U.P.B. Sci. Bull., Series D, Vol. 86, Iss. 4, 2024 ISSN 1454-2358

OPTIMIZATION OF WASTEWATER PRETREATMENT PROCESS IN THE SEWERAGE NETWORK

Tudor Adrian FLOREA[1], Corina BONCESCU[2]

This article presents theoretical and experimental research on oxygen dispersion in wastewater from the sewerage network. Laboratory analyses were performed to determine oxygen consumption in the sewer. Physical (temperature, appearance, color, suspension content), chemical (COD), and biochemical (BOD_5) parameters in the water samples were analyzed. In the second stage, mathematical modelling and simulations were performed for several oxygen dispersion coefficients to analyze the distribution of oxygen concentration along the pipeline. Research has shown that it is necessary to repeat the air injection every 3-4 m of the pipeline so that the introduction of oxygen into the main sewerage pipe has an effect. Also, in the first 2.5 hours, the organic matter decreases by 7.6%, and after 7 hours the organic matter decreases by 11%.

Keywords: oxidation process, pretreatment, sewerage network

1. Introduction

In recent years, due to the increasing population, the modernization of existing wastewater treatment plants (WWTPs) requires increasingly special attention [1]. The latest research done in wastewater treatment plants shows that water quality parameters at the outlet of the plant no longer comply with the legally imposed limits because of extremely high organic loads in wastewater. The results of analyses conducted for several wastewater treatment plants showed that the BOD_5 concentration is 30% higher than the accepted limit at discharge [2, 3].

The modernization of the wastewater treatment plant refers to the improvement of treatment processes and can mean reducing the organic load through pretreatment processes. Currently, such processes have focused only on improving nitrification and denitrification processes and have been carried out in wastewater before biological tanks by adding coagulants, such as Acquapol, and Tanfloc [4]. Studies conducted by the Faculty of Engineering of Putra Malaysia University and those made by the University of Brazil have shown that they lead to an improvement in the nitrogen removal process by up to 70% [5,6].

[1] PhD Student, Faculty of Energy Engineering, Dept. of Hydraulics, Hydraulic Machinery and Environmental Engineering, POLITEHNICA Bucharest, RAJA S.A., Constanta, Romania adrian.florea@rajac.ro

[2]Lecturer, PhD, Faculty of Energy Engineering, Dept. of Hydraulics, Hydraulic Machinery and Environmental Engineering, POLITEHNICA Bucharest, Romania, e-mail: corina.boncescu@gmail.com

Wastewater pretreatment is a modern process that can be implemented along the wastewater route before the treatment process. The process reduces organic loads in wastewater to the limit where the wastewater treatment plant can operate properly and efficiently [7]. Thus, the sewerage system can be a key point for the pretreatment process. Using the sewerage network only for transporting wastewater is uneconomical and inefficient. In general, the main collector between the city and the wastewater treatment plant has a length of 5-15 km. This length could be used economically and efficiently for pretreatment processes.

Only processes of oxidation of organic matter in wastewater can be performed in the main collector of the sewerage network. The other pollutants will remain unaffected because they cannot be used to retain sand or solid particles. In this case, clogging processes with the formation of deposits that are difficult to clean would occur. The hydraulic flow through the sewerage network regime must provide the transport of pollutants to the wastewater treatment plant equipped with installations and tanks for their retention.

Oxidation processes are based on the introduction of air in the form of bubbles into wastewater. At the level of gas bubbles, physical processes of mass transfer of oxygen from air to water occur [8, 9]. The oxygen will be dispersed over a distance dependent on the hydraulic regime in the sewerage network [10]. Oxygen in the aqueous medium will attack organic matter, causing the reduction of organic loads in the main collector.

This article presents the results of theoretical research and experiments on oxygen transfer and its consumption in oxidation processes in a sewer. Experimental research conducted in the laboratory on water samples taken from sewerage aimed to determine the decrease in organic load over time correlated with the consumption of transferred oxygen. Mathematical modelling and simulations were performed to determine the dispersion of oxygen concentration along the sewer depending on the coefficient of oxygen dispersion in water.

Modelling a fluid flow process, with or without dispersed constituents, is a modern research method that allows obtaining the desired results in a noticeably short time [11]. It has the advantage that information and results can be obtained without high research costs and, if the model is well developed and calibrated, they can be compared with reality with errors below the limit of 2-3%.

2. Materials and methods

2.1. Experimental measurements

In this paper, experimental research was conducted on water samples from the Constanta sewerage system analysed in the accreditation laboratory from RAJA Constanta. Wastewater samples were taken from the sewerage network in Winkler bottles with ground-glass stoppers. The water in the samples taken was analyzed determining the physical (temperature, appearance, color, suspension content), chemical (COD), and biochemical (BOD_5) parameters. Atmospheric air was introduced into the water samples with a pool-type oxygenation system until the saturation concentration corresponding to temperature and wastewater was reached. Every half hour, the concentration of oxygen correlated with organic load was determined. In this way, the manner and rate of decrease of oxygen concentration by its consumption by organic matter was identified.

The analyzed sample was collected from the domestic collector CL 1400/890B – Dolphinarium area in Constanta, in a five liters recipient. Upon sample receipt, the temperature, dissolved oxygen concentration, chemical oxygen demand, and consumption time of dissolved oxygen concentration in the wastewater sample were determined depending on the organic load expressed as BOD_5 mg O_2/l.

In the next step, the sample was aerated for 2 hours and then it was divided into 11 Winkler glass bottles. Ten bottles were closed immediately after filling and one glass bottle remained uncorked. Throughout the experiment, the Winkler bottles were left in the incubator at t = 20°C, in the dark. Thus, the samples had no oxygen supply through the free surface. The following equipment was used to determine the oxygen concentration: WTW Inolab Oxi 7310 and a StirroxG type-oxygen probe.

2.2. Numerical modeling and simulation

The oxygenation of wastewater in the city sewage network is particularly complex due to the hydraulic flow regime, dispersion of dissolved oxygen, and the reaction of oxygen consumption by organic matter.

A device with five air injection points located on a pipe installed upright in the wastewater stream was considered to deal with the oxygen demand in the sewerage network. The pipe geometry was created using a 2D model with FlexPDE software. The mesh meets the quality criteria and has the following structure: the number of nodes varied from 47 to 60, the number of cells varied from 67 to 89, and the maxim error was 0.002.

The dimensions of the pipe for the modelling were: diameter D=0.6 m and the length of the pipe section varied from 1 to 4 m (Figure 1). To start, mathematical modelling and simulations were performed to see the dispersion of oxygen in the pipeline considering the following considerations:

- The flow regime was turbulent, this implies high longitudinal dispersion coefficients.
- Transverse dispersion coefficient values were high due to the turbulent regime characterized by the transverse transport of particles between layers of the flowing fluid.

- Oxygen consumption by oxygenation reaction of organic matter was fast because these substances are avid for oxygen.

For simulations, the turbulent transfer system and the occurrence of mass dispersion coefficients due to the turbulent mechanism were considered. The velocity in the direction Oy and Ox is neglected (v=w=0), thus the effect of molecular diffusion was reduced. Thus, equation 1 was obtained:

$$\frac{\partial}{\partial x}(uC) = \frac{\partial}{\partial x}\left(D_{tx}\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial z}\left(D_{tz}\frac{\partial C}{\partial z}\right) + k * C \tag{1}$$

where, C represents the concentration of oxygen in the aqueous medium, u - the component of the water flow velocity vector on Ox direction, D_{tx}, D_{tz} - the dispersion coefficients along the longitudinal axis and transverse dispersion, k - oxygen consumption factory.

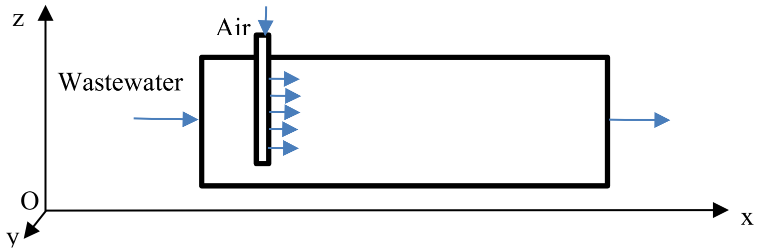

Fig. 1. Diagram of modelling and simulation of oxygen dispersion in sewage network

The calculation hypotheses for modelling and simulation were related to the oxygen dispersion coefficients, the oxygen consumption factor, and the air injection velocity in the pipe. The longitudinal dispersion coefficient, D_{tx}, varied between 14÷30 m/s^2, and the dispersion coefficient along the axis perpendicular to the flowrate direction, D_{tz}, varied between 8÷25 m/s^2. The oxygen consumption factor k took values between 8÷25. This factor determines obtaining a stable solution, and comparable to the experimental results. Compared to previous research where three-point air injection was considered and air velocity between 0.6÷0.9 m/s, in this case, oxygen dispersion equations were used for five-point air injection and the velocity was considered higher, 1 m/s [12].

3. Results and discussions

3.1. Results of experimental research

When taking the experimental sample, it was noticed that it has a turbid appearance, is poorly colored, and greyish, it has suspended solids, and has no film or iridescence. The results of the first laboratory analyses showed that the water temperature was t=19.7 °C, dissolved oxygen concentration O_2=1.76 mg/l, and chemical oxygen demand sample without aeration 209.6 mgO_2/l.

In the first stage, the consumption time of dissolved oxygen concentration, in the wastewater sample was analyzed, depending on the organic load expressed in BOD_5, mgO_2/l. The results presented in Figure 2 show that, for a BOD_5 concentration of 483 mg/l, the amount of oxygen in water was consumed in one hour, and when BOD_5 was five times lower, the consumption time increased four times.

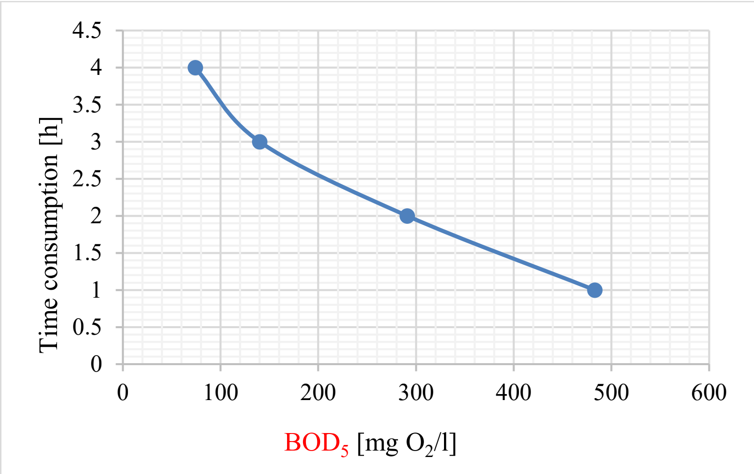

Fig. 2. Variation of the oxygen consumption time in water depending on the level of organic matter concentration

After the aeration process, measurements were made every 30 minutes until the minimum oxygen concentration was reached. The temperature was maintained between 19.8°C÷20.3°C. The variation in oxygen concentration is shown in Figure 3.

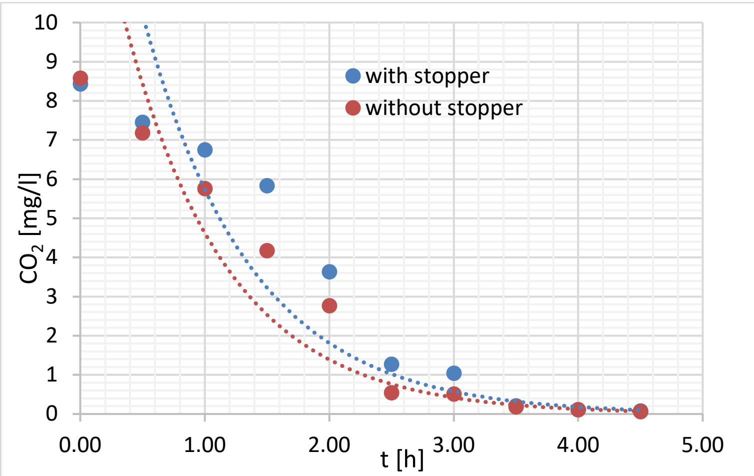

Fig. 3. Decrease of the dissolved oxygen concentration

Following the results obtained, it can be noticed that the oxygen concentration is higher in the samples with the stopper due to the air exchange with the free surface. Also, oxygen consumption occurs in about 2.5 hours, decreasing from 8.5 mg/l to 1 mg/l.

Table 1. Values measured in the aerated water sample to saturation

Date	Time	Aerated sample to saturation		
		COD	BOD	
		mg/l O_2	Dilution	result
			ml	mg/l O_2
05.02.2024	13:00	200.5	30	88.35
	16:00	-	30	79.43
	19:00	-	30	75.97

3.2. Results of mathematical modeling

The purpose of mathematical modelling was to analyze the distribution of oxygen dispersion in the pipe for lengths between 0.6 m and 4 m. For oxygen dispersion coefficients and mass consumption coefficients, three cases were considered as presented in Table 2:

Table 2. Coefficient values for three cases

Case		A	B	C
D_{tx}	m/s^2	14	20	30
D_{tz}	m/s^2	8	15	25
k	-	8	12	25

The increase in the three coefficients is due to the turbulent flow regime of water. The oxygen velocity was considered equal to 1 m/s for all analyzed situations.

Following modelling, it was noticed that for all three cases, for the pipe length between 0.6 and 1.3 m, the distribution of oxygen dispersion is evenly distributed over the entire surface. Figure 4 shows the concentration distribution in case A for the pipe length of 0.6 m and Figure 5 shows the oxygen concentration distribution in case C for the length of 1.3 m.

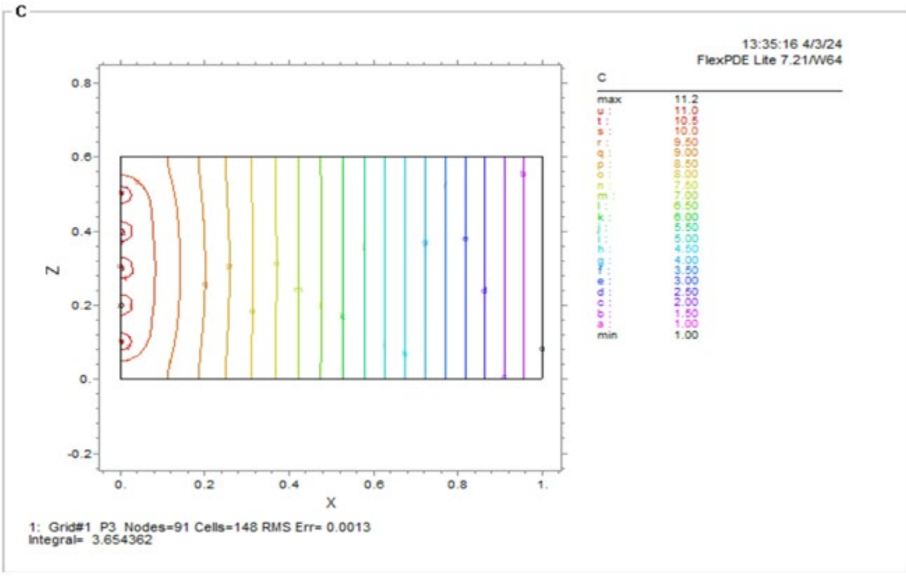

Fig. 4. Distribution of oxygen concentration, case A, L=0.6 m

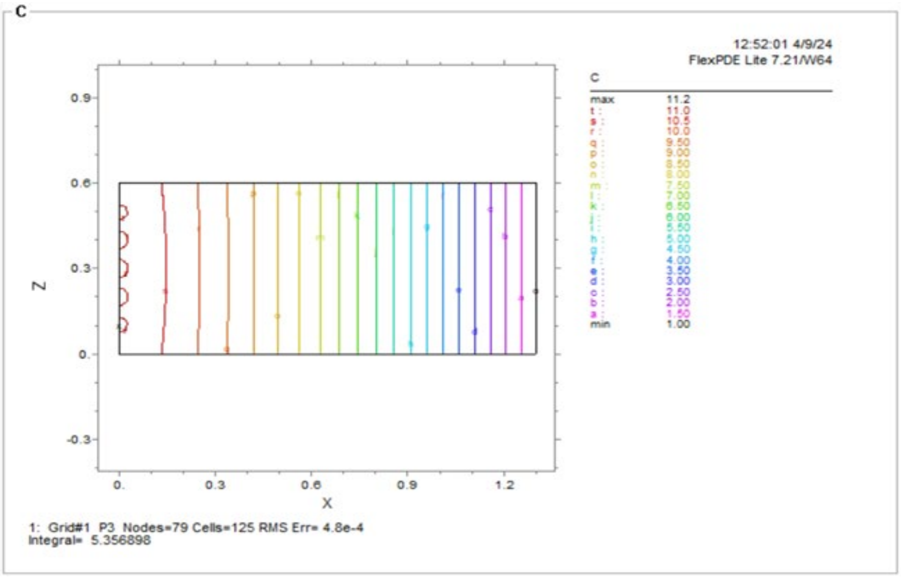

Fig. 5. Distribution of oxygen concentration, case C, L=1.3 m

Further modelling has shown that as the pipe length increases, also dispersion coefficients increase, oxygen concentration remains constant at saturation concentration over a longer length of pipe and then it suddenly drops. Figure 6 shows the oxygen dispersion for case A at a length of 2 m, where in the first 0.7-0.8 m the concentration is kept constant at 11 mg/l and then it suddenly drops to zero to a length of 2 m.

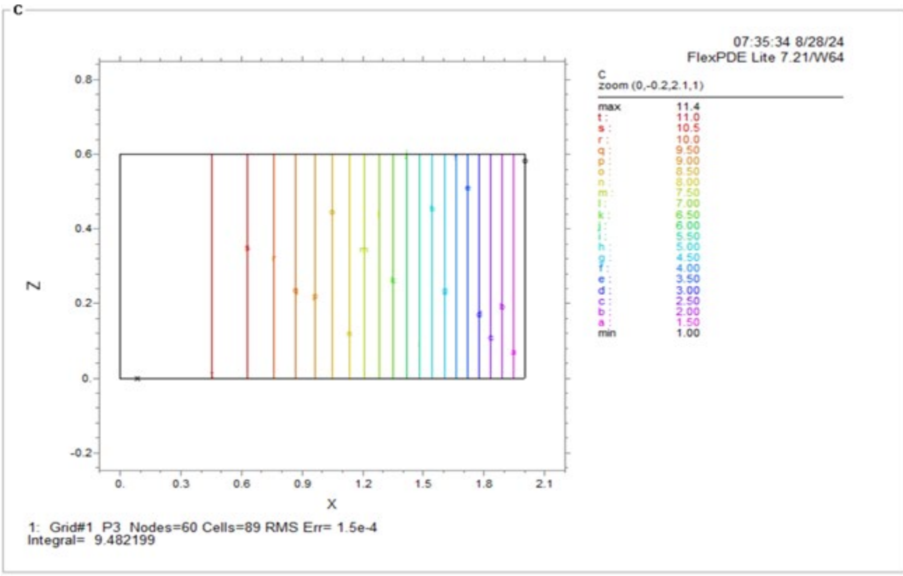

Fig. 6. Distribution of oxygen concentration, case B, *L*=2 m

Figure 7 shows the distribution of oxygen concentration in case C for the length of 4 m. In this case, it was necessary to repeat the amount of oxygen introduced because in the first 0.6 m of length, the dissolved oxygen concentration decreased to zero.

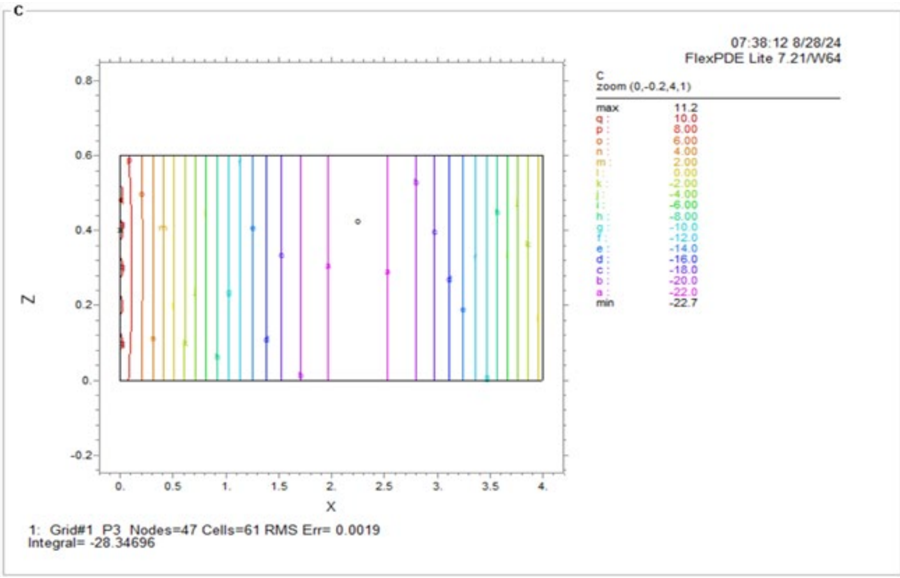

Fig. 7. Distribution of oxygen concentration, case C, *L*=4 [m]

Research has shown that the distance at which oxygen supply must be repeated, and the number of air-injections depends on the degree of turbulence. For a low degree of turbulence, the oxygen supply can be achieved at 3-4 m, and at a high degree of turbulence, the distance decreases to 1-2 m.

4. Conclusions

Experimentally, it has been shown that the time when the dissolved oxygen concentration measured in the water sample decreases from the saturation value to 1 mgO_2/l is about 2.5 hours depending on the organic load in the aqueous medium. In the same time interval, the organic load, expressed by the BOD_5 indicator, decreases by about 7.6%, and if the time increases to 7 hours, the decrease is about 11%. These figures were expected because the sewerage network cannot function as a wastewater treatment plant but manages to reduce the organic load enough to lighten the burden on the processes and facilities within the plant itself.

The modelling results show that if the flow regime changes from laminar to turbulent, a rapid consumption of oxygen concentration results. it must not be forgotten that it is necessary to maintain a small amount of organic matter concentration in the wastewater required for the biological process in the wastewater treatment plant.

Theoretical and experimental research aimed at the possibility of reducing organic loads in wastewater by introducing air into the main collector of the sewerage network. Theoretically and experimentally, they proved the possibility of oxidation of organic matter in the collector of the sewerage network. Future research work will be done by installing the aeration system in the sewer before WWTP and performing measurements in the pipe to offer a technological solution for reducing organic matter in the sewer network.

R E F E R E N C E S

[1] *K. Kosek, A. Luczkiewicz, S. Fudala-Książek, K. Jankowska, M. Szopińska, O. Svahn, J. Tränckner, A. Kaiser, V. Langas, E. Björklund*, Implementation of Advanced Micropollutants Removal Technologies in Wastewater Treatment Plants (WWTPs) - Examples and Challenges Based on Selected EU Countries, Environmental Science & Policy, **Vol. 112**, 2020, pp. 213-226.

[2] *T. Hachi, M. Hachi, H. Essabiri, D. Belghyti, M. Khaffou, R. Benkaddour, A. El Yaacoubi, R Mounir, El H. Abba*, Water Quality and Environmental Performance of a Municipal Wastewater Treatment Plant (Case of M'rirt City. Morocco), Materials Today: Proceedings, **Vol. 72**, no. 7, 2023, pp. 3795-3803.

[3] *Md Anowar Hossen, G.S. Sattar, M.G. Mostafa,* Factors Affecting the Performance of a Pharmaceutical Wastewater Treatment Plant: Characterization of Effluent and Environmental Risk, Heliyon, **Vol. 10**, 2024, e29165.

[4] *Michael H. Gerardi*, Nitrification and Denitrification in the Activated Sludge Process, JOHN WILEY & SONS, INC, New York 2002.
[5] *Y. T. Hameeda, A. Idrisa, S. A. Hussaina, N. Abdullaha, H. Che Manb*, Effect of Pre-treatment with a Tannin-Based Coagulant and Flocculant on a Biofilm Bacterial Community and the Nitrification Process in a Municipal Wastewater Biofilm Treatment Unit, Journal of Environmental Chemical Engineering, **Vol. 8**, no. 2, 2020, 103679.
[6] *J. Dorcados Santos, M.T. Veit, P. T. Juchen, G. da Cunha Gonçalves, S. M. Palácio, M. Fagundes-Klen*, Use of Different Coagulants for Cassava Processing Wastewater Treatment, Journal of Environmental Chemical Engineering, **Vol. 6**, no. 2, 2018, pp.1821-1827.
[7] *A. Stoddard, J. B. Harcum, J. T. Simpson, J R. Pagenkopf, R. K. Bastian*, Municipal Wastewater Treatment: Evaluating Improvements in National Water Quality, JOHN WILEY & SONS, INC. New York., 2002.
[8] *M. Vlăsceanu (Banu), D. Robescu, M. Căluşaru (Constantin)*, Theoretical and experimental research concerning the modification of dissolved oxygen concentration in aeration tanks equipped with surface aerators, U.P.B. Sci. Bull., Series D, **Vol. 77**, no. 1, 2015, pp. 177-184.
[9] *I. Bratu*, Oxygen transfer efficiency in fine bubble diffused aeration - factory testing, U.P.B. Sci. Bull., Series D, **Vol. 86**, no 1, 2024, pp. 85-94.
[10] *L. D. Robescu, F. Stroe, A. Presura, D. N. Robescu*, Wastewater Treatment Techniques, Ed. Tehnica, Bucharest, 2011.
[11] *L. D. Robescu,* S. Lanyi, Modeling and Simulation of Purification Processes, Ed. TEHNICA, 2004.
[12] *T.A. Florea*, Dispersion and Consumption of Oxygen in the Main Sewer, 11th International Conference on ENERGY and ENVIRONMENT (CIEM), 2023, DOI: 10.1109/CIEM58573.2023.10349760.