated according to longitudinal losses in streamline regime using the following relation:

$$h_1 = \lambda \cdot \frac{l}{d} \cdot \frac{v^2}{2 \cdot g}, \qquad (7)$$

where $\lambda = \frac{64}{Re}$; *Re* is the Reynolds number [8].

Turbulent losses are found in all components of the system that resist the passage of fluid through bends, connections, joints, faucets and other types of fittings, as well as to friction with the inner walls of the pipes, depending on their roughness.

These local losses can be calculated experimentally using the relation [8]:

$$h_{local} = \zeta \cdot \frac{v^2}{2 \cdot g}, \quad (8)$$

where ζ represents the local loss coefficient, and v is the average section speed.

Thus, by levelling the relations (7) and (8), a calculation relation can be obtained for an equivalent length of local resistance, depending on the component elements used in the pipeline system, Table 3:

$$\frac{l_{echiv}}{d} = \frac{\zeta}{\lambda}. \quad (9)$$

Table 3: *The Equivalent Length of Local Resistances[8]*

Work term	*Diameter [mm]*					
	50	*100*	*150*	*200*	*250*	*300*
Elbow 90˚	1.5	2.5	4	5	6	7.5
90˚ Welding elbow	7.5	17.5	29	42	50	70
Elbow 120˚	1	1.7	2.5	4	5	6
T-bend	4.5	9	14.5	20	26	30
Cross-piece	5	11.5	17.5	26	36	47
Suction filter	0.9	2.2	3	4.5	6	7,5
Plug valve	13	29	50	73	95	120
Valve	0.6	1.5	2	3	4	5

Local loss at the entrance to the self-cleaning pump may be reduced if a diffuser with a conical passage from a diameter of *Ø50* mm, representing the D_a disposal-diameter from the filter, to a diameter of *Ø60* mm, representing the D_0 input diameter of the pump, previously calculated.

7. Conclusions

Proper compliance with the nominal bore and the one of the self-cleaning system corresponding to the filter shall be made on the basis of the marine standards in force, in order to obtain the necessary installation, usage and maintenance certification. The paper presented models of industrial filters used in ballast water treatment plants, as well as the presentation of a pumping system for self-cleaning of these types of filters, with running characteristics and parameters in accordance with the monitoring rules of the IMO Convention, 2004.

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