FLOW MODELLING FOR COMPACT WASTEWATER TREATMENT PLANTS

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Principalul obiectiv al cercetărilor experimentale este de a dezvolta/concepe o stație compactă de epurare a apelor uzate. Pentru o poiectare cât mai corectă nu sunt suficiente calculele inginereşti. Prin modelări matematice şi simulări numerice se poate stabil iforma optimă a bioreactorealor, iar prin deteminări numerice volumele compatimentelor.

The main objective of the experimental researches is to develop a compact wastewater treatment plant. For a correct and optimum designing, simple engineering calculations are not sufficient. From numerical determinations only the volume for each reactor can be established, but the correct shape can be determined only from mathematical modelling and numerical simulations.

Keywords: mathematical modelling, numerical simulations, compact WWTP, oxygen dispersion, lamellar settler

1. Introduction

The main objective of the experimental researches is to develop a compact wastewater treatment plant (WWTP). The technological process of WWTP consists in 5 stages. A biological step (MBBR) is implemented, which is followed by a mechanical treatment. All the reactors must be designed in order to obtain a flow without parasites. The compact WWTP was realized and it was demonstrated that the correct configuration for all 5 reactors was chosen.

2. Technological process

The biodegradation reactors are realized in five stages, for an increased efficiency of wastewater treatment: 2 stages for the aerobic treatment, 2 anoxic steps for nitrogen removal and a final stage of mechanical settling for suspended solid disposal [1]. The first compartment contains biofilm carriers and an aeration system with medium bubbles. The aeration system is made of stainless steel. In this bioreactor complex phenomena take place and the organic matter is decomposed to partial fractions like carbon dioxide and water molecule. Inside the

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bioreactor no. 2 biofilm carriers and an aeration system with raw bubbles are placed. This compartment is designed for decomposing the remained organic matter after bioreactor no. 1. Compartments no. 3 and 4 also contain biofilm carriers, but are not aerated and here, with the help of two mixers, the nitrogen compounds are reduced. Inside compartment no. 5, separation of suspended solids are evacuated as sludge is realized. A lamellar settling was conceived for better separation efficiency. The most difficult part was to conceive the lamellar settling and to establish the right configuration for aeration system. The compact WWTP is presented in Fig. 1.

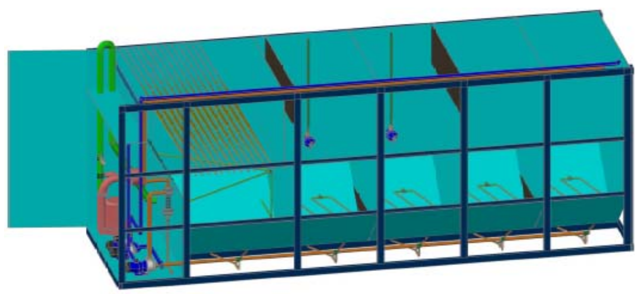

Fig. 1. Process applied at the compact wastewater treatment plant

3. Design of lamellar settling for the compact WWTP

This type of settling was chosen because it has been proved that, in conventional tanks, small depths lead to increased separation efficiency. For this reason, solutions have been adopted for the development of lamellar settling tanks using counter-current, one way and cross-current flows. The operation of lamellar tanks is based on dividing the inflow flow rate in superposed layers, each of h/n depth, where h is the depth of the conventional tank (see Fig. 2). The position of the lamella fascicle (tubes or parallel plates) generates a great number of independent separation phases in the settling zone. In order to facilitate the removal of the settled sludge, the system is slanted at an angle θ to the horizontal plane. The terminal settling velocity of sludge particles is [2, 3]:

$$w_s = \frac{Q}{n \cdot A \cdot \cos\theta} \tag{1}$$

where A is the elementary load surface in each element;
n – the number of elements.

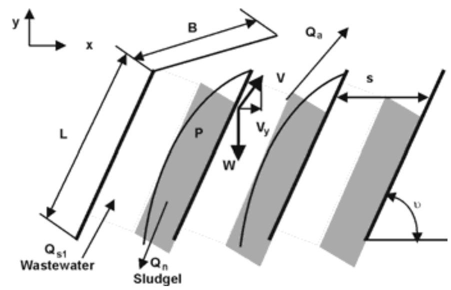

Fig. 2. Diagram of a lamellar tank

The raw water enters the lamellar tank with n elements (plates making an angle ϑ to the horizontal) and fills *n+1* individual compartment or elements. For settling tanks fitted with plates with counter-current stream, the axial velocity component of the liquid is $v = q/sB\sin\vartheta$, the vertical component is $v_y = v\sin\vartheta = Q/Bs$, and the horizontal component is $v_x = v\cos\vartheta = q/sB\,tg\vartheta$. The vertical component of the settling velocity is $v_{sy} = v_y - w = q/sB - w$.

A particle entering the inter-plate system at point *A* will cover the vertical distance over a time period t_1, and the horizontal distance over a time t_2. This inequality becomes [2]:

$$t_2 \le t_1;\ \frac{s + L\cos\vartheta}{v_x} \le \frac{L\sin\vartheta}{v_{sy}};\ \frac{s + L\cos\vartheta}{\dfrac{q\cos\vartheta}{sB\sin\vartheta}} \le \frac{L\sin\vartheta}{\dfrac{q}{sB} - w} \qquad (2)$$

The condition of settling in a lamellar tank is formulated by:

$$\frac{q}{BL} \le w\left(\cos\vartheta \pm \frac{s}{L}\right) \qquad (3)$$

with the "+" sign for the ascending flux and the "–" sign for the descending one. Since *S/L* is practically a negligible value with respect to th*e cos* ϑ values, the inequality can be simplified to:

$$\frac{q}{BL} \le w\cos\vartheta \qquad (4)$$

4. Mathematical modelling and numerical simulations

For simulations, the FlexPDE programme was used. For motion equation, div(grad(psi))=0, in potentian motion of fluid. The border conditions are formulated by Dirichlet and Neumamn adequate to walls and flow zone. A large number of configurations were taking into account. Some of the preliminary results and their interpretations are presented below. In Fig. 3 at the entrance a vertical plane/wall immersed in wastewater mass was conceived.

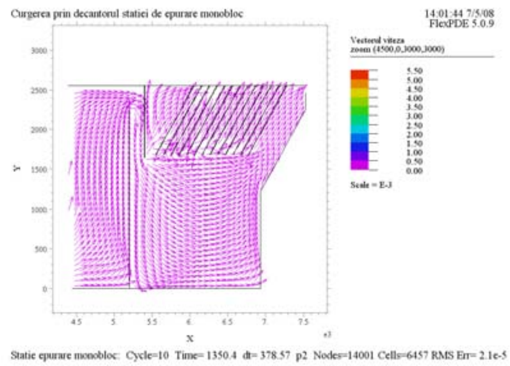

Fig. 3. Results obtained during numerical simulations

As it can be easily observed between lamellae 2 and 5 the flow is reversed, from the upper part up to the lower level of the reactor. Also in this case, an important fraction from the total wastewater mass is by passing the lamellae (the water flows underneath lamellae and go directly to the exit). Also the lamellae are too short. In these conditions, some other configurations must be tested. In figure 4, the lamellae are longer. As in the previous case, the wastewater passes beneath the lamellae up to the discharge area.

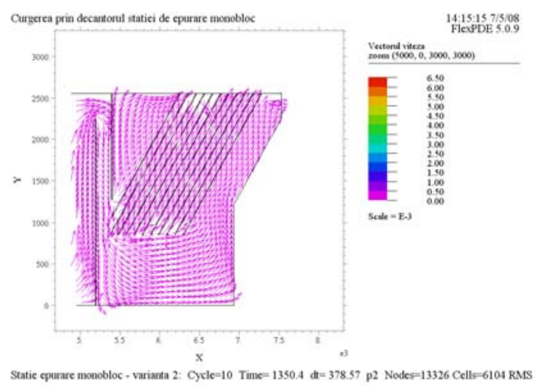

Fig. 4. Results obtained during numerical simulations

In Fig. 5 it was desired to see what is happening if the entrance is situated at a lower level. In Fig. 6 the lamellar settling was flattered. In these two cases the by-pass also occurs, so other shapes must be tested for a correct flow inside the lamellar settler.

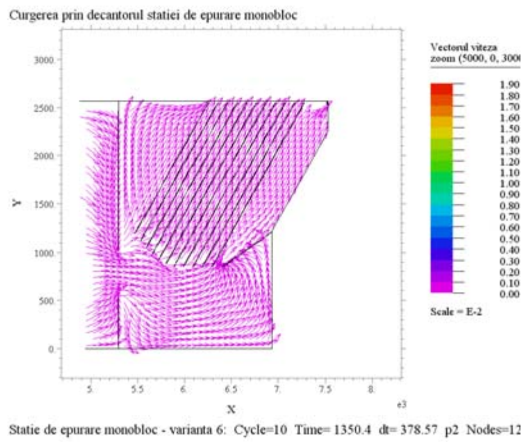

Fig. 5. Results obtained during numerical simulations

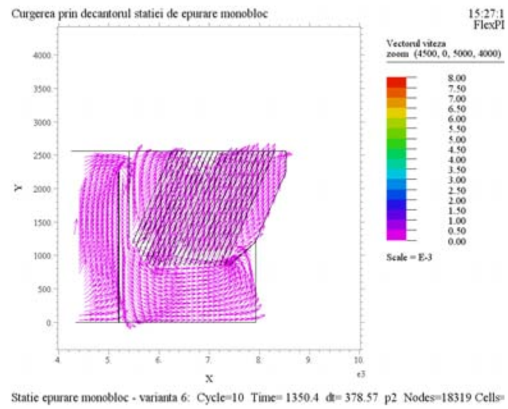

Fig. 6. Results obtained during numerical simulations

After some other numerical simulations the final shape was chosen and it is represented in Fig. 7. Here, the water will not by-pass the lamellae and the flow inside the settling is normal, from the bottom of the lamellae to the discharged area.

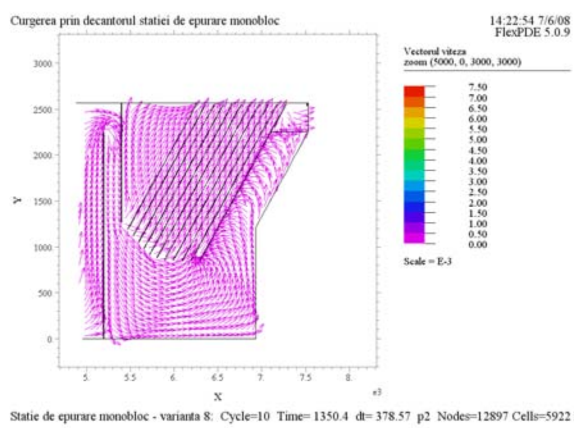

Fig. 7. Results obtained during numerical simulations

To build the mathematical model for the oxygen dispersion inside the compact WWTP, the general equation of dispersion is considered [2, 4, 5]:

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

where ε_x, ε_y, ε_z are the longitudinal, transversal and vertical dispersion coefficients. A complete solution of this equation, to which the equations of motion and continuity must be attached, is impossible to obtain due to the dependence of dispersion coefficients to the flow regime, the nature, shape and size of dispersed particles and so on. Because of this, a simplified model was applied:

$$\frac{\partial \overline{C}}{\partial t}+\frac{\partial}{\partial x}\left(\overline{u}\overline{C}\right)+\frac{\partial}{\partial y}\left(\overline{v}\overline{C}\right)=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial \overline{C}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial \overline{C}}{\partial y}\right) \quad (6)$$

where quantities are averaged over a period of time. By simulation, the oxygen concentration profile inside the anaerobic reactor was determined (Fig. 8). The aeration system has a proper design and the air bubbles are dispersed in the whole wastewater mass.

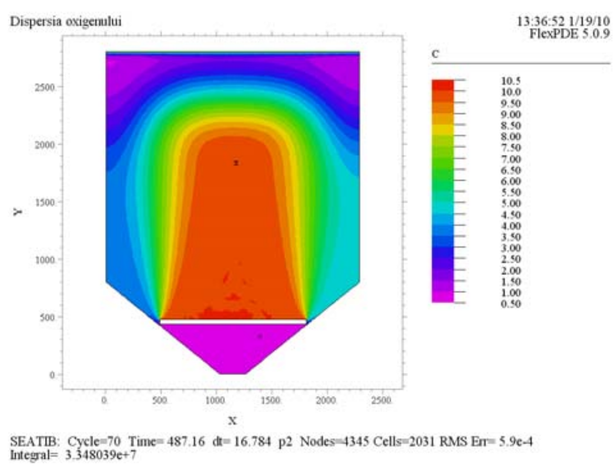

Fig. 8. Dissolved oxygen profile inside the WWTP

5. Experimental researches

The pilot WWTP was realized and mounted at S.C. AGROLACT EUROLINE S.R.L. The pilot WWTP is presented in Fig. 10. Here, several sets of measurements were made.

Fig. 9. The pilot WWTP mounted at S.C. AGROLACT EUROLINE S.R.L

In table 1 the values of the parameters discharged effluent are presented. The values respect the imposed limits specified in NTPA regulations.

Table 1

The values for quality parameters for both influent and effluent

No.	Quality parameter	U.M.	Influent	Effluent
1	pH	unit. pH	7.1	7.6
2	Nitrogen	mg/dm^3	45	14
3	Nitrite	mg/dm^3	6	2
4	Nitrate	mg/dm^3	45	29
5	Phosphorous $_{total}$	mg/dm^3	4.8	1
6	Suspended solids	mg/dm^3	335	32
7	Biochemical Oxygen Demand	$mg\ O_2/dm^3$	285	19
8	Chemical Oxygen Demand	$mg\ O_2/dm^3$	550	57

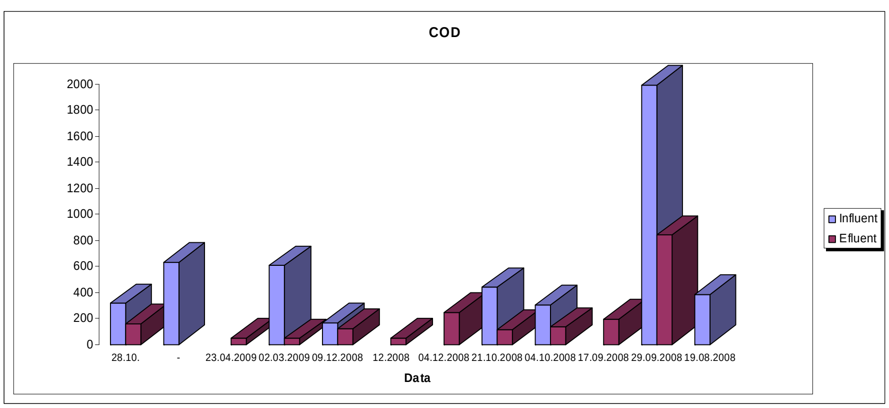

Fig. 10. COD values for influent end effluent measured for a period of 9 months

The parameters of the treated water were determined for a period of 9 months. In Fig. 10, is represented the variation of COD for both influent and effluent from all the measured values. It can be easily observed that the COD for effluent is significantly reduced and the WWTP was correctly designed.

6. Conclusions

Mathematical modeling and numerical simulation are increasingly important in the design of different installations and equipments. Using these methods, the investors will save both funds and time. Besides engineering calculations, numerical simulations represent an important and absolutely necessary activity. In the present study, the optimum shape and number of plates for the lamellar settling tank had been reached. Compact wastewater treatment plant was built, and experimental researches made on it have demonstrated its functionality. The lamellar settling has an increased efficiency and the quality parameters of the water discharged accomplish the NTPA regulations.

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