UNIVERSITATEA „POLITEHNICA” din BUCUREŞTI
ŞCOALA DOCTORALĂ DE ENERGETICĂ

THESIS SUMMARY

Theoretical and experimental research on the polyphase fluids flow through the wastewater treatment plant in order to optimize energy

Cercetări teoretice şi experimentale asupra curgerii fluidelor polifazate prin staţia de epurare în scopul optimizării energetice

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Foreword

The field of air-water polyphase fluid flow, as well as in biological waste water treatment tanks, is especially important for many applications in the technical field. Many researchers, higher education and industry collectives are working in this area that have made the contributions mentioned in Chapter 1. It is a scientifically interesting field because the flow of mixture fluids has its own laws little known to mechanics. It is an area of interest to specialists because the dispersion of air in water and the transfer of oxygen from the gas into the aqueous medium require a great deal of energy.

This PhD thesis analyzes this field both through theoretical research and experimental research in order to elucidate the aspect that occurs in the generation and movement of air bubbles through the water. In their ascending way, the air bubbles yield to the liquid, the oxygen that is so necessary to the biological process and to life.

The research aims both to identify the impact of the movement on the oxygen transfer as well as the energy consumption aspect so as to achieve a technical and economic balance of the biological treatment process. Chapter 5 presents aspects related to energy consumption in a wastwater treatment plant. Studies have shown that blowers used for the biological treatment process are the most energy-consuming. In chapter 6, the experimental researches "in situ" aimed to determine the economic and hydraulic parameters for two types of mechanical equipment with the power consumption of 25 kW and 37 kW respectively.

Conclusions from the researches revealed that economically lesser aerator is more beneficial, but from a hydraulic point of view, the higher power provides better conditions for the biological process.

To improve the biological treatment process it is necessary to understand in detail the formation and movement of air bubbles in the water. To this end, chapters 7 and 8 present the results of the experimental research carried out in the laboratory and the mathematical modeling that complements them. These investigations aim to identify a correlation between the air inlet pressure, the diameter of the hole through which the mass of gas passes and the motion generated in the mass of water by the air bubbles. The results have shown that swirl formation is an important factor in the transfer of oxygen from air to water.

An ultimate aspect of the thesis concerns the impact of the presence of air in the water mass on the pressure losses. Laboratory research and mathematical modeling support the fact that the loss of charge in motion of the biphasic mixture is higher than in the flow of water.

Thus, the thesis becomes a basis for the hydrodynamic characteristics of the bifasic air-water mixture in the sewage treatment plants. As a result of these researches, a balance can be established between the energy, hydraulic and economic coefficients in order to reduce the energy consumption at the level of biological tanks.

1. Polyphase Fluids - Introduction

1.1. Complexity of polyphase fluids

The main problem in analyzing polyphase fluids flow is represented by the rheological behavior of the mixture. In the case of a biphasic gas-liquid mixture problems arise at the interface between the two components due to: the change of the shape of the gas bubble in motion, the mechanical interactions of the bubbles, the gas transfer, and the fluid flow by the bubbles in their upward movement.

Natural phenomena of polyphase fluid flow are very complicated and can not be described in a single mathematical model. Starting from the system of basic equations describing the motion of polyphase fluids, Navier-Stokes and the continuity equation [40], [41] [85], mathematical models can be developed by which these phenomena can be solved.

1.2. Polyphase fluids in the wastwater treatment plant

The main parameters characterizing wastewater are: Total Solid Suspensions (TSS), Biochemical Oxygen Demandd (BOD) and Dissolved Oxygen (DO). In order to combat pollution, treatment systems have become mandatory, developing comprehensive environmental legislation in this area [117], [119-124]. In Romania, the wastewater treatment for sites with over 10000 inhabitants is currently imposed by legislation.

2. The current state of research in the study of mixture flow in wastwater treatment plants

Through wastewater treatment plant, polyphase mixtures of different substances and particles are dissolved or dispersed through the aqueous medium in granular or colloidal form. There are physical, chemical and sometimes biochemical interactions between the constituents. In the PhD thesis were presented several researches and mathematical models made over time which led to solving many problems in this field. The essay refers to decant flow models, researches made in the study of hydrodynamic behavior of the sludge in the wastewater treatment plants and analysis of the aeration process in biological basins.

2.1 Research objectives

The subject of the PhD thesis is the study of the flow of the air-water mixture in the aeration basins of the wastewater treatment plant. The purpose of the paper is to determine the impact of water mass entrainment in the upward movement of the air bubble on the biological treatment process and the transfer of oxygen from air into water.

3. Biological wastewater treatment

3.1. Aerobic biological treatment

For the performance evaluation of aeration equipment, the basic size is the energy index E [kg O_2 / kWh], which is recommended to be greater than 3 kg O_2 / kWh [60]. Numerous studies have found that the intensity of hydrodynamic induced in the aeration tank can be estimated globally by δ [W / m^3], which represents the power of the equipment used for oxygen injection relative to the volume unit of the tank and whose values must exceed 20 W / m^3, considered as the lower limit of assessment of sludge flock deposition [39].

The main task of wastewater engineers is to understand the phenomenon of mixing microorganisms, wastewater and dissolved oxygen, and to find ways to improve this phenomenon in order to achieve high efficiency and low costs. In this chapter, a classification of the aerobic biological treatment processes and flow patterns of the air-water mixture [14] was presented.

4. Dynamics of air bubble in the water

In the study of the air-water mixture flow it is very important to identify a correlation between the properties of the fluids, the physical constants, the properties of the air-water mixture, and the flow properties in the inlet area. Within this chapter there are presented all these parameters and the criteria of similarity with which the researches within the thesis were carried out. These include: air bubble velocity, air bubble diameter, velocity generated and induced in the water, air pressure, diameter of the erosion entry aperture, etc.

5. Energy consumption in SEAU Constanța Sud

The power supply of the Constanta Sud Wastewater Treatment Plant is made on two lines of medium voltage of 20 kV. Five transformation points PTA, PT2, PT1, PTB and PT7 are fed from these two lines. In total, there are 199 consumers for which the required average power of 500 MWh / month and 17 MWh / day was recorded.

The measurements at the 5 transformation points over a period of one week showed that the highest energy consumption, 53% of the energy demand of the entire WWTP, was recorded at the PTA point where the blowers needed to oxygenate the water from the aeration tanks. The aim of the thesis is to identify a solution for the efficiency of the emergence consumption by achieving a balance between the air supply flow rate, the hydrodynamic parameters of the air-water mixture and the air-to-water oxygen transfer coefficient.

6. Experimental research “in situ”

6.1. Determination of oxygenation performances using transient test method

The focus of the "in situ" researches in this thesis was the comparison of the aeration equipment taking into account the technical and economic parameters and the oxygenation performance: CO [kg O_2 / h], E [kg O_2 / kWh] δ [W / m^3], for surface mechanical aeration equipment with different power of 25 kW and 37 kW, respectively, at the Brazi wastewater treatment plant.

For the calculation of the oxygenation capacity the transient test method was used [116]. Based on the results obtained from the measurements and statistical processing, the dissolved oxygen concentration was plotted as a function of time for the mechanical aerator with power 25 kW [20]. The following values were obtained: $k_{La,\ 25kW} = 0{,}05$ [min^{-1}] and

CO_{25kW} = 14,18 [kg O_2 / h]. For the 37 kW mechanical surface aerator, the results were $k_{La,\ 25kW}$ = 0,09 [min^{-1}] and CO_{25kW} = 25,52 [kg O_2 / h].

The results for the economic coefficient were obtained E_{25kW} = 0,56 [kg O_2 / kWh] and E_{25kW} = 0,68 [kg O_2 / kWh], and for the specific power index resulted δ_{25kW} = 60 [W/m^3], δ_{25kW} = 88 W/m^3, respectively.

To determine the rate generated and induced, a Neyrpic type micromachine with automatic recording was used. The velocity values were correlated with dissolved oxygen concentration values measured with the fluorescent dissolved oxygen sensor (LDO) mounted on a portable HQd series controller.

The aeration tank at the Brazi wastwater treatment plant has a volume of 2500 m^3 and a height of 3,8 m, with six aerators in it. The measuring points for which the investigations were carried out for the 25 kW mechanical aerator are identical to those carried out for the 37 kW fan and are shown in Figure 6.1 [16].

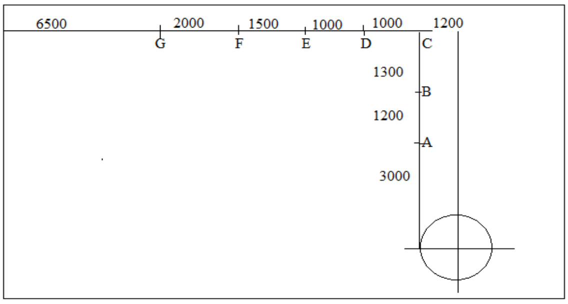

Fig. 6.1. Schematic representation of the measurement verticals distribution in the aeration tank of SEAU Brazi against the mechanical surface aerator shaft.

6.2. Conclusions

As a result of the researches made, it was observed that when the rate increases, usually the dissolved oxygen concentration is increased. This is due to whirlpools that help to homogenize the active air-water-sludge mixture and have a positive impact on the mass transfer coefficient. It has also been demonstrated that the use of higher unit-specific power has led to the dissolved oxygen concentration required for the development of micro-organisms on almost the whole area under consideration.

Following the application of the method of determining the oxygenation capacity, it was demonstrated that for an increase of the power consumed by 48%, there were obtained: an increase of the oxygenation capacity by 79%, an increase with 33% of the specific power and a 2% increase of the economic coefficient.

7. Experimental research in the laboratory

7.1. Experimental plant

The experimental plant in the laboratory consists of a parallelepiped shaped basin made of transparent pexiglass. At the base there is a plate on which is mounted a nozzle with a hole diameter of 0.5 mm, which was subsequently changed with nozzles of larger diameters. Air pressure was measured using a metal gauge.

Laboratory experimental investigations measured gas pressure (0-1 bar), gas bubble velocity, gas bubble diameter, gas inlet diameter, water column height (maintained constant at h = 1 m).

The first stage of the research is to determine the gas pressure flow regimes.

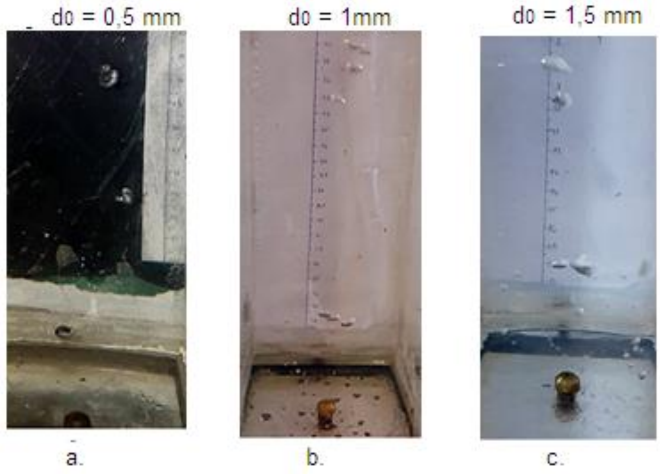

Fig. 7.1. Formation of air bubbles for the diameter of the hole d_0 = 0,5 mm (a), d_0 = 1 mm (b) şi d_0 = 1,5 mm (c) for which bubble bulb flow regime has been achieved

In the case of diameter d_0 = 0.5 mm the bubble flow regime was obtained for the pressure range 0.05 - 0.1 bar. At a pressure increase of more than 0.15 bar, the melt and annular flow patterns (for pressures greater than 0.5 bar) were obtained. Increasing the pressure to 0.8 bar caused turbulent flow. Bubble lifting velocity values were obtained between 0.19 - 0.21 m / s and diamteter of the gas bubble 5 - 6 mm.

With the diameter picking, the flow regimes were speculated at different air injection pressure values. Also, the diameter of the gas bubbles has increased by 10 mm. The theoretical calculation of the specific mass transfer coefficient resulted in values for k_l in the range 0,02 - 0,30 min^{-1}.

7.2. Conclusions

Increasing the diameter of the hole through which the air is introduced into the water mass causes the minimum pressure required to achieve the aeration process to increase. Increasing the minimum required pressure will increase the power consumption of the plant.

8. Mathematical modeling of the dynamics of the air-water mixture

8.1 Mathematical modeling using the dispersion equation

In this thesis, the first numerical simulations were made for oxygen dispersion in order to identify an optimal ratio between the dispersion coefficient, ε_z, and the reaction coefficient, k, of the microorganisms with oxygen so as to obtain the desired concentration of oxygen dissolved in the waste water. [49].

Simulations of oxygen dispersion for a gas velocity interval were performed w = 0,2 – 0,8 m/s and for a vertical dispersion coefficient value in the range ε_z = 0,2 - 20 m^2/s. In the simulations, the reaction coefficient k range was obtained, for which the dissolved oxygen concentration was obtained in the range of 0.2 mg / l (as the minimum required concentration in the bioreactor) and 10 mg / l (the concentration of oxygen to saturation).

8.2 The mathematical model for determining the velocities generated and induced in water

To study of velocities generated in the water mass, the mathematical modeling and numerical simulation was bi-dimensional, having the same dimensions obtained by similitude with the experimental installation. The gas velocity values are between v_g = 0.10 - 1.0 m / s and the diameter of the inlets d_0 = 0.5 - 1.5 mm. The FLUENT, the VOF model, was used for unstady state, laminar flow [19]. The equations underlying the model are the continuity equation and the equation of the volumetric gas fraction derived from the impulse conservation equation.

For all the analyzed cases - three orifice diameters (0.5 mm, 1 mm and 1.5 mm) and four initial air intake speeds (0.17 m / s, 0.25 m / s, 0, 40 m / s and 0.90 m / s), the time step used was 0.001 s, a modeling for 1000 steps was performed and the numerical calculation was stopped at one second and represented by three distinct graphics.

The first numerical simulations were made for the size of the hole d_0 = 0,5 mm and the air velocity introduction $v_{g,0}$ = 0,17 m/s [19]. The air bubbles have a spherical shape of about 3 mm in diameter and have generated relatively variable and reduced velocities in the mass of water, with the resulting whirlwinds being small.

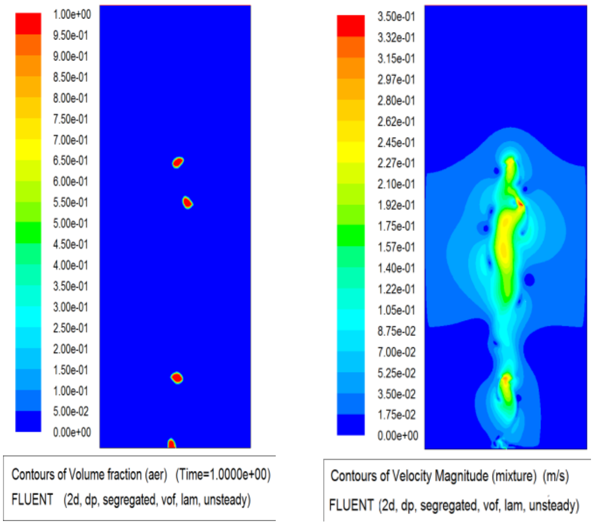

Fig. 8.1. Representation of the volumetric air fraction and the contours of velocity (d_0 = 0,5 mm şi $v_{g,0}$ = 0,17 m/s)

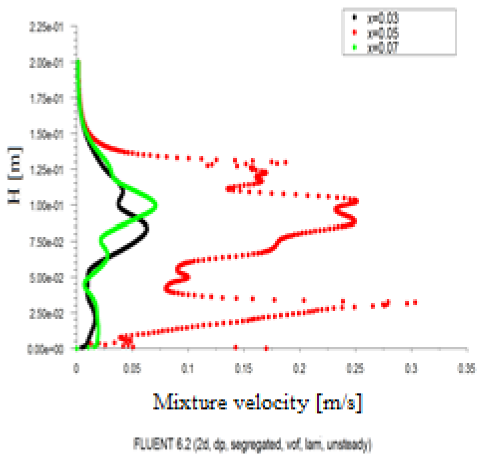

Fig. 8.2. Splitting velocities along three verticals, la x = 0,03 m, 0,05 m şi 0,07 m (d_0 = 0,5 mm şi $v_{g,0}$ = 0,17 m/s)

Increasing air intake velocity at $v_{g,0}$ = 0,25, the bubbles begin to deform to the spherical shape and the velocity generated in the mixture increases to maximum 0,25 – 0,27 m/s. For $v_{g,0}$ = 0,40 m/s the bubbles change shape, and bubble fractionation occurs. At value $v_{g,0}$ = 0,90 m/s there are whirlwinds that impact on the movement of air bubbles. There is a phenomenon of coalescence, which causes the formation of large bubbles of air, which then breaks bubbles of smaller size.

Mathematical simulations and modeling have been performed as in the first case for the diameter of the 1 mm and 1.5 mm holes. Gradual increase of diameter and speed to

d_0 = 1,5 mm, and $v_{g,0}$ = 0,90 m/s, have led to the identification of the optimum solution to ensure both the formation of spherical bubbles necessary to effect oxygen transfer from air to water and the generation of generic varieties in the mixing mass so as to achieve the mixture of the two phases.

8.3 Conclusion

For the proposed configuration following the obtained results, determine the range of the ratio values k/ε_z = [0,066-0,79], by which the value of the oxygen dispersion coefficient ε_z can be obtained. This is directly proportional to the vertical flow velocity wg. By knowing the amount of organic matter in the waste water, the gas flow rate required to obtain a dissolved oxygen concentration in the range of C = 2-10 mg / l can be determined. Achieving the optimal flow rate of gas in the aeration tank results in increased efficiency of biological treatment and lower energy costs.

According to the obtained numerical results it can be stated that both from the point of view of the bubble formation and the velocity generated in the mixing mass the best solution corresponds to an orifice diameter d_0 = 1 mm and velocity $v_{g,0}$ = 0,17 m/s. Errors obtained compared to experimental data are 0.15 – 0.2%.

9. Comparison of aeration equipment from the energy point of view

9.1. Energy calculation

In the experiments conducted for three values of the diameter of the air inlet in the tank, the first calculation was made for the surface mechanical aerator with the power of 25 kW, for which the value of the transfer coefficient is k_l = 0.05 min^{-1}. It has been compared to the three air dispersing systems (with a hole diameter of 0.5 mm, 1 mm and 1.5 mm respectively). Also calculations were made for the mechanical aerator on the surface with the power of 37 kW. The calculation aimed to determine the economics of peters between mechanical and pneumatic aeration equipment.

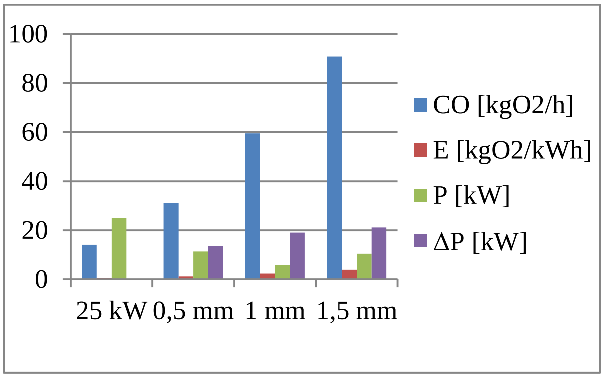

Fig.9.1. Comparison for the power output of 25 kW mechanical equipment and the less power calculated pneumatic installation

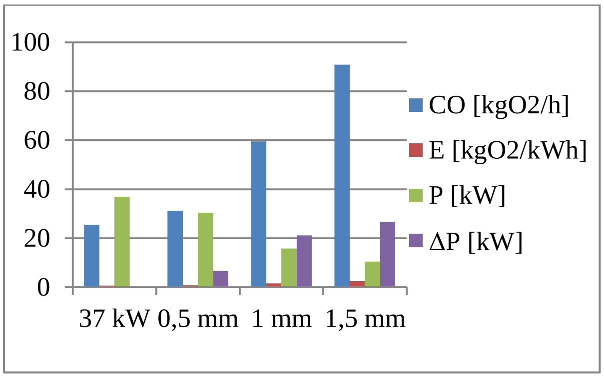

Fig. 9.2. Comparison for the power output of 37 kW mechanical equipment and the less power calculated pneumatic installation

9.2. Conclusions

Comparison of mechanical and pneumatic oxygen systems demonstrates very clearly that equipment based on compressed air dispersion in the aqueous medium is more efficient.

Between the analyzed oxygen systems, the one based on 1 mm diameter holes and velocity $v_{g,0} = 0{,}17$ is the best solution for both aeration and hydrodynamic performance.

10. Research on pressure drop at the flow of water-air mixture

10.1. Experimental research in the laboratory and mathenatical model

In the thesis, an own research was carried out on the impact of the presence of air in the water mass on the pressure and the pressure drop in the movement of the air-water mixture. The study consisted of experimental researches and mathematical modeling for different concentrations of air in the biphasic system.

The experimental installation is a closed system made of a pipe with a inner diameter D_i = 0,036 m and the total length of L = 10,22 m. The flow was ensured by a Cris's pump with a maximum flow of 6 m^3 / h. Pressure drops were measured with mercury differential manometers. The aperture was used to measure the flow. Measurements were made for the upward, downward, diaphragm flow area and the 90^o flow direction changeover areas.

In the experimental researches, the load losses were determined for different water flows (2.5 m^3 / h, 3.05 m^3 / h, 5.15 m^3 / h, 5.69 m^3 / h and 6 m^3 / h). The flow regime was determined based on the Reynolds nomber. (Figure 10.1).

Research has shown that pressure drops are directly proportional to the flow to a supra-unitary power. In the area of change of flow direction and diaphragm the measured values are higher than in the rectilinear flow area due to the occurrence of local pressure drop. Also, on the ascending movement section, values comparable to the pressure drop on the downward movement section were obtained..

Mathematical modeling and numerical simulations have been performed in FLUENT 3D, for turbulent regime for a 10 second time interval of 0.1 s. This resulted in 100 steps of time. The equations underlying the model are the continuity equation, the Navier-Stokes transport equation and motion equations, and k-ε standard [17], [18], [116] were used to simulate the turbulence.

Numerically simulated was done for water and for air to water mixture with two different air concentrations: 0.04 and 0.07. With simulations, it has been identified that the presence of air has a significant impact on pressure drop. The results are presented in Figure 10.2 [15].

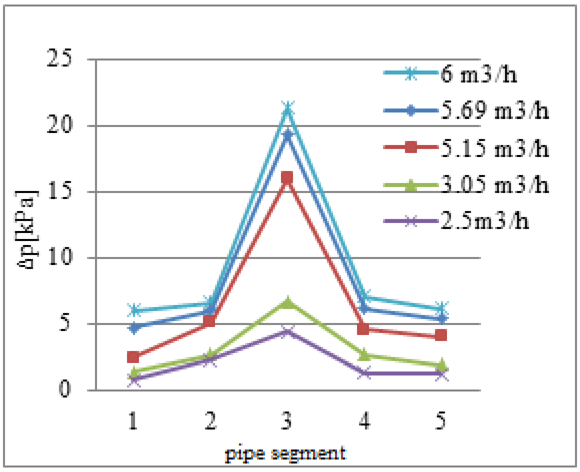

Fig. 10.1.Ppressure drop on the five pipeline segments

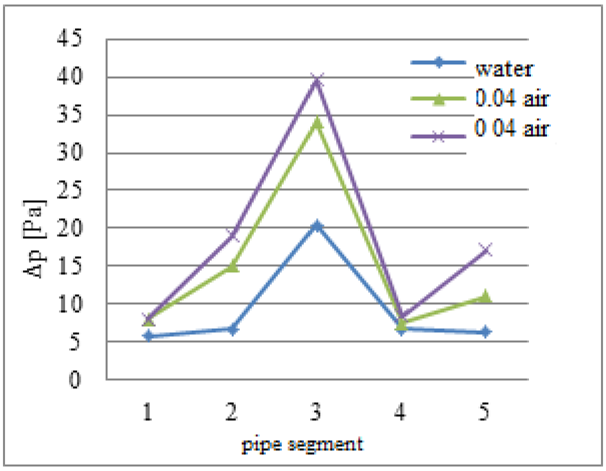

Fig. 10.2. Pressure drop on the five pipe segments for water flow, biphasic mixture (air volume fraction 0.04 and 0.07) at a flow rate of 6 m^3 / h

10.2. Conclusions

Both in the case of water flow and biphasic mixture, the pressure loss increases as the flow increases. This results in greater power of the equipment used for transport, resulting in greater power. For the flow of the bifasic air-water mixture to obtain low pressure drop it is preferable to achieve ascending flow conditions.

11. General Conclusions, original contributions and future research

The subject of the thesis is the study of the flow of polyphase mixture into the aeration tanks of the wastewater treatment plant. The purpose of the paper is to determine the impact of water mass entrainment in the upward movement of gas bubbles on the biological treatment process and on the transfer of oxygen from air into water.

As a result of theoretical research and experiments, it has been identified that the installation of fine air bubble aeration systems has a higher efficiency and lower energy consumption. The application of the transient oxygenation method has shown that for an increase in the power consumed by the aeration equipment by 48%, there were obtained an increase in the oxygenation capacity by 79%, an increase with 33% of the specific power and a 2% increase in the economic coefficient.

In-situ and laboratory experiments to visualize and characterize air bubble motion in the water mass have led to lifting speeds ranging between 0.2 - 0.4 m / s for bubble diameters of 1 - 3.5 mm.

The theoretical researches consist in the development of mathematical models for: the study of the physical dispersion of oxygen in the aqueous environment (the FlexPDE integration program), the physical process of forming, releasing and moving the air bubbles vertically to a water-filled basin (FLUENT 2D); and movement of the bifasic air-water medium in the closed-circuit system with the determination of load losses at different concentrations of the introduced gas (FLUENT 3D).

The research is a starting point in the detailed understanding of the hydrodynamic properties of the bifase air-water mixture. Correlations between the velocity generated and induced in the mass of water and the dissolved oxygen concentration required for microbiological activity have been identified.

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