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THESIS ABSTRACT

Theoretical and experimental researches on increasing the dissolved oxygen content in water

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Content

INTRODUCTION

The water aeration process is based on a transfer of air to water; oxygen from the air (21% volumetric participation) is transferred by various processes to the water. The air bubbles generated by the aeration equipment's are introduced into a volume of water, [1] [2].

The most efficient systems are those that generate very fine bubbles (<l mm).

The performance of a water aeration system can be assessed by two parameters:

- Water oxygenation efficiency;
- Water oxygenation efficacity.

The two parameters can be modified by the efficiency of the air dispersion devices in the water.

By aeration and oxygenation, the content of dissolved oxygen in the water is increased.

The term oxygenation is used when introduced into water:

- A mixture of air + oxygen from a cylinder;
- Pure oxygen from a cylinder;
- Air with low nitrogen content (95% O_2 and 5% N_2) delivered by oxygen concentrators;
- A mixture of atmospheric air and ozone (O_3).

Depending on the principle of operation, aeration systems are classified into three classes [3] [4]:

A) Mechanical aeration installations;

B) Pneumatic aeration installations;

C) Mixed aeration installations.

The three classes will be detailed in Chapter I.

All three classes aim to increase the dissolved oxygen content in water.

Chapter I. Current state of researches on aeration or oxygenation processes

This chapter presents a classification of water aeration processes and then describes the main constructive solutions of water aeration equipment's. At the end of the chapter, the objectives of the PhD thesis are presented.

Aeration of water can be achieved by agitation at the surface (load generally performed by mechanical aerators) by introducing air at the base of the tank, lake, etc. (aeration by pneumatic installations) or by spraying air with a device to allow the exchange of oxygen at the surface and the release of harmful gases.

Aeration systems can be classified according to several criteria [5].

a. According the interphase contact surface obtaining mode:

* installations that spray water in air and cascade installations; (mechanical installations for water aeration);

** installations that disperse the gas in water, (pneumatic installations, mechanical installations, FBG);

*** mixed installations - which spray water in the form of drops and entrain the atmospheric air through the effect of jet when re-entering the body of water in the tank, (mechanical surface aerators).

b. According to the movement criteria of the active organ of the aeration equipment's:

- water aeration with static equipment's (pneumatic installations, ejectors, etc.);
- aeration of water with dynamic equipment's (mechanical surface or deep aerators).

c. According to the gas dispersion mode can be classified into:

- installations that disperse air into water (deep mechanical aerators, pneumatic aerators, ejectors, etc.);
- installations which disperse pure oxygen in the water of the aeration tank (pneumatic installations);
- equipment's with the introduction of ozone or ozone-enriched air into water (fluid jet pumps).

d. According to the constructive solution:

- pneumatic oxygenation installations with porous diffusers (static aerators, etc.);
- surface mechanical installations, medium or deep (with rotor, brush, etc.);

- mixed oxygenation installations.

e. According to the immersion of the dispersing device:

- surface installations (mechanical surface aerators with rotor or brush);
- medium depth installations;
- deep sea installations.

The following objectives are pursued in this paper:

1. Elaboration of a study regarding the current scientific level of the processes and equipment's that ensure an efficient aeration of the waters;
2. Numerical integration of the differential equation of the oxygen transfer rate to water;
3. Elaboration of a calculation program regarding the modification of the dissolved oxygen concentration in water according to other parameters;
4. Presentation of solutions for the water aeration and oxygenation procedure;
5. Economic analysis of the solutions in point 4 in order to find an optimal solution from an energy point of view.
6. Design and construction of an experimental installation for water aeration researches.
7. Experimental researches will validate or not the theoretical results obtained in point 5.

Chapter II. Mass transfer

This chapter analyzes the air - water interphase mass transfer. The equation of the rate of oxygen transfer to water and the parameters that influence this speed are presented; the four versions of gaseous mixtures that will be introduced into water are exposed [6]b[7]:

- Version I: atmospheric air (21% O2 and 79% N2);
- Version II: atmospheric air + oxygen from a cylinder;
- Version III: low nitrogen air (95% O2 and 5% N2);
- Version IV: atmospheric air + ozone.

The scheme of the installation to introduce atmospheric air into water used to carry out experimental researches is presented in Figure 2.1.

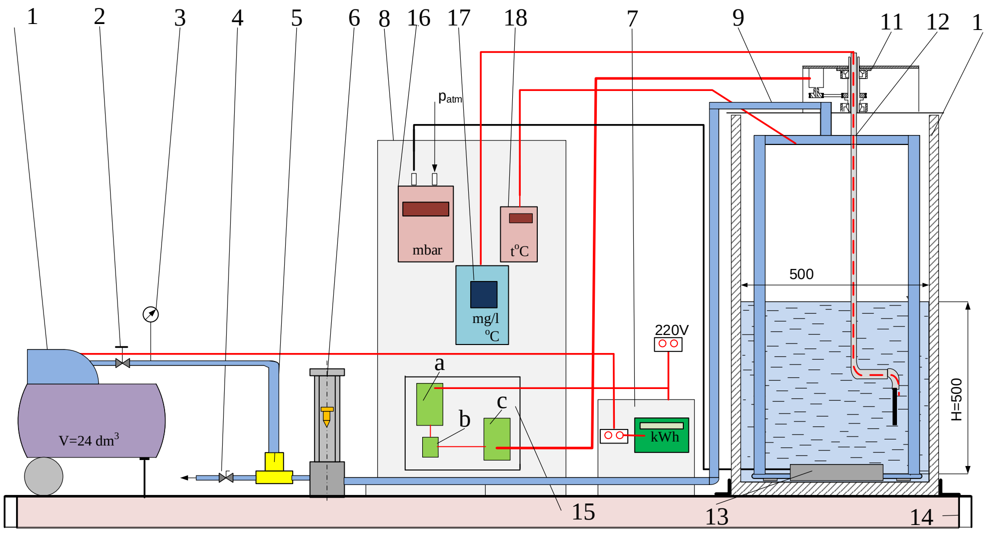

Fig. 2.1. Scheme of the experimental installation for water aeration researches

1 - electrocompressor with air tank; 2 - pressure reducer; 3 - manometer; 4 - connection for evacuating air into the atmosphere; 5 – T-joint; 6 - rotameter; 7 - electrical panel; 8 - panel with measuring devices; 9 - pipe for transporting compressed air to the microbubble generator; 10 - water tank; 11 - mechanism of actuation of the probe; 12 - oxygenometer probe; 13 - microbubble generator; 14 - support for installation; 15 - control electronics: a - power supply, b - switch, c - control element, 16 - digital manometer; 17 - oxygenometer; 18 - digital thermometer

Figure 2.1 shows that, after compressing the air, the air temperature, pressure and flow rate are measured; subsequently it is entered in the MBG with the parameters: $\dot{V} = 600 \left[\mathrm{dm}^3/\mathrm{h}\right]$; p = 573 [mm H_2O].

The duration of the experiments is 2 hours, during which the concentration of dissolved oxygen in the water increases from C_0 to C_s.

The scheme of the installation is used to introduce a mixture of air and pure oxygen into the water (figure 2.2).

From an energy point of view, a large amount of energy is saved, by using pure oxygen, corresponding to the unnecessary compression and introduction into the water mass of nitrogen, the main component of air [8].

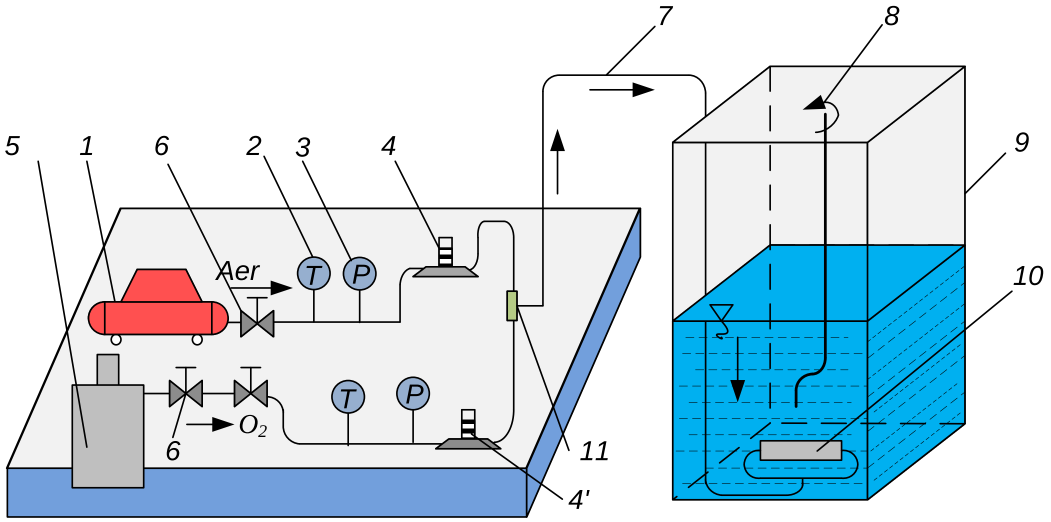

Fig. 2.2. Scheme of the installation for introducing a mixture of atmospheric air and oxygen into the microbubble generator

1 - air electrocompressor; 2 - gas temperature measuring device with digital indication; 3 - gas pressure measuring device with digital indication; 4, 4 '- rotameter; 5 - oxygen cylinder; p = 120 bar; 6 - pressure reducers; 7 - air + oxygen supply pipe of the microbubble generator; 8 - oxygenometer probe; 9 - water tank; 10 - microbubble generator; 11 - mixing chamber of the two gas currents

The operating parameters of the installation are the same as in paragraph 2.3.1: $\dot{V} = 600\ \left[\mathrm{dm}^3/\mathrm{h}\right];\ p = 573\left[mmH_2O\right]\ \tau = \left[2h\right]$.

Atmospheric air and oxygen delivered from the cylinder are measured separately with rotameters (4 and 4 ').

In the water tank is introduced successively a gas flow rate $\dot{V} = 600\ \left[\mathrm{dm}^3/\mathrm{h}\right]$ composed of:

Version II, case 1: $\dot{V}_{O_2} = 150\ \left[\mathrm{dm}^3/\mathrm{h}\right]$ and $\dot{V}_{air} = 450\ \left[\mathrm{dm}^3/\mathrm{h}\right]$;

Version II, case 2: $\dot{V}_{O_2} = 300\ \left[\mathrm{dm}^3/\mathrm{h}\right]$ and $\dot{V}_{air} = 300\ \left[\mathrm{dm}^3/\mathrm{h}\right]$;

Version II, case 3: $\dot{V}_{O_2} = 450\ \left[\mathrm{dm}^3/\mathrm{h}\right]$ and $\dot{V}_{air} = 150\ \left[\mathrm{dm}^3/\mathrm{h}\right]$;

Version II, case 4: $\dot{V}_{O_2} = 600\ \left[\mathrm{dm}^3/\mathrm{h}\right]$ and $\dot{V}_{air} = 0\ \left[\mathrm{dm}^3/\mathrm{h}\right]$.

The general scheme of the installation for introducing low-nitrogen air into water is shown in Figure 2.3.

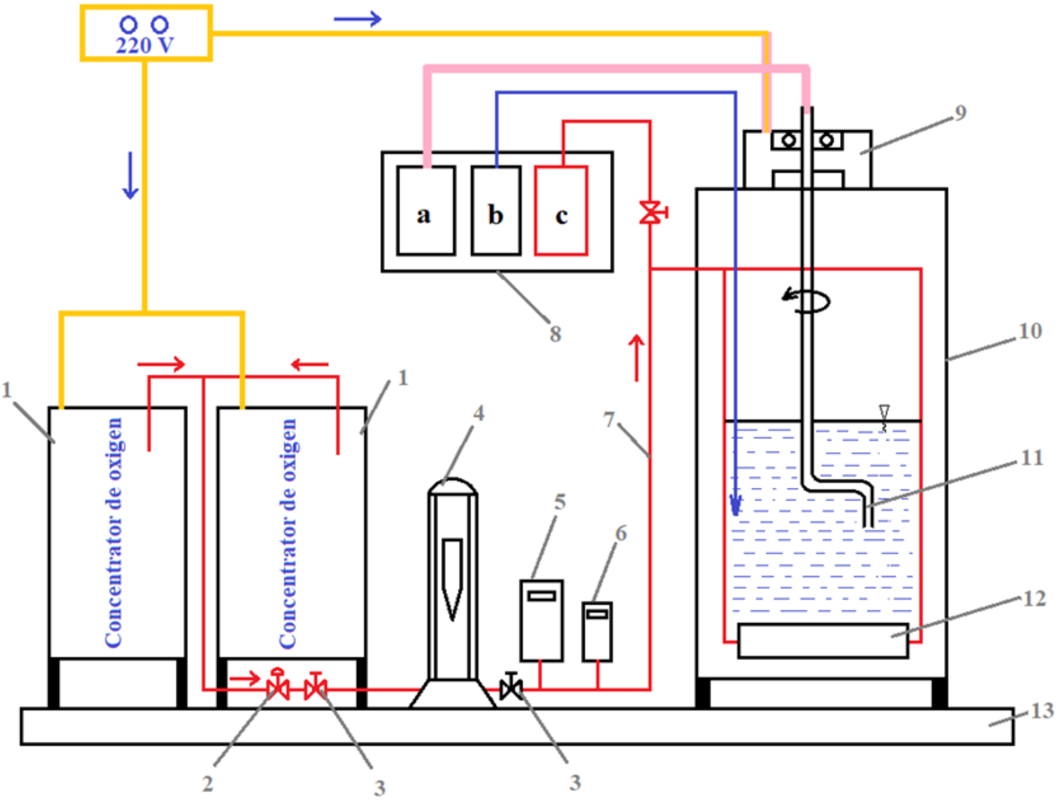

Fig 2.3. Scheme of the experimental installation for water aeration researches
1-oxygen concentrators; 2- pressure regulator; 3- valves; 4- rotameter; 5-manometer with digital indication; 6- thermometer with digital indication; 7- compressed air duct; 8- panel with devices; a- oxygenometer; b- thermometer; c- manometer; 9- electromechanical mechanism for actuating the oxygenometer probe; 10- water tank; 11- oxygenometer probe; 12- fine bubble generator;13- experimental installation support plate

Oxygen concentrators (1) deliver 5 dm^3 / min, ie 300 [dm^3 / h] each, so in total the installation delivers a flow rate of 600 [dm^3 / h] per p> patm [9] [10].

Also for the movement of the probe in the water tank it is necessary to operate a mechanism for rotating the probe in the water tank.

In figure 2.4. the scheme of the low nitrogen air intake system in the MBG is presented; the air delivered by the oxygen concentrators passes through each rotameter and then enters the microbubble generator (MBG).

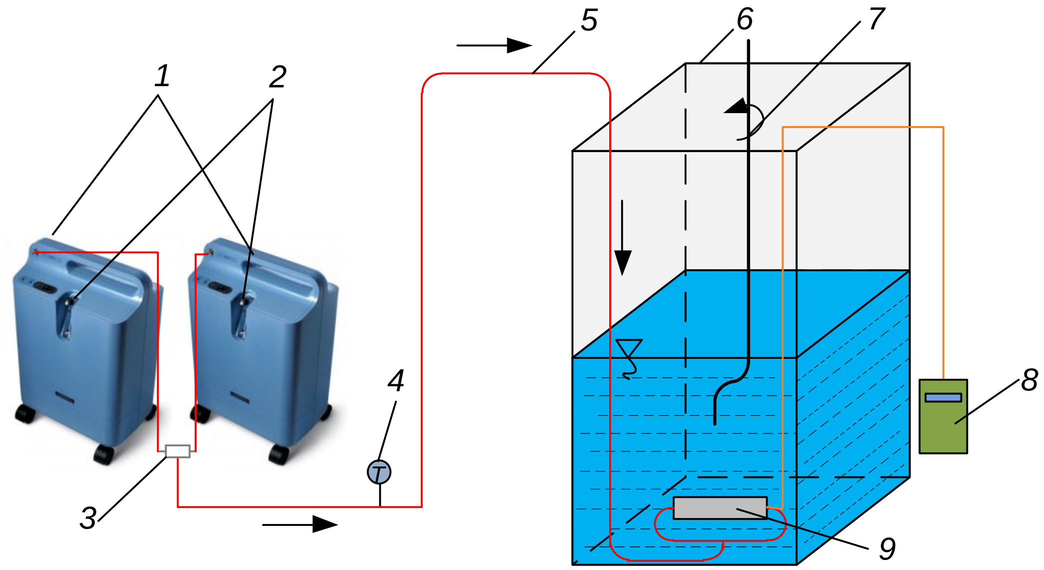

Fig. 2.4. Scheme of the low nitrogen air intake system in the MBG.

1 - oxygen concentrators; 2 - rotameters; 3 - mixing chamber of the two gas currents; 4 - gas temperature measuring device with digital indication; 5 - low nitrogen air supply pipe of the microbubble generator; 6 - parallelepiped tank with water; 7 - oxygenometer probe; 8 - gas pressure measuring device with digital indication; 9 - microbubble generator with 152 orifices Ø 0.1 [mm].

Each concentrator delivers 5 [dm^3 / min], i.e. 300 [dm^3 / h]; the two concentrators provide a flow rate of 600 [dm^3 / h].

Other types of MBG with EDM perforated plates are presented in papers [11] [12] [13].

For the introduction into the water of a mixture of air and ozone, the scheme of the installation in figure 2.6 is presented.

Ozone (O_3) is supplied by devices called ozone generators or ozone generators.

In figure 2.5. an ozone generator is observed which is supplied with electric current at 220 [V] and by electric discharges produces ozone [14] [15].

Ozone generators (Figure 2.7, TCB300O3 generator and Figure 2.8, OzonFix generator) can be used for a wide range of applications (from domestic to municipal), both for air, drinking water and wastewater [16].

Ozone generators are intended to produce a mixture of air or oxygen with ozone suitable for several types of processes, such as [17]:

- Treatment of drinking water and pool water;
- Water purification;
- Water cooling;

- Disinfection;
- The oxidation process in industry.

Fig. 2.6. Ozone generators TCB300O_3 [15][18]

In figure 2.6. the diagram of the installation for water aeration is presented:

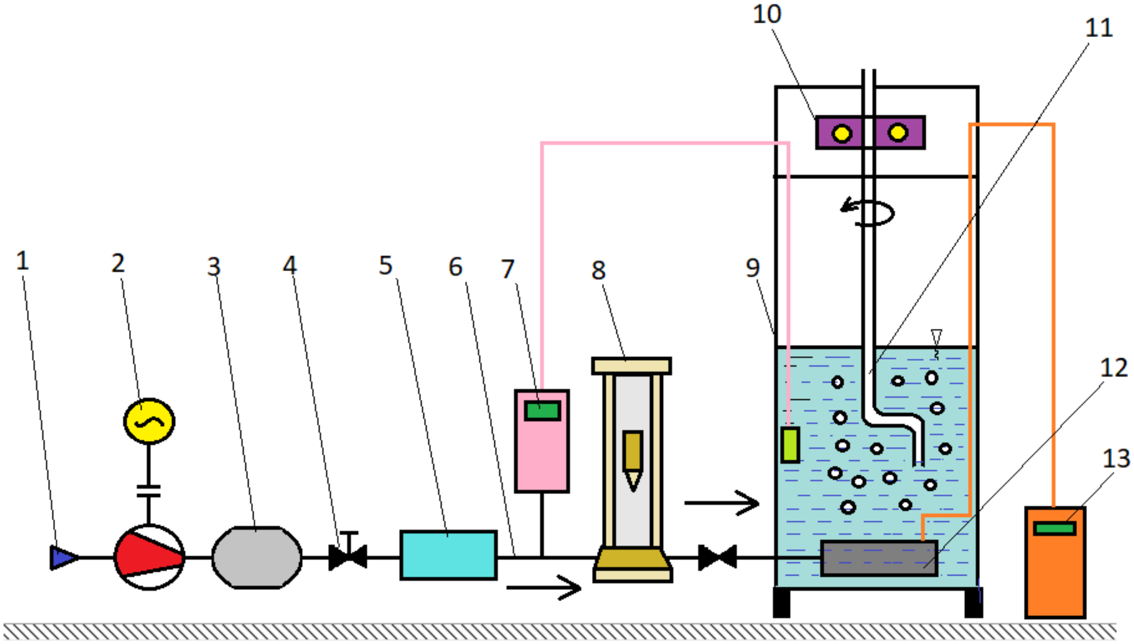

Fig. 2.6. Scheme of experimental installations for water aeration

1– air filter; 2– electrocompressor; 3 - compressed air tank, 4 - pressure reducer; 5 - ozone generator; 6– pipe; 7– thermometer with digital indication; 8– rotameter; 9– water tank; 10– mechanism for rotating the oxygenometer probe in water; 11– oxygenometer probe; 12– fine bubble generator; 13– manometer with digital indication

Chapter III. Development and running a calculation program for each version

In this chapter a calculation program is established for each of the four version. The calculation results indicate the variation of the concentration of dissolved oxygen in the water, depending on the time elapsed during the experiment.

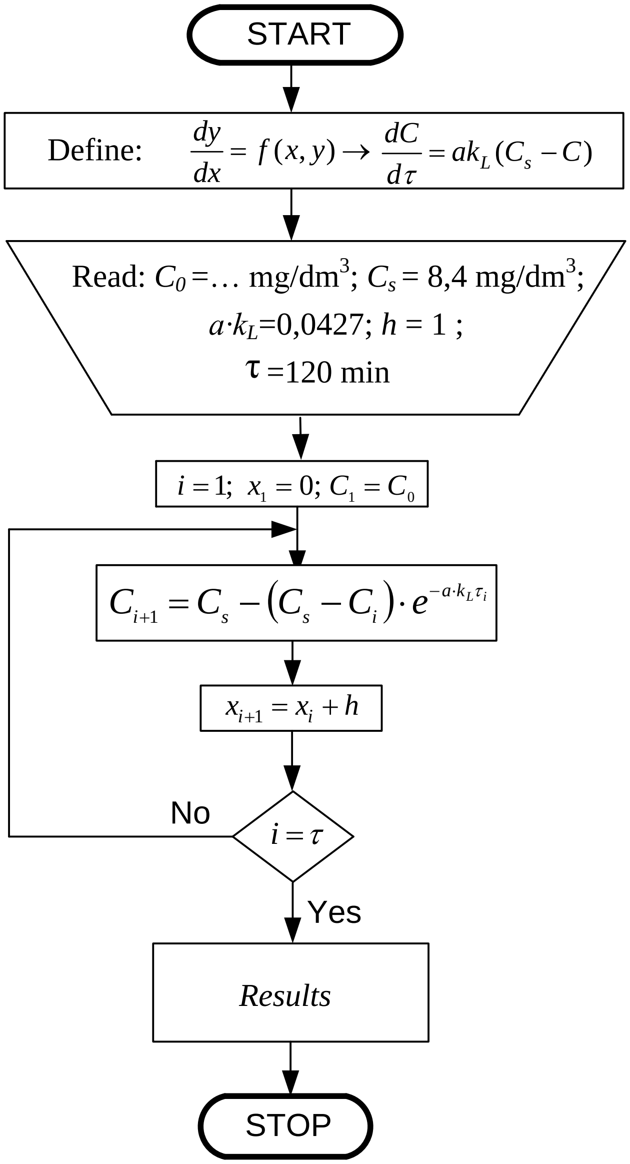

Fig. 3.1. Logical calculation scheme for concentration variation as a function of time in case of introduction of atmospheric air into water (version I)

Following the running of the calculation program presented in figure 3.2. the values presented in figure 3.2 resulted.

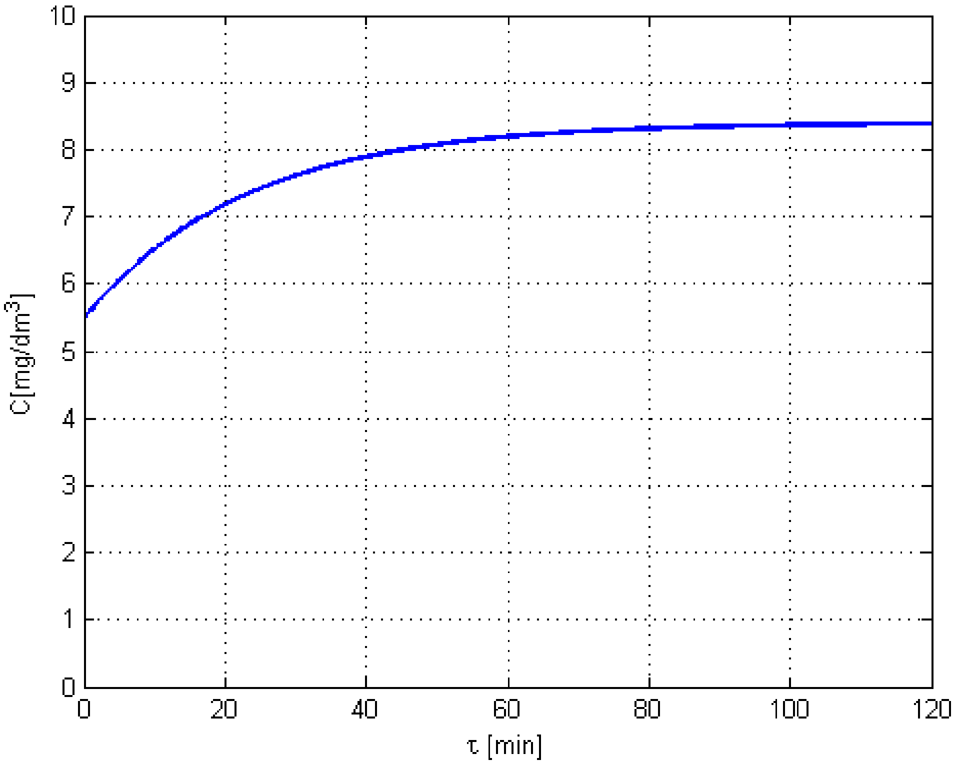

Fig. 3.2. Graphical representation of the variation of the dissolved oxygen concentration in water in version I

In version II, a gaseous mixture of air and oxygen from a cylinder is introduced into the water; oxygen has the volume participation: $r_{O_2} = 25[\%]$, $r_{O_2} = 50[\%]$, $r_{O_2} = 75[\%]$, $r_{O_2} = 100[\%]$; the total volume of the mixture must be the same in all versions, i.e.: $\dot{V} = 600\left[dm^3/h\right] = 0,6\left[m^3/h\right]$.

In figure 3.3. the calculation scheme for version II is presented.

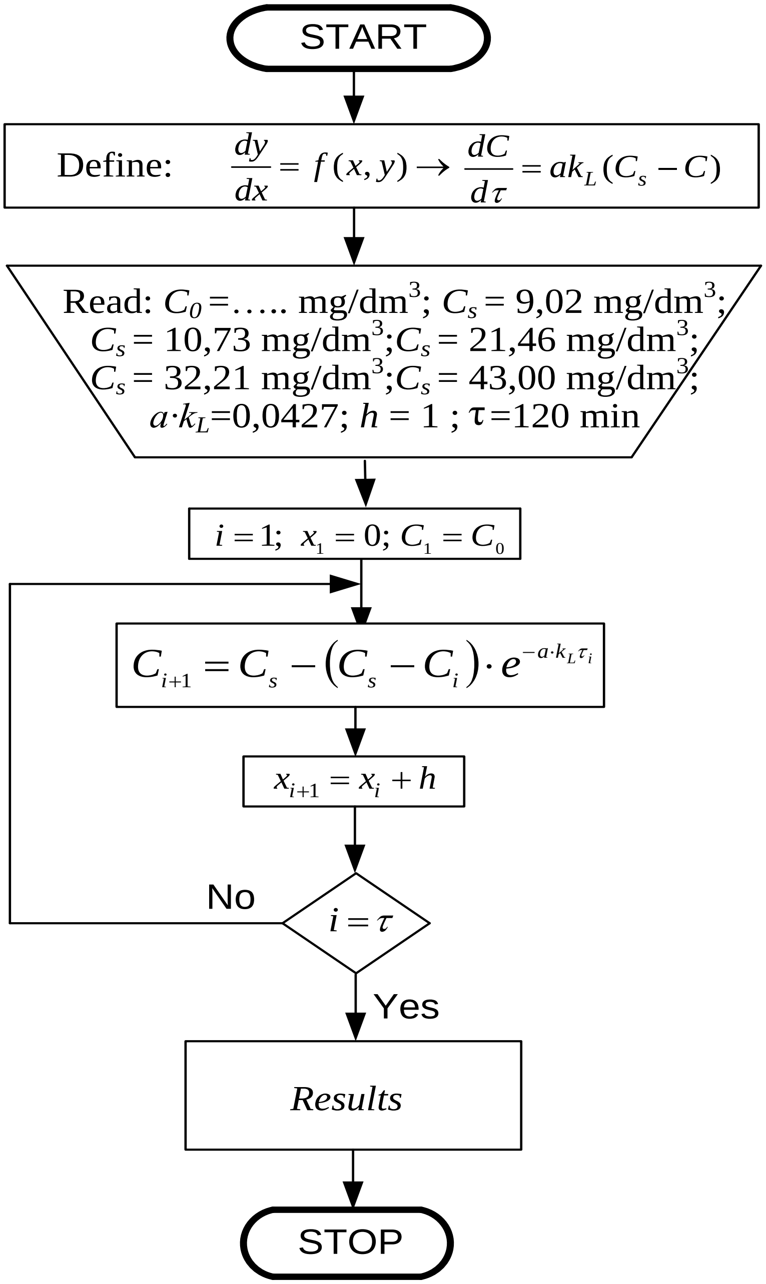

Fig. 3.3. Logical scheme for version II (air + O_2 in the cylinder) C = f (τ)

The comparison of the function C = f (τ) for version I (curve 1) and the four cases of version II (curves 2, 3, 4, 5) presented above can be seen in figure 3.4.

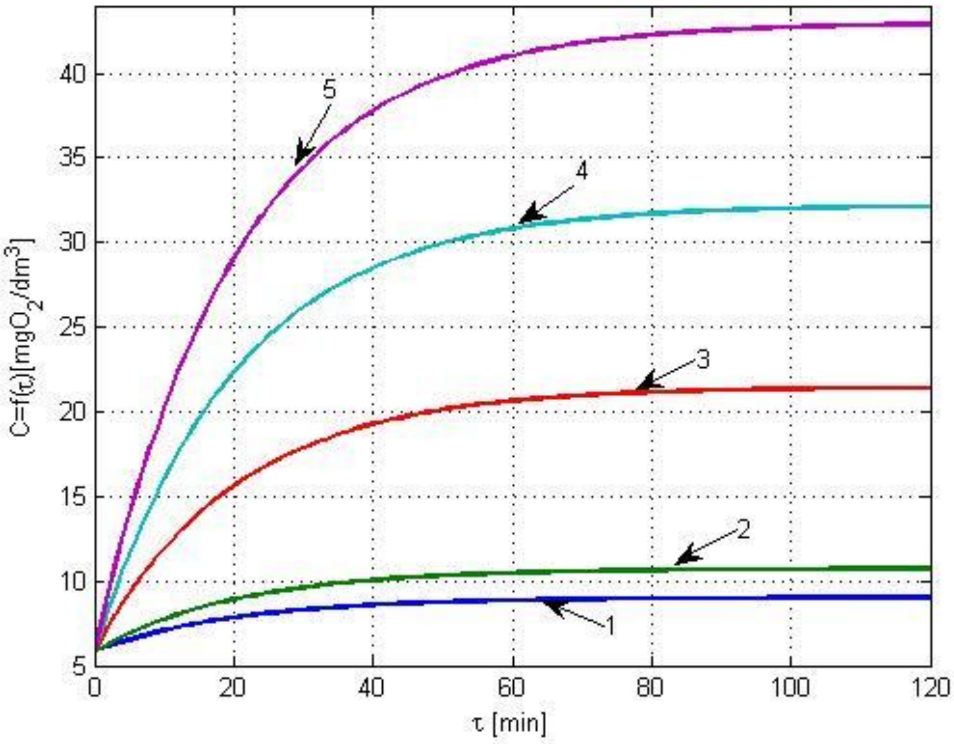

Fig. 3.4. Graphical representation of the variation of the dissolved oxygen concentration in water for version I and the four cases of version II

From figure 3.4. it is found that with the increase of the oxygen supply from the cylinder, the value of the dissolved oxygen concentration in the water also increases.

In the case of version III, atmospheric air with a low nitrogen content is introduced into the water; with volumetric participations: $r_{O_2} = 95[\%]$, $r_{N_2} = 5[\%]$.

The volume of nitrogen introduced into the water will be:

$$\dot{V}_{N_2} = \frac{5}{100} \cdot 600 = 30\left[dm^3 / h\right] \tag{3.1}$$

The remaining of 600 – 30 = 570 $\left[dm^3 / h\right]$ will be oxygen.

The logical scheme for the numerical integration of the oxygen transfer differential equation is presented as follows:

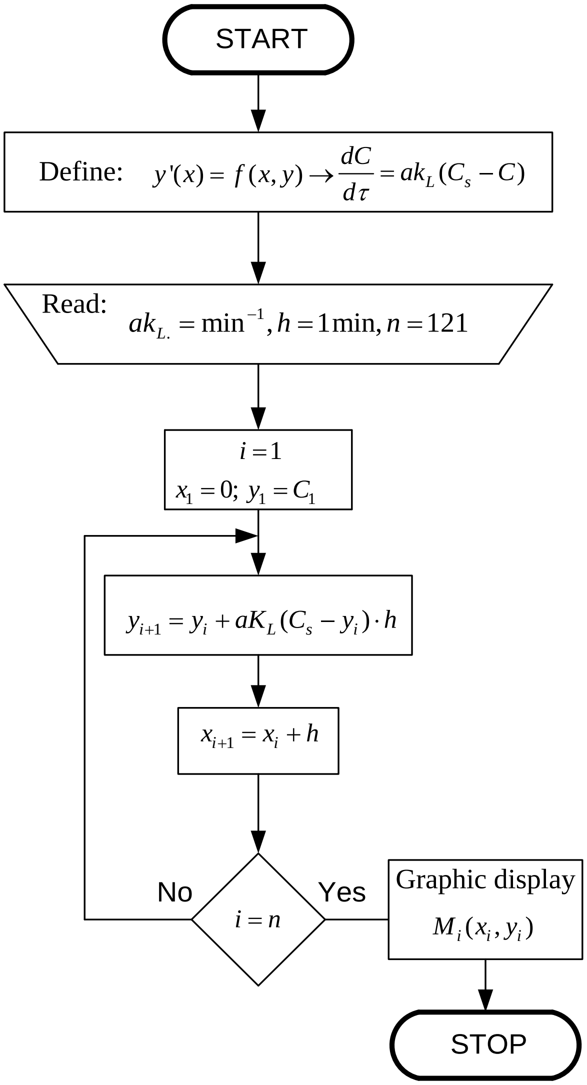

Fig. 3.6. Logical calculation scheme for version III

In the water oxygenation processes, the use of air for t = 29 [^oC] and p = 760 [torr] is investigated, for air the saturation concentration is C_s, air = 7.7 [mg / dm^3].

$$\dot{V}_{N_2} = \frac{5}{100}\cdot 600 = 30\left[dm^3 / h\right] \qquad (3.2)$$

Of the total of 600 [dm^3 / h], 95% is O2 (i.e., 570 [dm^3 / h]), and 5% (i.e., 30 [dm^3 / h]) is nitrogen.

Following the running of the calculation program, the graph in figure 3.7 was drawn.

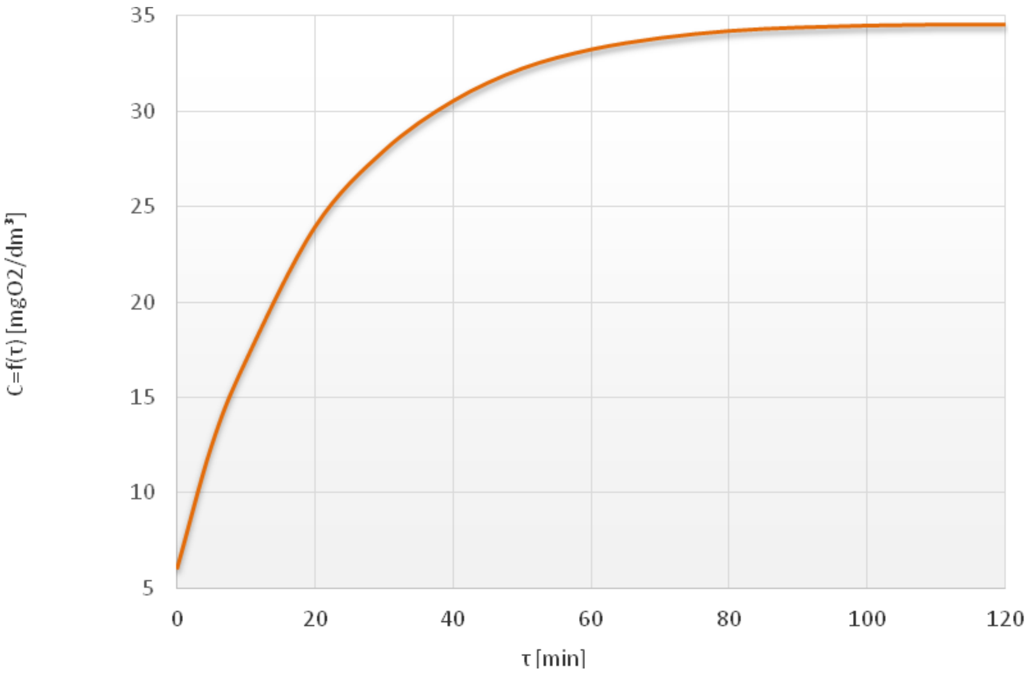

Fig. 3.5. Graphical representation of the variation of dissolved oxygen concentration in water for version III

In the case of version IV, initial data are: $C_0\left[mg/dm^3\right]$ $C_s\left[mg/dm^3\right]$, $\tau\left[\min\right]$, $\dot{V}_{air}\left[dm^3/h\right]$, $t_{H_2O}\left[{}^oC\right]$, $t_{aer}\left[{}^oC\right]$, $\dot{V}_{water}\left[dm^3/h\right]$.

In figure 3.7. the logic scheme of the calculation program for determining the concentration of dissolved oxygen in water is presented, in version IV.

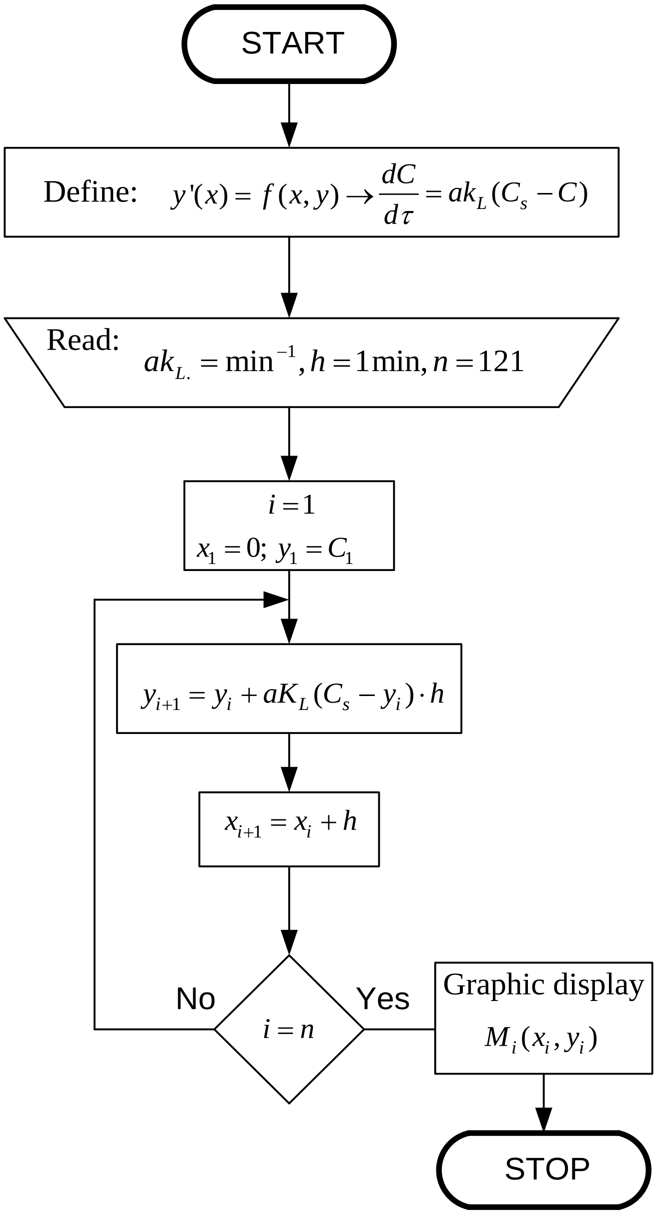

Fig. 3.7. Logical calculation scheme for the numerical integration of the differential oxygen transfer rate equation, for version IV

After running the calculation program, it was possible to draw the graph of the function Cs = f (τ) for version IV, represented in figure 3.8.

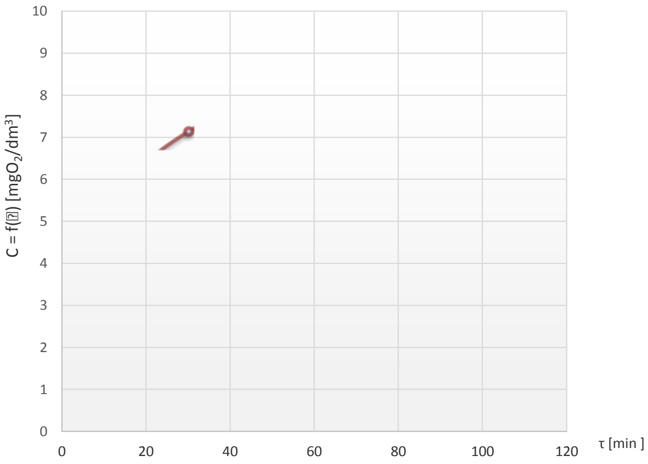

Fig. 3.8. Graphical representation of the function C= f (τ) for version IV

The value of C_s from version I, $C_s = 8.4$ [mg O_2 / dm^3] is reached after 75 [min].

Chapter IV. Gas supply sources of the experimental installation (four versions)

This chapter presents the gas source for each version.

In the laboratory researches, a low - pressure, single - stage volume compressor will be used.

The compressor as a compressed air source is type CHICAGO PNEUMATIC - CPRA 24 L20, shown in figure 4.1.

Fig. 4.1. Compressor CHICAGO PNEUMATIC – CPRA 24 L20 [12]

Oxygen from a cylinder, i.e., a liquefied gas, was used in the laboratory.

For cooling, the following processes are applied separately or in combination:

- Compression followed by indirect cooling, such as liquefaction (condensation) of refrigerant (ammonia, sulfur dioxide, etc.) in the condenser of refrigeration installations; applies to high critical point gas or using cascade cooling and to other gases;
- Free expansion, without the production of mechanical work, by using the Joule - Thomson effect;
- Expansion with work production in a regulator.

Low nitrogen sources of air

The devices that deliver this gas (95% O_2 and 5% N_2) are called oxygen concentrators. Two DeVilbiss type oxygen concentrators shown in figure 4.2 were used in the laboratory.

Fig. 4.2. Front view of DeVilbis type oxygen concentrator [43]

Each concentrator delivers 300 [dm^3 / h] at a pressure of 5 ± 0.5 [psi]; 1 psi = 0.07 [bar] = 0.07 · 105 [N / m^2] = 0.07 [Pa], so both concentrators provide the gas flow rate used, i.e., 600 [dm^3 / h] [19] [20].

Sources of ozone

Ozone is produced by a generator; the air being transported through the ozonizer by means of a compressor.

In figure 4.3. a general ozone production scheme is presented.

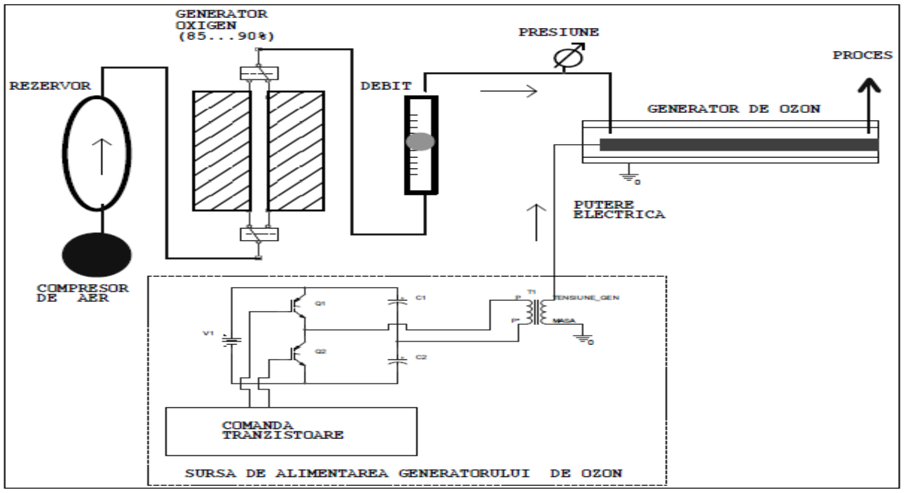

Fig. 4.3. Simplified scheme of ozone production equipment [14]

Chapter V. Theoretical establishment of energy consumption, for the four studied versions

In this chapter, the energy consumption is calculated separately for each version.

- For version I, 0.6 m^3 / h of atmospheric air is introduced into the water. Energy E is the product of the power consumed P_I [kW] and the operating time of the installation τ [h].

For version I one can obtain:

$$E_I = P_I \cdot \tau_I \left[kWh \right] \tag{5.1}$$

Admitting an efficiency of the η_{agr}, compressor + electric drive motor, of 0.5, the real drive power results.

$$P_I = \frac{P_t}{\eta_{agr}} = \frac{7 \cdot 10^{-3}}{0,5} = 14 \cdot 10^{-3} \text{ [kW]} \tag{5.2}$$

The operation time of the installation is two hours, so the mechanical energy consumed to reach from C_0 to C_s will be:

$$E_I = P_I \cdot \tau_I = 14 \cdot 10^{-3} \cdot 2 = 28 \cdot 10^{-3} \left[kWh \right] \tag{5.3}$$

It is known that the average efficiency of a coal-fired power plant is about 30%, as a result of the electricity absorbed from the electricity grid in the case of the first version will be:

$$E_{I,el} = \frac{E_I}{\eta_{CTE}} = \frac{0,028}{0,3} = 0,0933 \left[kWh \right] \tag{5.4}$$

- For the four cases in version II the volume of gas sucked by the compressor will be: $V_a = \frac{0,6}{3600} \left[m^3 / s \right]$, and the compression ratio is ε = 1.5, the same as in version I.

As a result, the electricity absorbed from the grid will be the same:

$$E_{I,el} = \frac{E_I}{\eta_{CTE}} = \frac{0,028}{0,3} = 0,0933 \left[kWh \right]. \tag{5.5}$$

- In version III, the PLATINUM type oxygen concentrator (2 pieces) used in the installation supplies 300 [dm^3 / h] of O2, so both work with 600 [dm^3/h] = 0,6[m^3/h].

From the technical data of the oxygen concentrator, it results that the maximum pressure at the outlet of the compressed gas is 0.35 bar.

As a result, the electricity consumed from the network will be lower:

$$E_{III} = 0,0935 \cdot 0,09756 = 0,0900 \left[kWh \right] \tag{5.6}$$

$$E_{III} < E_I$$

- In version IV, air + ozone is introduced in the installation; the air flow and air pressure are the same as in version I; here appears an electricity consumption of the ozone generator.

The theoretically calculated values are presented in table 5.1.

Table 5.1. Theoretically calculated values

Version no.	Introduced gas	Operation time $C_0 \rightarrow C_s$ [τ]	C_s value [mg O_2/dm^3]	Time to reach C_s	Consumed electricity [kWh]
I	Atmospheric air	2 h	8,40	2h	0,0933
II	Case I Air+ 25 % O_2	2 h	10,73	15’	0,0933
	Case II Air + 50 % O_2	2 h	21,46	5’	0,0933
	Case III Air + 75 % O_2	2 h	32,21	3’	0,0933
	Case IV 100 % O_2	2 h	43,00	2’	0,0933
III	Atmospheric air with low nitrogen content (95%)	2 h	34,80	2,5’	**0,0900**
IV	Air + ozone	2 h	8,98	87’	0,133

From table 5.1 one can observe that following the theoretical calculations the most advantageous method is version III.

For the four versions, the electricity consumption was evaluated starting from the power consumption and the operation time of the studied installation. The gas flow rate was: $\dot{V} = 0,6 \left[m^3 / s \right]$ and $\varepsilon = 1,5$.

Additional energy consumption was also taken into account as:

- For the operation of oxygen concentrators;

- For the operation of the ozone generator.

Following the evaluation of the energy consumption of the four variants, the most favorable option is version III.

Chapter VI. Design and construction of installations for insufflation of gas mixtures in water

This chapter presents the installation diagrams, the components and the operation of the installation for each version.

Version I: Installation for the introduction of atmospheric air into water

The installation for the introduction atmospheric air into water is shown in Figure 6.1 [21] [22].

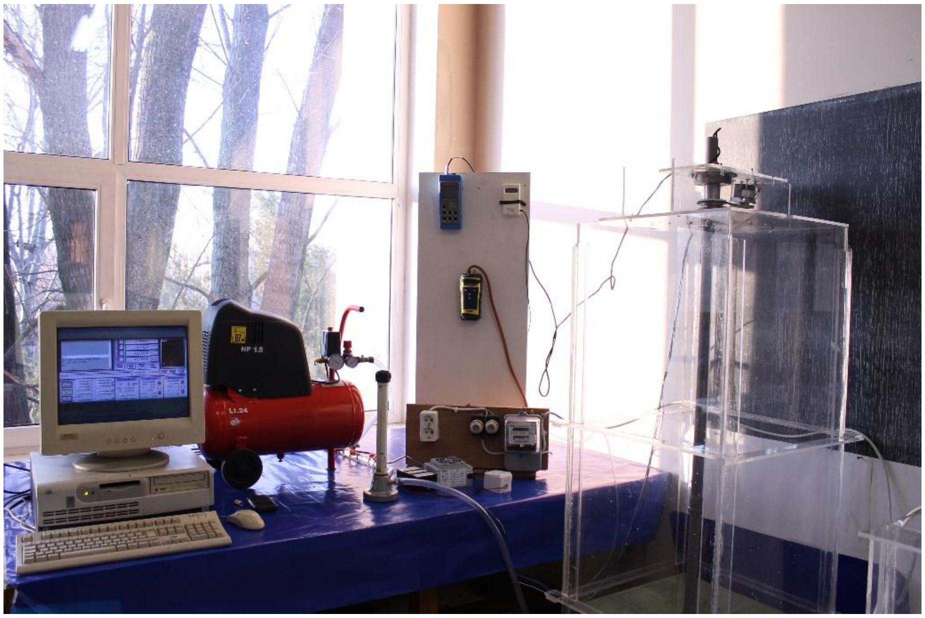

Fig. 6.1. Overview of the experimental installation for blowing atmospheric air

On the left side of figure 6.1. there is a computer, an electrocompressor, a rotameter.

Version II: Installation for blowing a mixture of atmospheric air and oxygen from a cylinder into water

In figure 6.2. are distinguished:

- On the left is a computer and the electric compressor with the air tank;
- In the center one can see the oxygen cylinder provided with pressure reducer and manometer;
- On the right is the transparent plexiglass parallelepiped tank.

Fig. 6.2. Overview of the experimental installation to the introduction of a mixture of gases (atmospheric air and oxygen)

Two hoses are inserted into the tank through which the MBG with a mixture of air and oxygen. Air flow and oxygen flow are measured separately with a rotameter; the air and oxygen are mixed in a mixing chamber and then the mixture reaches the G.M.B. through two hoses connected at the two ends of the G.M.B. [2] [3].

Version III: Installation for the introduction of air with low nitrogen content.

In figure 6.3. two oxygen concentrators are observed on the left side. The gas passes through a rotameter embedded in each oxygen concentrator and subsequently the gas pressure and temperature at the inlet to the MBG [24] [25] [26].

Fig. 6.3. Overview of the experimental installation for the introduction of air with low nitrogen content

The atmospheric air aspirated from the atmosphere passes through a filter, is compressed and sent to the zeolite filters; here nitrogen is retained so that at the exit of the device a gas containing 95% oxygen is obtained. Each oxygen concentrator delivers 300 [dm^3 / h].

Version IV: Installation for the introduction of a gaseous mixture of atmospheric air and ozone

The ozone generator TCB – 300 O_3 is a complex and controllable automatic device for decontamination of indoor air. The ozone generator TCB - 300 O_3 has a hard plastic body with degree of protection IP-56, which allows the use of this device in different conditions and spaces - residential, industrial, etc. [27] [28].

Fig. 6.4. Plan view of the pipeline-connected ozone generator [15]

In figure 6.4. the ozone generator connected to the pipes of the water oxygenation installation is presented.

Chapter VII. Experimental researches

This chapter reveals the researches methodology for each of the four versions.

Chapter 6 presented the experimental installations for the four study versions. This chapter reveals the researches methodology with the stages to be covered in the measurements.

Experimental researches conducted in the laboratory of the Department of Thermotechnics, Engines, Thermal and Refrigeration Equipment aimed to experimentally determine the variation of the dissolved oxygen concentration in water as a function of time for the four gas mixtures [29] [30] presented in four versions:

I. Atmospheric air (21% O_2 + 79% N_2);

II. Mixture of atmospheric air and oxygen in the cylinder;

III. Air with low nitrogen content (95% O_2 + 5% N_2);

IV. Air + ozone.

For each stage of measurements, the following phases follow one another [31] [32]:

1. The pressure test of the fine bubble generator is performed;
2. Fill the tank with water up to H = 0.5 m (hydrostatic load);
3. Measure the initial concentration of dissolved oxygen in water C_0 (mg / dm3);
4. Measure the water temperature in the tank and the air temperature;
5. Introduce the fine bubble generator into the water and note the time of beginning of the experiment;
6. Measure and keep the flow rate and pressure of the compressed air constant with the help of the control valves;
7. After 15 minutes, the oxygenation of the water is stopped and the oxygenometer probe is inserted in the water;
8. The electro-mechanism of actuating the probe is started, which ensures a speed of 0.3 m/s; when the value of the oxygen concentration on the oxygenometer screen stabilizes, it means that the measurement has been completed;
9. Remove the probe of the oxygenometer in the tank;
10. Restart the oxygenation system and note the time 15 '; 30 '; 45 '; 60 '; 75'; 90 '; 115 '; 120 '120' = 2 [h]; C_{O_2} is measured every 15 '.

Previous researches have shown that by introducing $\dot{V} = 600\left[dm^3 / h\right]$ air into the water tank with a hydrostatic load of H = 0.5 [m] with a volume of water (0.125 m3), the concentration of dissolved oxygen in the water is close to the saturation value after a time τ = 2 [h].

Chapter VIII. The results of experimental researches, their processing

This chapter graphically shows the variation of the concentration of dissolved oxygen in water as a function of time.

Results for Version I (atmospheric air introduced into water)

Based on the experimental data, the graph from figure 8.1 was drawn.

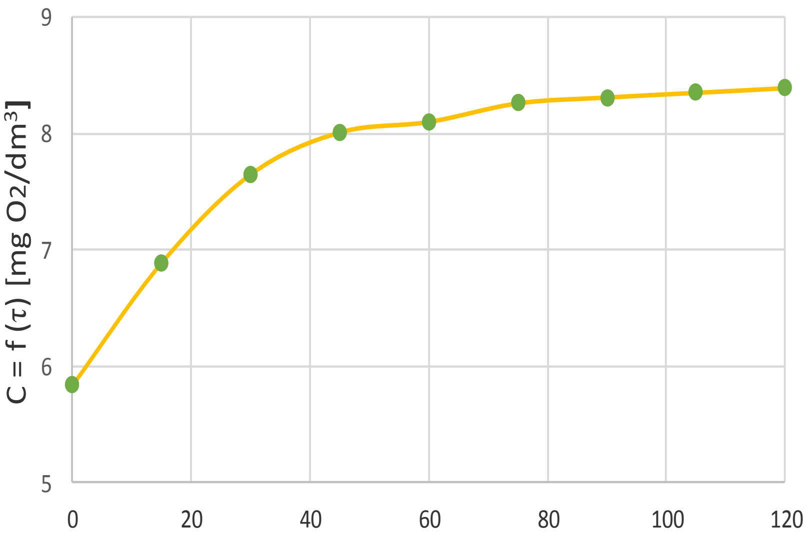

Fig. 8.1. Variation of dissolved oxygen concentration in water in version I

These results are in good agreement with those theoretically obtained, in the thesis as well as with those contained in similar papers [33] [34].

Results obtained for version II (introduction into water of a mixture of atmospheric air and oxygen from a cylinder)

Figure 8.2 shows the installation in which a mixture of gases consisting of atmospheric air and oxygen is introduced; the experimental results obtained are presented in figure 8.2.

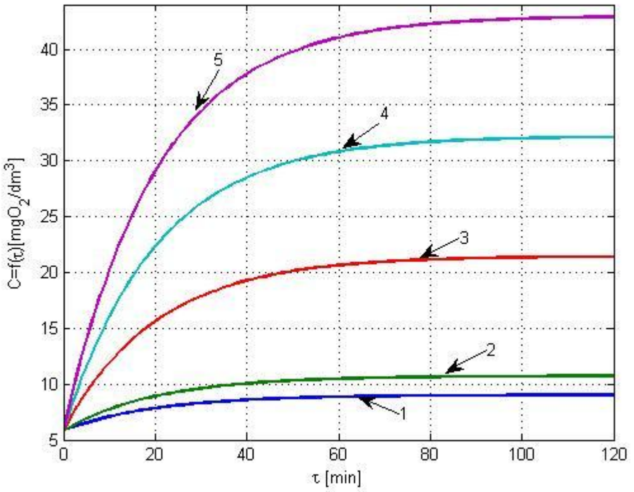

Fig. 8.2. Graphical representation of the variation of dissolved oxygen concentration in water for version I (curve 1) the four cases of version II (curves 2,3,4,5)

The comparison of the C = f (τ) function for version I and the four cases of version II presented above can be seen in figure 8.2.

Results obtained for version III (introduction of low nitrogen air)

In this case the oxygen content is 95% and nitrogen in the proportion of only 5%. Saturation value = 34.8 [mg O_2 / dm^3].

Following the experimental researches, the curve in figure 8.3 was obtained.

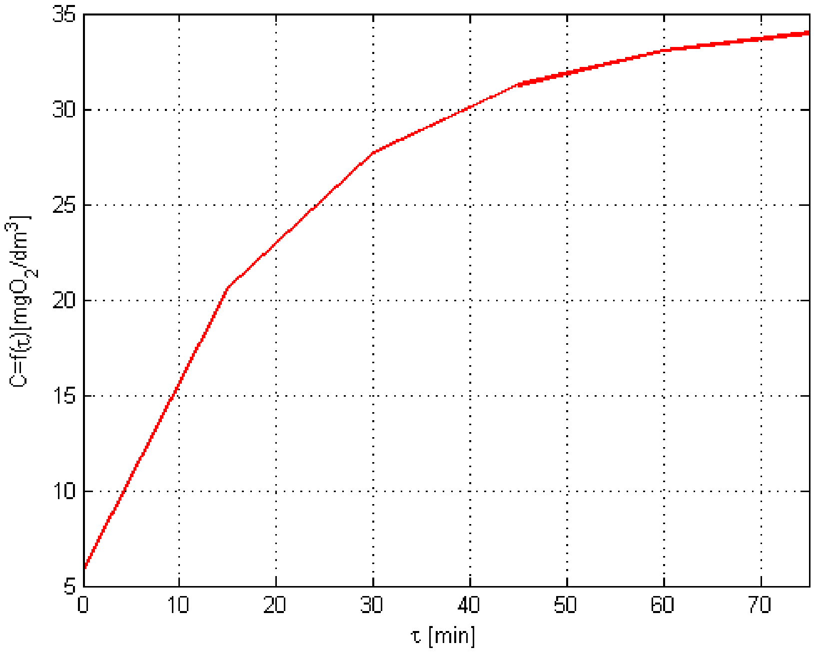

Fig. 8.3. Graphical representation of the variation of dissolved oxygen concentration in water for version III

Results obtained for version IV (introduction into the water of a gaseous mixture of atmospheric air and ozone)

For version IV, a gaseous mixture (air + ozone) is introduced in the fine bubble generator and the experimental researches resulted in the data in figure 8.4.

For the water temperature of 21 ºC the value of C_s = 8,90 [mg/dm^3].

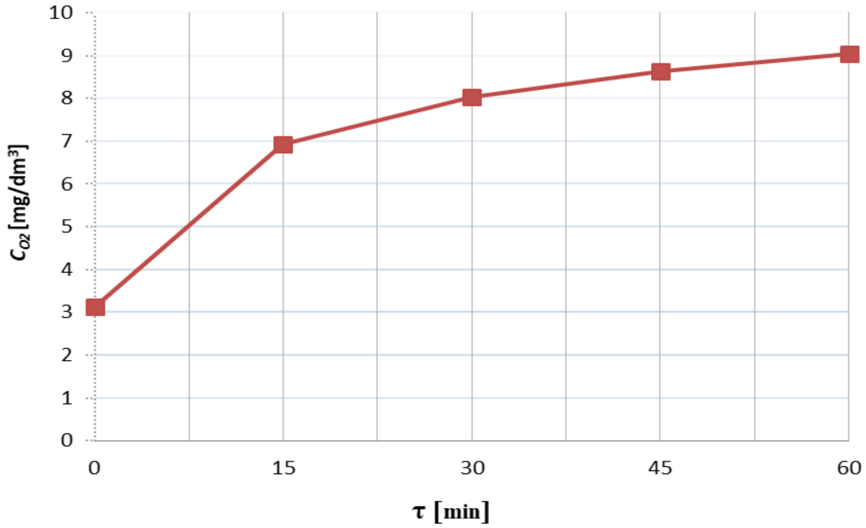

Fig. 8.4. The dependence C_{O_2} = f (τ), on introduction of a gaseous mixture of air and ozone

From figure 8.5. one can observe that when a gaseous mixture (atmospheric air + ozone) is introduced into the water by means of the fine bubble generator, the period in which it reaches from C_0 to C_s is reduced by half, which makes this process much more efficient; in other words, in order to reach C_o to C_s in the same hydrodynamic regime, the operating time for version IV is twice as short.

For the above researches, a microbubble generator (MBG) was used which is provided with a perforated plate with 152 orifices of Ø 0.1 mm made by micro-drilling (figure 8.5.) [35] [36] [37].

During the experimental researches, the following values are kept constant: gas pressure at the entrance to the MBG, gas flow rate, hydrostatic load.

At an interval of 15 minutes the air supply to the MBG is stopped and the oxygenometer probe is inserted; the signal taken from the probe is processed in the microcomputer and digitally displayed on the microcomputer screen [38], [39].

Figure 8.7. shows the operation of the MBG rectangular in shape.

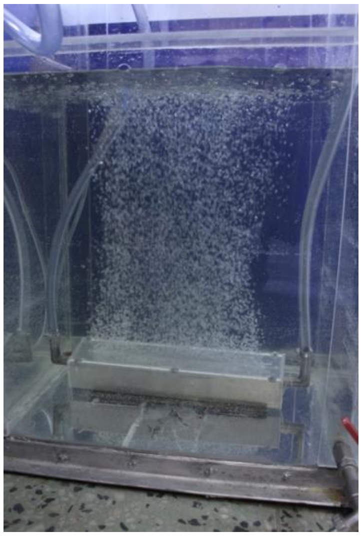

Fig. 8.5. Microbubble generator with 152 orifices Ø 0.1 mm in operation

In figure 8.6. all the results of the measurements performed are presented: 1 - 7 theoretical results; 8 - 12 experimental results.

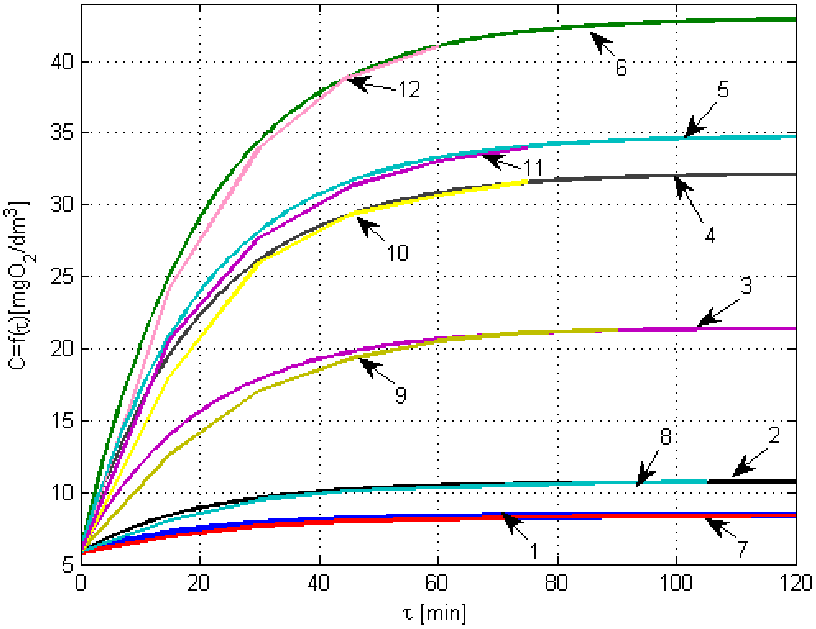

Fig. 8.6. Variation of the dissolved oxygen concentration in water in time for the four versions **Curves drawn based on theoretical data**: 1 - for atmospheric air; 2 - air + oxygen from the cylinder (150 dm^3 / h); 3 - air + oxygen from the cylinder (300 dm^3/ h); 4 - air + oxygen from the cylinder (450 dm^3/ h); 5 - for air with low nitrogen content; 6 - air + oxygen from the cylinder (600 dm^3/ h); **Curves drawn based on experimental data**: 7 - for atmospheric air; 8 - air + oxygen from the cylinder (150 dm^3/ h); 9 - air + oxygen from the cylinder (300 dm^3/ h); 10 - air + oxygen from the cylinder (450 dm^3/ h); 11 - for low nitrogen air; 12 - air + oxygen from the cylinder (600 dm^3/ h)

From figure 8.6. a good concordance is observed between the theoretical data and the data experimentally obtained. Obviously, the C_s value is reached the fastest when pure oxygen is introduced into the water.

The experimental results obtained are similar to those in recent scientific papers [41], [42].

Chapter IX. Comparative economic analysis of the four studied versions

In this chapter, the most favorable solution of the four variants is chosen.

The electricity consumption table is resumed and the cost of electricity is calculated:

Table 9.1. Theoretically calculated values

Version no.	Introduced gas	Operation time $C_0 \rightarrow C_s$ [τ]	C_s value [mg O_2/dm^3]	Time to reach C_s	Consumed electricity [kWh]
I	Atmospheric air	2 h	8,40	2h	0,0933
II	Case I Air+ 25 % O_2	2 h	10,73	15’	0,0933
	Case II Air + 50 % O_2	2 h	21,46	5’	0,0933
	Case III Air + 75 % O_2	2 h	32,21	3’	0,0933
	Case IV 100 % O_2	2 h	43,00	2’	0,0933
III	Atmospheric air with low nitrogen content (95%)	2 h	34,80	2,5’	**0,0900**
IV	Air + ozone	2 h	8,98	87’	0,133

From the analysis of the four versions (table 9.1.) one can observe that version III has the lowest electricity consumption, the lowest cost, so it is the most advantageous.

Obviously, in the case of version III, oxygen concentrators must be purchased, which increases the cost of the initial investment. Consumption of electricity, water, etc. is supported by the University Politehnica of Bucharest.

There are no exaggerated consumptions and no appliances that require large investments.

To choose the most efficient solution, calculate the total cost of electricity consumed when $C_0 \rightarrow C_s$:

Table 9.1 with electricity consumption is resumed.

Table 9.2. Theoretically calculated values

Version no.	Introduced gas	Operation time $C_0 \rightarrow C_s$ [τ]	C_s value [mg O_2/dm^3]	Time to reach C_s	Consumed electricity [kWh]	Energy cost [Lei/kWh]	Total cost [Lei]
I	Atmospheric air	2 h	8,40	2h	0,0933	0,0633	0,059
II	Case I Air+ 25 % O_2	2 h	10,73	15’	0,0933	0,0633	0,059
	Case II Air + 50 % O_2	2 h	21,46	5’	0,0933	0,0633	0,059
	Case III Air + 75 % O_2	2 h	32,21	3’	0,0933	0,0633	0,059
	Case IV 100 % O_2	2 h	43,00	2’	0,0933	0,0633	0,059
III	Atmospheric air with low nitrogen content (95%)	2 h	34,80	2,5’	0,0900	0,0633	0.056
IV	Air + ozone	2 h	8,98	87’	0,133	0,0633	0.084

It is noted that version III is favorable for the overall cost assessment.

CONCLUSIONS AND PERSONAL CONTRIBUTIONS

C1 GENERAL CONCLUSIONS

The paper highlights various solutions to increase the dissolved oxygen content in water.

Depending on the economic potential of a future beneficiary, one of the four versions presented must be chosen.

Of course, the most economical version is version III: the introduction in water of air with low nitrogen content (95% O_2 + 5% N_2), but this involves the purchase of oxygen concentrators. The paper [42] demonstrates that in the long run the investment is amortized.

C2 ORIGINAL CONTRIBUTIONS

The following contributions will be briefly presented:

A. Theoretical contributions

1) Presentation of the current state of researches in the field of air and stagnant water oxygenation;

2) Analysis of the equation of the oxygen transfer rate to water and its numerical integration;

3) Analysis of electricity consumption for the four calculation versions:

- Version I: introduction of atmospheric air into water (21% O_2 and 79% N_2);
- Version II: introduction a gaseous mixture of atmospheric air and oxygen from a cylinder;
- Version III: introduction of a stream of air with low nitrogen content (95% O_2 and 5% N_2);
- Version IV: introduction of a mixture of atmospheric air and ozone.

4) Calculation of the electricity absorbed from the electrical network for an efficiency of a thermal power plant: $\eta_{CTE} = 0,3$.

5) The economic analysis of the four versions in the sense of establishing the expenses with the consumed electricity;

6) Establishing an optimal version from an economic point of view; chosen version III which consumes the least amount of electricity, so it has the lowest operating costs.

B. Numerical contributions

1) Elaboration of the program for calculating the concentration of dissolved oxygen in water for the four versions; the input data for each program are of two categories:

- Common data: C_0 [mg / dm^3], τ [min], $\dot{V}_{air}\left[dm^3/h\right]$, t_{H_2O} [^oC], $H\left[mmH_2O\right]$;

- Different data: those specifying the composition of the gas introduced into the water.

2) Development of a calculation program for the numerical integration of the differential equation of the oxygen transfer rate to water using the Euler numerical method.

C. Experimental contributions

- Design and construction of experimental researches installations on:

- I: Aeration of water (introduction of atmospheric air into water);

• II: Oxygenation of water (introduction of a gaseous mixture of atmospheric air and oxygen from a cylinder);

• III: Oxygenation of water by introducing a stream of air with low nitrogen content (95% O_2 and 5% N_2);

• IV: Oxygenation of water by introducing a mixture of atmospheric air and ozone.

- Elaboration of a research methodology for each studied version.

- The experimental results obtained and their processing in graphic form.

C3 PROSPECTS FOR FURTHER RESEARCHES

Researches on increasing the concentration of dissolved oxygen in water can be extended to the following categories:

-The choice of devices to ensure the introduction of air not in the tanks, but directly in the wastewater transport pipes; this eliminates those large tanks that require very high investment;

- Finding some fine bubble generators in which the diameter of the air introduction orifices is of the order of nanometers (current researches has reached the diameter of an orifice of 0.1 mm).

Such tests are currently being studied in the laboratories of the University Politehnica of Bucharest.

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