WASTEWATER PRETREATMENT IN THE SEWAGE SYSTEM

Catalina Raluca MOCANU[1]

In the paper the author presents an innovative method for the practical application of the sewage network as a wastewater pre-treatment stage. This can be achieved by using alternative aeration systems along the sewage system, which lead to alternative aerobic and anaerobic areas and allow the development of the biological processes. The microorganisms that occurred partially decompose the organic pollutants from the wastewater in the sewage system due to the intensive aeration in the aerobic zones. In this paper the mathematical model and numerically simulations are presented, which were done to obtain the optimum horizontally distribution of aeration equipment in aerobic zones and the optimum length of aerobic and anaerobic zones.

Keywords: aeration, oxygen dispersion, pre-treatment, sewage systems, wastewater

1. Introduction

The length of the sewage system depends on the relative position of the wastewater treatment plant (WWTP) from the locality and it is around 5 to 15 kilometers. Taking in consideration this distance are necessary several hours for the wastewater to reach the WWTP. During this time the organic substances are anaerobically decomposed, eliminating toxic gasses (CH_4, CO_2, H_2S) and unpleasant smells through the apertures of the sewage system, with major implications for the safety of the maintenance personnel.

A innovative method for the wastewater pre-treatment proposed for rationally and efficiently use of the length of the sewage system. This method consists of the alternation of the aerobic and anaerobic areas into the sewage, using aeration systems, which allow the development of the biological processes. The grown bacteria partially degrade the organic substances from the sewer system.

By aerating the wastewater from the sewer the gaseous medium is modified and this lead on quickly and safety interventions in the sewer system, without dangers for the operators.

The aeration systems assure the oxygen needed in the aerobic areas for the decomposition of the organic pollutants, for the metabolism of the microorganisms and for the multiphase fluid mixing.

The mathematical model and numerically simulations are presented, which were done to obtain the optimum horizontally distribution of aeration equipment

[1] PhD, Dept. of Hydraulics, Hydraulic Machinery, and Environmental Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: mocanu_catalinaraluca@yahoo.co.uk

in aerobic zones and the optimum length of aerobic and anaerobic zones will be presented. A virtual sewage pipeline with immersed oxygen dispersion equipment will be simulated in ANSYS CFD software presented.

2. Mathematical model

Various examples can be found in literature about the dispersion and mass transfer of a gas in a liquid in the turbulent flow regime [1, 7, 12, 13]. These processes occur in aeration applications, water ozonation, chlorination in which a gas is injected directly into the water transport pipeline.

The purpose of mathematical modeling and numerical simulation is to identify the best position of the aeration equipment to have the optimum oxygen concentration in aerobic zones of wastewater, around 2 mg/l. Also, it is necessary to provide anaerobic zones, for denitrification [11]. The optimization of pre-treatment method is needed for reducing the maintenance and operation costs, for energetic optimization of treatment equipments and to obtain maximum performances in wastewater purification.

The aeration process depends on hydraulic flow regime through the sewage [2, 3, 4]. Hydraulically permanent motion and unidirectional horizontal motion are considered. The air is dispersed into the water using pneumatic equipment put on the bottom of the sewer and connected to a blower.

The mathematical model is based on the dispersion equation of dissolved oxygen in wastewater, considering complete mixing in the sewer [5, 10,13].

The profiles of dissolved oxygen concentration in the sewage system can be obtained from the dispersion general equation:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(\varepsilon_z\frac{\partial C}{\partial z}\right)+$$
$$+D_m\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}+\frac{\partial^2 C}{\partial z^2}\right)+S\left(x,y,z,t\right) \qquad (1)$$

Where: ε_x is the longitudinal dispersion coefficient; ε_y is the transversal dispersion coefficient; ε_z is the vertical dispersion coefficient on the fluid current; *u* is the horizontally water velocity; *v* is the vertical water velocity, *w* is the lift velocity because of gas bubbles; *C* is the oxygen concentration,; *D* is the molecular diffusivity coefficient, *S* is the in or out substance source from the system.

A complete solution of (1) is impossible to obtain due to stray dependence coefficients of the flow, the nature, the shape and dimension of dispersed particles and the physical properties of the considered medium [6, 8]. From these considerations simplified models will be considered.

The air is injected into the sewage system through the dispersion equipment, perforated pipes, placed on the sewage bottom.

For the numerical simulation the followings hypotheses are considered:

- The sewage system has a parallelepiped shape;
- Longitudinal flow;
- Pneumatic aeration;
- Permanent motion from the hydraulic point of view;
- The water vertical velocity is neglected in compered with horizontal velocity;
- Unsteady state flow regime from the mass transfer point of view;
- The complete mixing of the phases in the sewage;
- Plane movement – the water flow on the Ox axis, with a constant water velocity, *u*, the air bubbles rise on the Oy axis with the *w*, air velocity;
- The molecular diffusivity is neglected in compared with the turbulent convective diffusivity, so the term $D_m \Delta C$ from (1) is neglected;
- The term for transversal dispersion is neglected because has small values in compared with the similar phenomenon's from the Ox and Oy axis;
- Due to the ascendant movement of the air bubbles, the gas-lift phenomenon will appear. This will intensify the mixing and oxygen transfer from air into water;
- In (1) the velocity term *v* is replace with the gas bubbles velocity rising, *w*;
- The axial dispersion appears due to the multiphasic fluid movement along Ox axis and the ascent movement of the gas bubbles.

Taken in consideration the above hypotheses the dispersion equation (1) became:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+w\frac{\partial C}{\partial y}=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial C}{\partial y}\right)+S\left(x,y,t\right) \qquad (2)$$

Because the air is introduced from the bottom of the sewage system can be consider that $\varepsilon_x < \varepsilon_y$.

The oxygen concentration into the water is the result of two processes:

a) The oxygen mass transfer from air into the water due to the air bubbles movement;
b) The oxygen consumption due to the biochemical oxidation reactions of the organic matter.

Last right term from (2) take into account the reduction of oxygen concentration due to the consumption reactions. Considering a first degree consumption term (2) became:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+w\frac{\partial C}{\partial y}=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial C}{\partial y}\right)-k*C \qquad (3)$$

The mass transfer coefficient in the sewer depends on [9]:

- the air bubble size, especially be the type of the gas dispersion equipment;
- the value of the gas flow per unit of liquid volume;
- hydrodynamic characteristics of fluid medium, the environment and dependence on continued turbulence mixing produced by the injected air;
- the physic-chemical proprieties of the liquid phase.

The wastewater pretreatment process in the sewage system depends on:

- hydraulic flow in the system that influence the sedimentation processes. Due to corrosion action of the particles carried by the aqueous medium on the channel walls is required to place fines screens before the aeration systems.
- temperature is a major factor influencing the kinetics of chemical and biochemical processes, oxygen regime in the water.
- if there is an open sewage system an important role is the insolation with its seasonal and diurnal variation that directly influence the chemical and biochemical reactions of the multiphase medium.

3. Numerical simulation

The equation (3) is introduced in a customized ANSYS program in order to obtain the oxygen profiles in sewage wastewater. In equation (3) is introduced a term for oxygen consumption ($-k*C$) that considers oxygen demand for cellular metabolism and for mineralization of organic matters. For this term it was considered different expressions until the concentration profiles fit the real process. The constants in the equation (3) are: u=0.8m/s, w=0.3m/s, ε_x=0.3m^2/s, ε_y=2m^2/s, and k=0.3s^{-1}.. Maximum oxygen concentration in the wastewater is considered to be around 3 mg/l (0.003kg/m3).

The work fluids characteristics considered for the numerical simulation are:

- Water: laminar flow, continuous fluid, stationary domain motion, steady state analysis type
- Air: dispersed fluid, medium intensity turbulence (approximately 5%)

The domain geometry:

- Pipeline: length 7m, 0.3m diameter.
- Aeration pipe: length 0.5m, diameter 0.02m, air injection inlet diameter 0.002m.
- Distance between two aeration pipes 1m.

Initially the dissolved oxygen concentration in the liquid is zero.

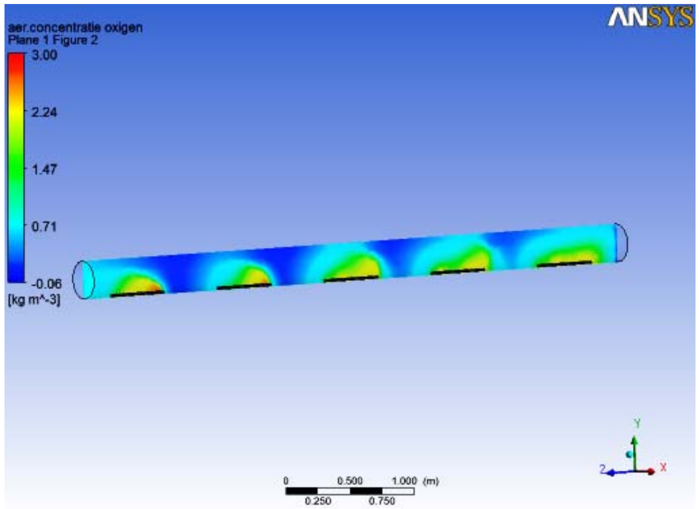

Fig. 1. Oxygen concentration in XY plane

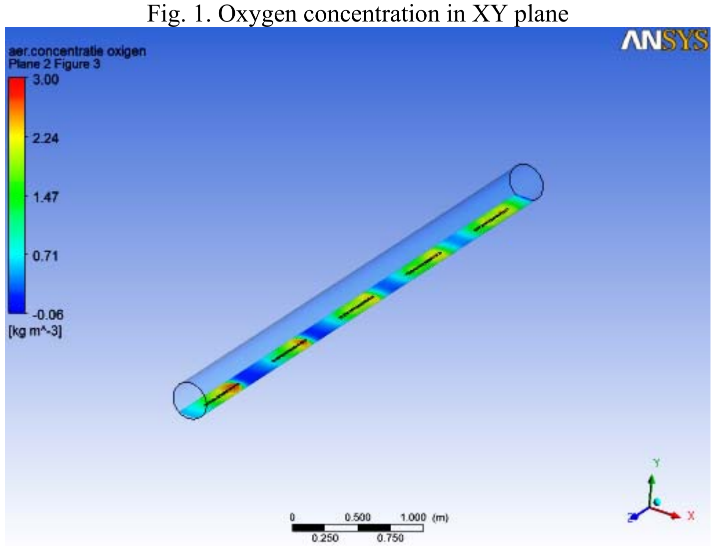

Fig.2 Oxygen concentration in XZ plane

In Figs. 1 and 2 one can observe the dissolved oxygen concentration evolution in the virtual sewage pipeline. Due to the consamption of the oxygen by the organic matter from the sewage wall the dissolved oxygen concentration is lower in the anaerob zones.

In Fig. 3 can be observe better the evolution of the dissolve oxygen concentration along the sewage pipe. For a better visualization 3 reference lines were traced, the blue line at the air injection pipe level, the red line at the middle of the sewage diameter and the green line at the water free surface into the sewage. In anaerobic zones the oxygen values are very low around 0.1mg/l. Also one can observe that at the top section of the sewage the dissolve oxygen concentration is low due to it consumption from the organic matter by the transported wastewater.

For the visualization of the dissolved oxygen concentration (Fig. 4) in the aerobic and anaerobic zones 8 reference lines were traced. The anaerobic zones are at the entrance in the sewage, at 0.75m, 1.75, 3.75m, 4.75m and the aerobic zone at 0.2m, 3.25m and 4.5m. One can observe that in the anaerobic zones the dissolved oxygen concentration is below 0.75mgO_2/l due to it consumption by the organic matter. At the end of the simulation domain the dissolved oxygen concentration is around 2mgO_2/l, this value is the optimum one.

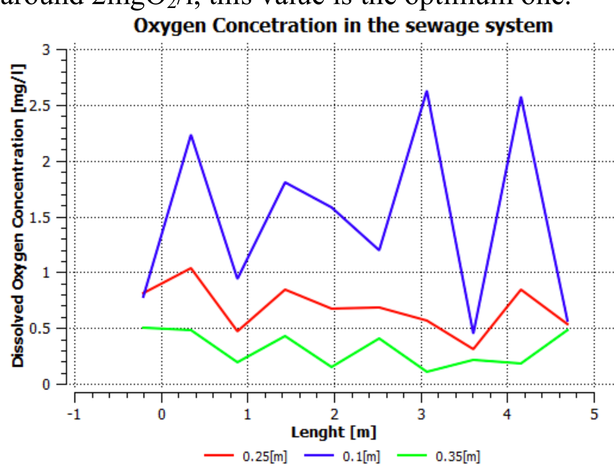

Fig. 3 Dissolved Oxygen Concentration along the sewage pipe

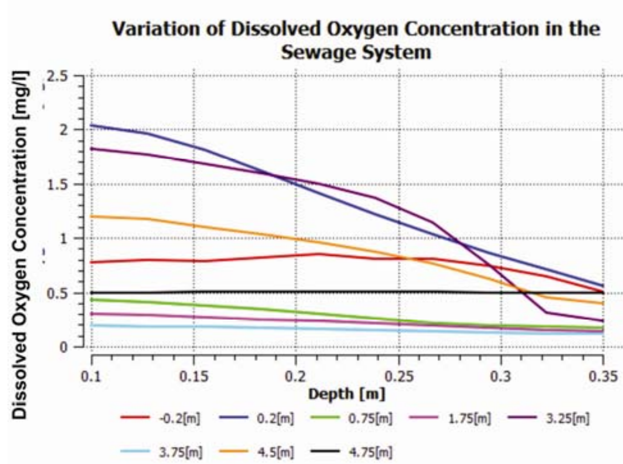

Fig. 4 Dissolved Oxygen Concentration in different area of the sewage pipe

If after the aeration process the energy consumption increase for air supplying the chosen solution is not reliable in terms of economic point of view, with major implications in increasing the costs of treated wastewater [14, 15]. If the solution is acceptable from the economic reasons, it can be easily adopted because reduces at least in terms of design and execution costs of wastewater treatment plants.

Due to the sewage system great lengths the aeration process must been realized in sections. From this point of view the numerical simulation showed that the maximum values of the dissolved oxygen concentration is on the end of the aerated zone. Keeping in mind the complexity of the sewage system the designers must considered all the physical, chemical and biological aspects of the transported wastewater [16].

Construction of sewage system must ensure a perfect seal and a clear separation from the mains water transport pipes is necessary in order to avoid it contamination with undesired compounds. Also, the sewage system must have a sufficient fall, not too tight bends, and the appropriate depth so in the winter frost does not occur, adequate diameters that will allow the flow processing, without congestions and no discharges outside the system.

From these considerations the dissolved oxygen concentration varies in every point of the sewage system, but also because of the mass transfer movement process that appears. The transfer velocity of the oxygen into the water mass dD/dt is directly proportional to the size of the forces driving the process $D = C_s - C_0$, oxygen deficit from saturation concentration.

4. Conclusion

The results of theoretical researches realized for the pre-treatment of wastewater in the sewage systems show that the application of this method decrease the organic loadings in influent of wastewater treatment plant. As a consequence, wastewater treatment plant energy costs are smaller and the wastewater treatment plant efficiency increased.

The numerical simulation were performed in order to determine the optimum horizontally distribution of the aeration equipment in the aerated zones, so that the concentration of dissolved oxygen to be around 2-3 mg/l on the transversal section of the sewage pipe.

The theoretical researches show that the alternation between the aerobic and anaerobic areas should be around 60 m. In these intervals the organic substances are decomposed. It was found that the removing of the organic substances was around 15 – 17% using this method on 10 kilometers of the sewage system.

For future researches the method will be tested in a laboratory scale installation in order to point the practical importance of the process.

Acknowledgment

The work has been co-funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/89/1.5/S/62557.

R E F E R E N C E S

[1] *H.E. Babbitt*, "Sewerage and sewage treatment" Ed. John Wiley, New York, 1954.

[2] *P. Balmer, M. Tagizadeh-Nasser*, "Oxygen transfer in gravity flow sewers". Water Sci Technol 31, pp 127–35, 1995.

[3] *B. Chachuat, N. Roche, MA. Latifi*, "Optimal aeration control of industrial alternating activated sludge plants", Biochemical Engineering Journal, vol. 23, pp 277–289, 2005;

[4] *G. Deronzier, PH. Duchene, A. Heduit*, "Optimization of oxygen transfer in clean water by fine bubble diffused air system and separate mixing in aeration ditches", Water Science and Technology, vol. 38, no. 3, p 35-42, 1998.

[5] *A. Hasanen, P. Orivuori, J. Aittamaa*, "Measurements of local bubble size distributions from various flexible membrane diffusers", Chemical Engineering and Processing, vol. 45, pp 291–302, 2006.

[6] *B. Haut, T. Cartage*, "Mathematical modeling of gas–liquid mass transfer rate in bubble columns operated in the heterogeneous regime", Chemical Engineering Science, vol. 60, pp 5937 – 5944, 2005.

[7] *J.L. Huisman, N. Weber, W. Gujer*, "Reaeration in sewers", Water Research, vol. 38, pp1089–1100, 2004.

[8] *A. Kongto, S. Limtrakul, K. Ngaowsuwan, P. Ramachandran, T. Vatanatham*, "Mathematical modeling and simulation for gas–liquid reactors", Computers and Chemical Engineering, vol. 29, pp 2461–2473. 2005.

[9] *C.R. Mocanu, D. Robescu*, "Technical and economical concepts in using the waste water transport pipe's has an pretreatment method", Scientific Bulletin, Series C: Electrical Engineering, Vol 69, No.4, 2007, pp. 525 – 530.

[10] *C.R. Mocanu*, "Contributions to the study of hydrodynamics of waste water treatment processes", PhD Thesis, University Politehnica of Bucharest, 2008.

[11] *L.D. Robescu*. "Mathematical modeling of the biological wastewater treatment processes", Ed. Politehnica Press, 2009, 244 pages.

[12] *D. Robescu, S. Lanyi, L.D. Robescu, I. Constantinescu, A. Verestoy*, Waste water Treatment - Technologies, Installations and equipment. Technical Publishing, 2001.

[13] *D. Robescu, C.R. Mocanu,* "Oxygen dispersion modelling in the water transport pipes", UPB, Sci Bull., Series D – Mechanical engineering, Vol 68, No.1, 2006, pp. 35 – 42.

[14] *LD. Robescu, S. Lanyi, A. Verestoy, D. Robescu*, Modelarea si Simularea Proceselor de Epurare (Mathematical modelling and numerical simulation of wastewater treatment processes). Technical Publishing, 2004.

[15] *L.D. Robescu, D. Robescu*, "Modeling and simulation of oxygen concentration profiles in mobile bed biofilm reactor", Proceedings of the 7th International Conference on System Science and Simulation in Engineering (ICOSSSE'08), Venice, Italy, November 21-23, 2008, pp. 235-239

[16] *R. Schafer, C. Merten, G. Eigenberger*, "Bubble size distributions in a bubble column reactor under industrial conditions", Experimental Thermal and Fluid Science, vol. 26, pp 595–604, 2002.