THEORETICAL AND EXPERIMENTAL RESEARCHES ON THE PERFORMANCES OF AN AERATION SYSTEM USED FOR HYBRID WASTEWATER TREATMENT

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Lucrarea prezintă un studiu teoretic şi experimental privind eficienţa de transfer a oxigenului pentru sisteme de aerare cu bule medii folosite în treapta de epurare biologică cu peliculă biologică ataşată a tehnologiilor hibride de epurare a apelor uzate. A fost elaborat un model teoretic de transfer al oxigenului, rezultatele teoretice corelându-se bine cu cele experimentale, obţinute pentru o instalaţie de laborator. Performanţele sistemului de aerare rezultate sunt foarte slabe pentru procesul biologic, fiind precizate soluţii de îmbunătăţire a acestora.

This paper presents an experimental and theoretical study of the oxygen transfer efficiency for a medium bubble aeration system used in hybrid biological wastewater treatment technology for the first attached-growth biological treatment stage. A theoretical model for oxygen transfer was elaborated, the theoretical results being in good agreement with experimental ones conducted on laboratory installation. Despite that, performances of the aeration equipment are too weak for biological process. Some solutions to improve these performances are indicated in the paper.

Keywords: aeration, oxygen transfer efficiency, biological hybrid processes

1. Introduction

In biochemical processes, the oxygen injected by the aeration equipment is consumed by the mineralizing bacteria and for an energy-efficient process, it is necessary to maintain the concentration of residual dissolved oxygen constant within the range of 1-3 mg O_2/l [1]. For a proper operation the aeration equipment must be optimally adjusted to the parameters of the aeration tank and to the treatment technology applied. The paper presents experimental researches on transfer efficiency from air into the water and a mathematical model for oxygen transfer in hybrid activated sludge – attached growth wastewater treatment system. The hybrid process, that use both suspended and attached growth within

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the same reactor, is an economically attractive solution, when activated sludge wastewater treatment plant need to be upgraded.

The removal of total nitrogen (TN), i.e. ammonium, nitrate, and nitrite, is an increasingly important goal for municipal and industrial wastewater treatment plants. Practically and cost-effective technologies are needed, especially for obsolete plants with limited space for expansion. TN removal typically is achieved through successive nitrification and denitrification. Another approach is to add fixed or suspended biofilm attachment surfaces, which is the basis for the integrated fixed-film activated sludge [2].

Although the hybrid process has been known for many years, the number of full-scale plants is still low. Most hybrid plants use immobile carriers such as blocks with vertical tubes of different shapes, ropes with plastic rings, plastic grids, rotating plastic discs [3, 4, 5]. Mobile carriers, such as plastic cylinders with cross sections, plastic rings, plastic beads and sponge cubes, usually have higher specific surface area, which is an advantage in terms of nitrification.

2. Experimental researches

The dissolved oxygen is a key parameter for the biological processes and it has to be taken into account for the biological reactor design. It has to be optimally adjusted to the treatment technology applied. The tests performed followed the accurate determination of the parameters specific to oxygen transfer from air into water, using the transitory regime method. For these tests is used an existing installation in the Laboratory of Multiphase Fluid Flow and Wastewater Treatment Equipment from Department of Hydraulics, Hydraulic Machinery and Environmental Engineering, University "Politehnica" of Bucharest. This installation consists of two aeration tank and one settling tank. The experimental researches were done for the first aeration tank that is equipped with perforated pipes that have the role to disperse the compressed air supplied by an air blower (TS), figure 1. On the main air pipe was mounted an air flow meter (D). The dissolved oxygen in the aeration tank was achieved using optic oxygen proves (OD), with high performances, that allow the storage of the acquired field data.

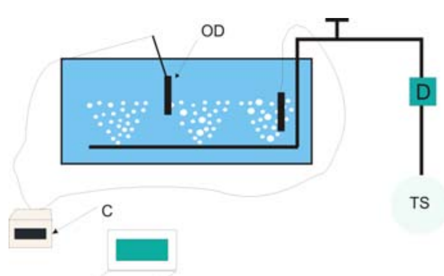

Fig. 1. Experimental setup

In literature [1] are described various testing methods for determining the oxygenation efficiency. Some of these methods use as representative the stationary operation mode for the aeration equipment while others give the non-stationary one as reference.

The test method used in this paper is based on the removal of the dissolved oxygen from the tap water volume in the aeration tank by addition of chemicals (sodium sulphite in the presence of cobalt ions) followed by reaeration to near the saturation level. The dissolved oxygen inventory of the water volume is monitored during the reaeration period by measuring the dissolved oxygen concentrations at several determination points selected to best represent the tank contents. The data obtained at each determination point are then analyzed through a simplified mass transfer model to estimate the mass transfer coefficient and the steady state dissolved oxygen saturation concentration.

The oxygen transfer rate into water is proportional to the driving force of the process:

$$\frac{\partial C}{\partial t} = v_0 = K_{La} \cdot (C_S - C), \tag{1}$$

where C is the concentration of oxygen in water at a given time; C_S is the oxygen saturation concentration in water (dependent on temperature, chemical composition of the water and on the partial pressure of oxygen in air); K_{La} – rate constant (oxygen transfer coefficient from air into water) influenced by the temperature and the operational properties of the aeration system; v_0 – oxygenation rate. The rate constant is the only dimension that includes the operational parameters of the aeration system and will be the one used for expressing its oxygenation capacity. This dimension can be expressed as the slope of the straight line represented by the function $v_0 = K_{La} \cdot (C_S - C)$ equivalent to $v_0 = K_{La} \cdot D$, where D is the oxygen deficit, or mathematically starting from Eq. (1) using the method of linear or non linear regression. After separation of the variables and replacing the partial derivatives Eq (1) becomes:

$$\frac{dC}{C_S - C} = K_{La} \cdot dt, \tag{2}$$

Through integration it results:

$$K_{La} = \frac{\ln(C_S - C_1) - \ln(C_S - C_2)}{t_2 - t_1}, \tag{3}$$

or introducing the notations: $C_S - C_1 = D_1$ - oxygen deficit at the moment t_1; $C_S - C_2 = D_2$ oxygen deficit at the moment t_2;

$$K_{La} = \frac{\ln D_1 - \ln D_2}{t_2 - t_1}, \tag{4}$$

From the analysis of Eq (4) it results that at limit, when $t_2 \to t_1$ the oxygen transfer coefficient from air into water, K_{La}, is the derivative of the function $\ln D=f(t)$. On the range between the ordinates $\ln D_1 = \ln(0.2\ C_S)$ and $\ln D_2 = \ln(0.8\ C_S)$ it presents an acceptable linearity, justifying in this way the description of the function on this interval through a constant slope given by Eq. (4).

The experimental tests were performed for different operation conditions, obtained through the variation of the air flowrate dispersed into the biological tank. The preliminary data were considered within the range $0.2C_S$ - $0.8C_S$ through the elimination of high dispersion points from the analysis. A written script in Matlab is used to obtain the mass transfer coefficients of oxygen into water through the linear regression method, using the following structure:

- input of primary data for the dissolved oxygen concentration variation in time;
- oxygen deficit calculus for each determination, depending on the measured values for dissolved oxygen concentration;
- setting the interpolation line for the oxygen deficit logarithm through the linear regression method:

$LDG = \log(DG)$;

$coef\,G = polyfit(tG, LDG, 1)$;

where LDG is the logarithm of the deficit DG in the measurement point G and $coefG$ are the coefficients of the interpolation linear line

$LDG = coefG(1) \cdot tG + coefG(2)$, tG is the time;

- the coefficient for oxygen transfer from air into water is determined as the slope of the interpolation linear line $K_{LaG} = coefG(1)$;
- the data correlation coefficient is determined:

$CRG = corrcoef(tG, LDG)$;

- it is graphically represented the deficit logarithm as time dependent, as it result from the primary data and from the linear regression curve;
- the averaged transfer coefficient K_{Lam} is determined as the weighted average of the previously determined coefficients, the weight factor being the velocity induced in the sampling point of the analyzed probe;

Figs. 1 and 2 represent the experimental data obtained for different flowrate conditions and figs. 3 and 4 represent examples of interpolation line obtained running Matlab script. The obtained values for oxygen transfer coefficients are K_{La1}= 0.0537 min^{-1}, K_{La2}= 0.0571 min^{-1}. As one can observe they are too weak for an aeration system used in biological wastewater treatment.

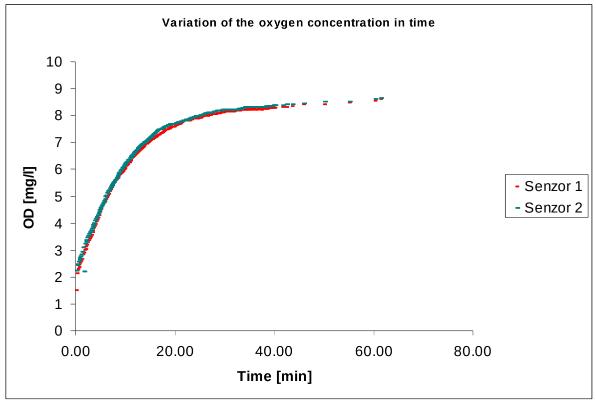

Fig. 1. Variation of the oxygen concentration in time at a flow rate of 50 Nm^3 /h

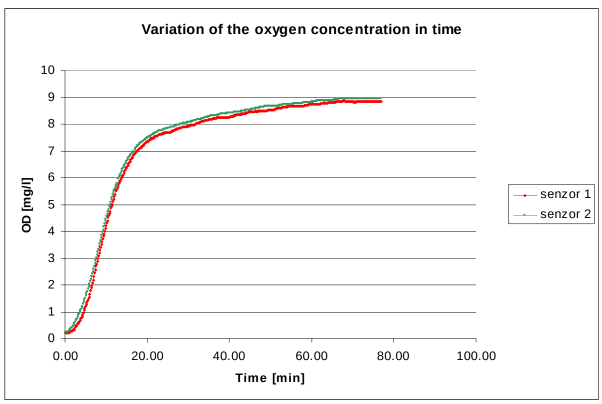

Fig. 2. Variation of the oxygen concentration in time at air flowrate of 25 Nm^3 /h

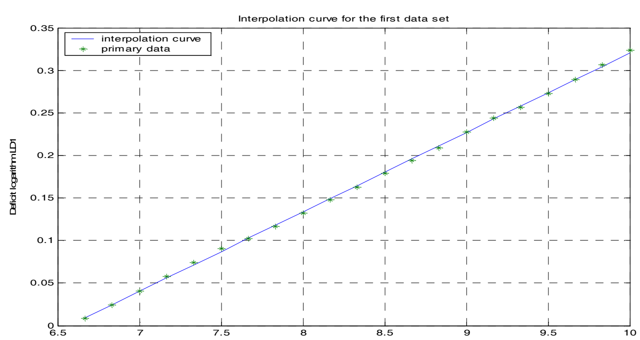

Fig. 3 Interpolation curve for the first set of experimental data, air flowrate 25 Nm^3/h

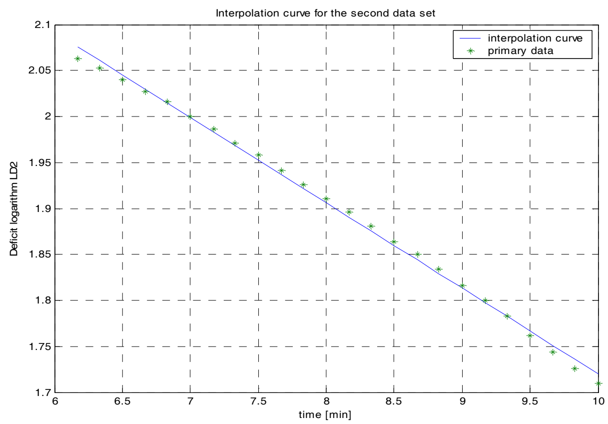

Fig. 4 Interpolation curve for the second set of experimental data, air flowrate 25 Nm^3/h

3. Theoretical model

A model for the theoretical predicting of the oxygen concentration profiles in the aeration tank using the dispersion equation is developed [8]. A parallelepiped–shaped aeration tank with longitudinal flow and with aeration from the bottom is considered (fig. 5). The air is dispersed in the water using pneumatic equipment consisting of two pipes with perforations, connected to a blower. The following hypotheses are taken into account: hydraulically permanent motion; unidirectional horizontal motion; no stationary system as to mass transfer; perfect mixing in biological tank.

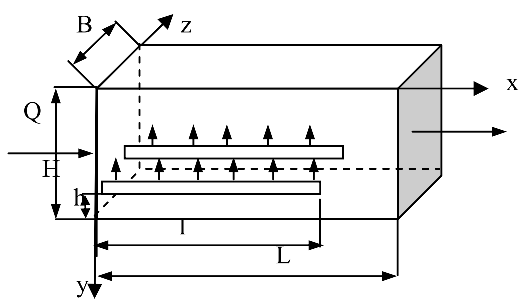

Fig. 5 Aeration tank

Q- water flowrate; B- width of the reactor; H – depth of the reactor; L – length of the reactor; h- position from the bottom of the aeration equipment; l- length of the aeration pipes

The general oxygen dispersion equation is:

$$\frac{\partial \overline{C}}{\partial t}+\frac{\partial}{\partial x}\left(\overline{u}\,\overline{C}\right)+\frac{\partial}{\partial y}\left(\overline{v}\,\overline{C}\right)+\frac{\partial}{\partial z}\left(\overline{w}\,\overline{C}\right)=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial \overline{C}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial \overline{C}}{\partial y}\right)+$$
$$\frac{\partial}{\partial z}\left(\varepsilon_z\frac{\partial \overline{C}}{\partial z}\right)+D_m\left(\frac{\partial^2 \overline{C}}{\partial x^2}+\frac{\partial^2 \overline{C}}{\partial y^2}+\frac{\partial^2 \overline{C}}{\partial z^2}\right)+S(x,y,z,t), \tag{5}$$

where C – the oxygen concentration, ε_x – the axial dispersion coefficient, ε_y - the transversal dispersion coefficient, ε_z – the vertical dispersion coefficient, S – the consumption of oxygen, D_m – the mass diffusion coefficient. The upper bar means that the respective quantities are averaged due to the turbulence.

The following additional modeling hypothesis can be formulated in order to resolve the Eq.5:

- planar movement process (water flows on the *Ox*-axis with the constant velocity $u_0=\frac{Q}{BA}$, Q – water flowrate, B – wide of the tank, A – horizontal area of the tank; gas bubbles flow along *Oy* – from now on standing for the vertical axis instead of *Oz*);
- the terms for the transversal turbulent dispersion are neglected because their very small values against similar phenomena on *Ox* and *Oy*;
-due to upward movement of air bubbles occurs a gas lift phenomenon that enhances mixing and oxygen transfer into water;
- in the Eq.1, the component v of velocity is replaced with the raising velocity of air bubbles, *w;*
- the axial dispersion occurs due to the multiphase flow along Ox axis and upward movement of gas bubbles;
- there is perfect mixing of phases.

The dispersion equation in these conditions becomes:

$$\frac{\partial \overline{C}}{\partial t}+\frac{\partial}{\partial x}\left(\overline{u}\overline{C}\right)+\frac{\partial}{\partial y}\left(\overline{w}\overline{C}\right)=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial \overline{C}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial \overline{C}}{\partial y}\right)+D_m\left(\frac{\partial^2 \overline{C}}{\partial x^2}+\frac{\partial^2 \overline{C}}{\partial y^2}\right)+S(x,y,t), \tag{6}$$

Since the air is introduced at the bottom of the tank by the pneumatic equipment, it is considered that $\varepsilon_x<\varepsilon_y$. The oxygen concentration in water is the result of two processes: a) the oxygen mass transfer from the air into the water due to air bubbles movement; b) the oxygen consumption for the biochemical oxidation of the organic matter. The last right term of the equation takes into account the oxygen concentration decay because of the consumption reactions. It is considered a term for mass transfer of oxygen from air into the water and the first-order decay term for the oxygen consumption:

$$\frac{\partial \overline{C}}{\partial t}+\frac{\partial}{\partial x}\left(\overline{u}\,\overline{C}\right)+\frac{\partial}{\partial y}\left(\overline{w}\,\overline{C}\right)=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial \overline{C}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial \overline{C}}{\partial y}\right)+ \\ +D_m\left(\frac{\partial^2 \overline{C}}{\partial x^2}+\frac{\partial^2 \overline{C}}{\partial y^2}\right)+K_{la}(C_s-C)-k\cdot\overline{C}, \qquad (7)$$

For the numerical integration of the Eq. (7) a customized program is written using FlexPDE software, [6,7]. FlexPDE is a "scripted finite element model builder and numerical solver". It means that from a script written by the user, FlexPDE performs the operations necessary to turn a description of a partial differential equations system into a finite element model, solve the system, and present graphical and tabular output of the results. FlexPDE has no pre-defined problem domain or equation list. The choice of partial differential equations is totally up to the user, [9].

The constants in the equation (7) are determined from the design relationship for experimental aeration tank geometry: u=0.003 m/s, w=0.3 m/s, ε_x=0.3 m^2/s, ε_y=2 m^2/s, k=0.1 s^{-1}, D_m =0.0155 m^2/s, C_S = 10 mg/l.

For mass transfer coefficient K_{la} a medium value from the experimental ones is chosen. Initially the dissolved oxygen concentration in the liquid is C=0.1 mg/l. The pipes for air dispersion are placed to the bottom of the tank at a distance from the bottom of h = 50 mm and they have orifices of 2 mm diameter, horizontally distributed at 20 mm. The aeration produces medium bubbles. Bubbles start to flow upwards from the bottom of the tank at time zero.

Some theoretical results are presented in fig.6 and 7.

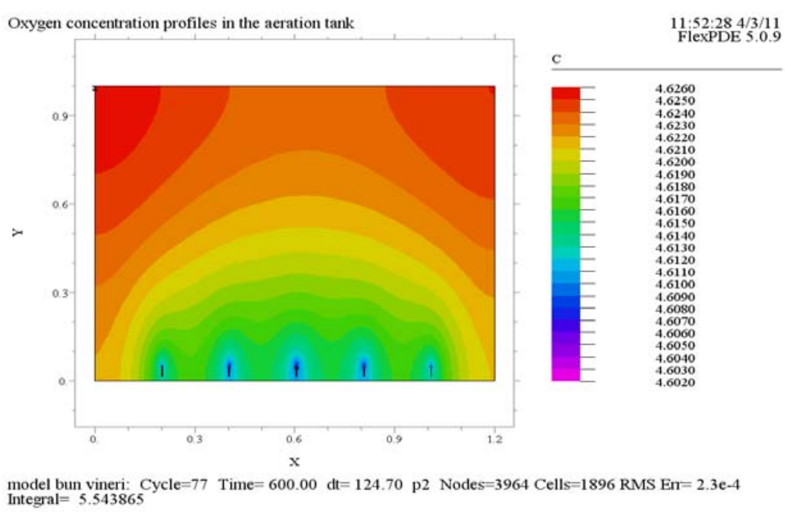

Fig. 6 Oxygen concentration profiles after 10 minutes

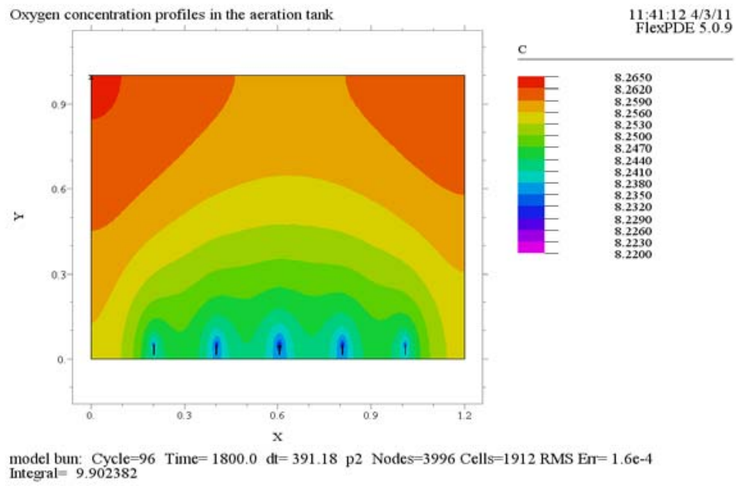

Fig.7 Oxygen concentration profiles after 30 minutes

The results for dissolved air concentration for 25 m^3/h air flow rate are presented in Table 1 and fig. 8, superposed on theoretical ones. The results show a good correlation between the theoretical model and experimental results.

Table 1

Experimental and theoretical dissolved oxygen concentration

Time [min]	DO [mg/L]-model	DO [mg/L]-prove 1	DO [mg/L]-prove 2
10	4.62	4.21	4.47
20	7.73	7.35	7.48
30	8.25	7.92	8.06

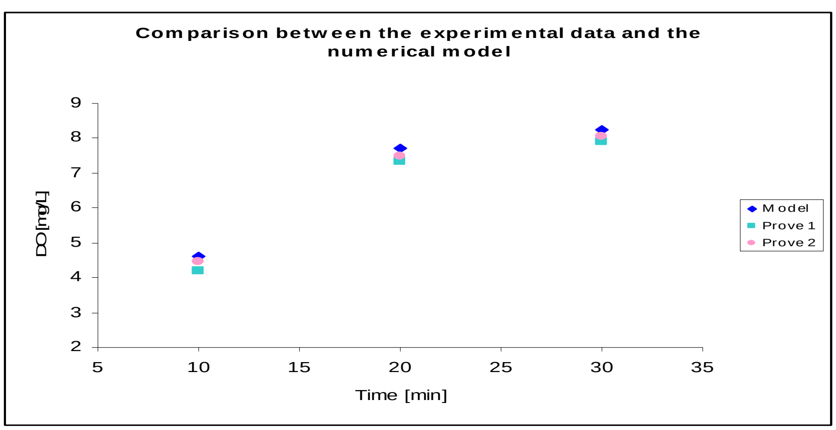

Fig. 8 Theoretical and experimental results for dissolved oxygen concentration

6. Conclusions

In this paper a theoretical and experimental study concerning the aeration capacity of an aeration system is presented. A good agreement between theoretical and experimental results is obtained. The experimental determined coefficients for mass transfer of oxygen in water are weak for the biological process, because the aerations system with perforated pipes produces medium bubbles of air and there are insufficient holes for air injection. Further works is now underway to test another aeration system, combining perforated pipes with fine pore aeration. The results can be used in the optimization and control of the biological wastewater treatment operation and in the design stage for choosing the appropriate aeration equipment in the tank.

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