DESIGNING METHODS BASED ON MATHEMATICAL MODELLING AND NUMERICAL SIMULATIONS FOR COMPACT WASTEWATER TREATMENT PLANTS

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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 can be established only the volume for each reactor, but the correct shape can be determined only from mathematical modelling and numerical simulations.

Keywords: mathematical modeling, numerical simulations, lamellar settling.

1. Introduction

The main objective of the experimental researches is to develop a compact wastewater treatment plant. The technological process of wastewater treatment consists in 5 stages. A hybrid biological stage (fixed biofilm and activated sludge) is implemented and it is followed by a mechanical treatment. All the reactors must be designed in order to obtain a flow without parasites. Inside the compact wastewater treatment plant the current flow is sinusoidal. In the first reactor the wastewater entrance is situated at the upper part of the installation. In the second reactor the wastewater entrance is situated at the bottom part and so on until the lamellar settling, where admission is also placed at the upper part. This situation is unusual, because the wastewater must pass between lamellas and in our case, the water current will cross over the lamellas and the installation efficiency will be minimum.

A cross wall/baffle must be realized in order to course the flow between lamellas. For a correct designing were made numerical simulations in FlexPDE 6. Different configurations were tested and in the end the final shape was established. The compact wastewater treatment plant was realized and it was demonstrated that were chosen the correct configurations for all 5 reactors.

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2. Technological process

The biodegradation reactors are realized in five stages, for an increased efficiency of wastewater treatment: 2 stages for the aerobic treatment (nitrification), 2 anaerobic stages for nitrogen removal (denitrification) and a final stage of mechanical settling (the last reactor is a lamellar settling) for suspended solid disposal [1]. Wastewater is introduced in the first compartment. This contains biofilm carriers and an aeration system with raw (medium) bubbles. The aeration system is made from stainless steel. In this bioreactor complex phenomenon take place (nitrification-denitrification) and the organic matter is decomposed in simple elements such as carbon dioxide and nitrogen, which are released into the atmosphere. Inside the bioreactor no. 2 are placed biofilm carriers and an aeration system with raw bubbles. This compartment is designed for the "finishing" of wastewater treated in bioreactor no. 1. Compartments no. 3 and 4 also contain biofilm carriers, but are not aerated and here, with the help of 2 mixers (necessary for mixing the wastewater and biofilm carriers) the nitrogen compounds are reduced (denitrification).

Inside the compartment no. 5 is realized the separation of suspended solids, which are evacuated as sludge. A lamellar settling was conceived for better separation efficiency. The technological process described is presented in figure no. 1.

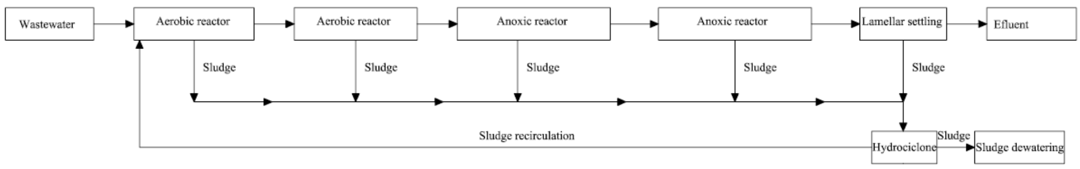

Fig. 1. Process applied at the compact wastewater treatment plant

All 5 compartments have a cone-shaped, facilitating the sludge accumulation at the bottom part of the installation. Periodically and automatic the sludge is simultaneous collected and evacuated from all 5 compartments and it is redirected to the hydrociclone where is separated in 2 phases, term density.

The dense sludge, mineralized, "thicked", is send to specific installation for sludge dewatering. Because of the performant system of separation, the sludge is completely mineralized in maximum 2 weeks and it can be deposit at landfills or use in agriculture.

The sludge with lower density, insufficiently mineralized, "the active sludge", is redirected back into the first bioreactor and the whole cycle of treatment is renewed. The recirculation of the active sludge is very useful for maintaining the microorganisms in bioreactors.

The whole treatment process is completely automated. Due the large surface of exposure offered by biofilm carriers, all biological processed are 5 times faster and efficient than the classical systems. The total area covered by the wastewater treatment module is considerably reduced.

The most difficult part of the designing was to conceive the lamellar settling

2. Designing of the lamellar settling of the compact WWTP

This type of settling was chosen because it has been proved that, in conventional tanks, small depths lead to an increase in 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. Principally, the lamellar tank can be considered to be a multiplied version of the same construction, each element or compartment containing identical water – sludge separation surface (see figure no. 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 settling speed 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.

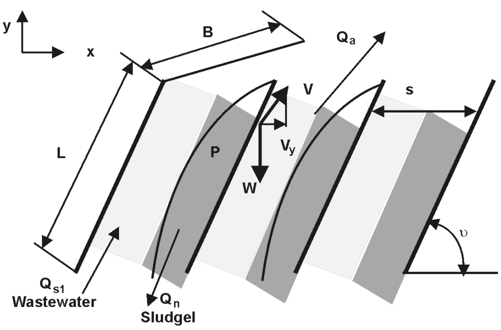

Fig. 2. Diagram of a lamellar tank

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 (figure 3) with counter-current stream, the axial velocity component of the liquid flux is $v = q/sB\sin\vartheta$, the vertical component is $vy = v \sin\vartheta = Q/Bs$, and the horizontal component is $vx = v\cos\vartheta = q/sB\ tg\vartheta$. The vertical component of the settling speed is $vsy = vy - w = q/sB - w$.

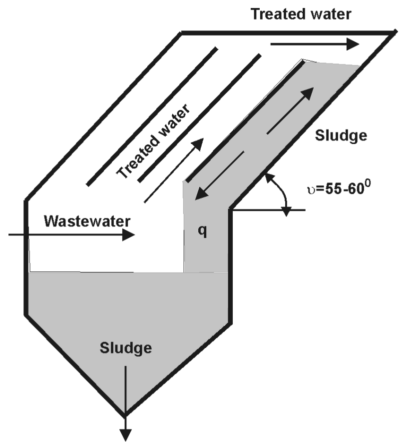

Fig. 3. Lamellar settling tank

A particle entering the inter-plate system at point A will cover the vertical distance over a time period *t1*, and the horizontal distance over a time *t2*. This inequality becomes [2]:

$$t2 \le t1;\ \frac{s + L\cos\vartheta}{v_x} \le \frac{L\sin\vartheta}{v_{sy}};\ \frac{s + L\cos\vartheta}{\frac{q\cos\vartheta}{sB\sin\vartheta}} \le \frac{L\sin\vartheta}{\frac{q}{sB} - w} \tag{2}$$

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

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

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 the *cos* ϑ values, the inequality can be simplified to:

$$\frac{q}{BL} \le w\cos\vartheta \tag{4}$$

The relation can also be formulated relative to the total flow rate by the formula:

$$\frac{Q}{(n+1)BL} \leq w\cos\vartheta \tag{5}$$

or, where there are many compartments, we can use the expression:

$$\frac{Q}{nBL} \leq w\cos\vartheta \tag{6}$$

where *nBL* is the total surface are of the compartments in the lamellar tank.

3. Mathematical modelling and numerical simulations for the lamellar settling of the compact wastewater treatment plant

For simulations was used FlexPDE programme. A large number of configurations were taking into account. Some of the preliminary results and their interpretations are presented below.

In figure 4 at the entrance was conceived a vertical plane/wall immersed in wastewater mass.

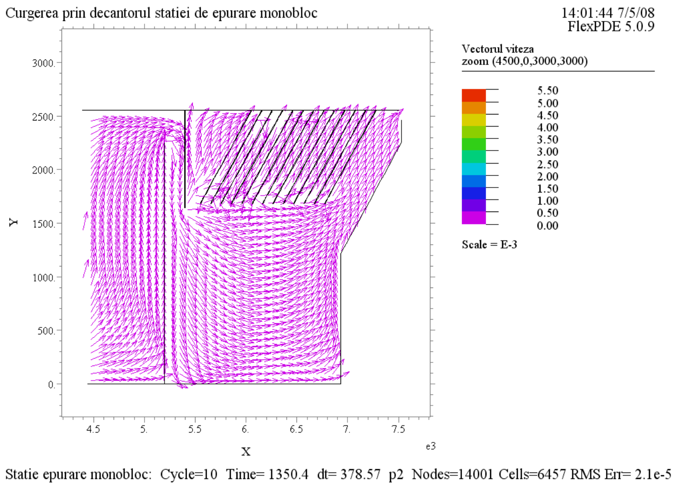

Fig. 4. Results obtained during numerical simulations

As it can be easily observed between lamellas 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 lamellas (the water flows underneath lamellas and go directly to the exit). Also the lamellas are too short.

In these conditions some other configurations must be tested. In figure 5, the lamellas are longer.

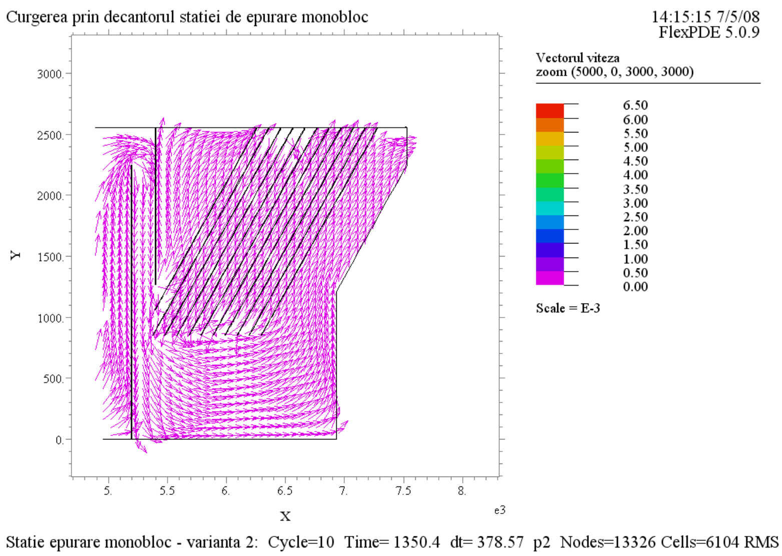

Fig. 5. Results obtained during numerical simulations

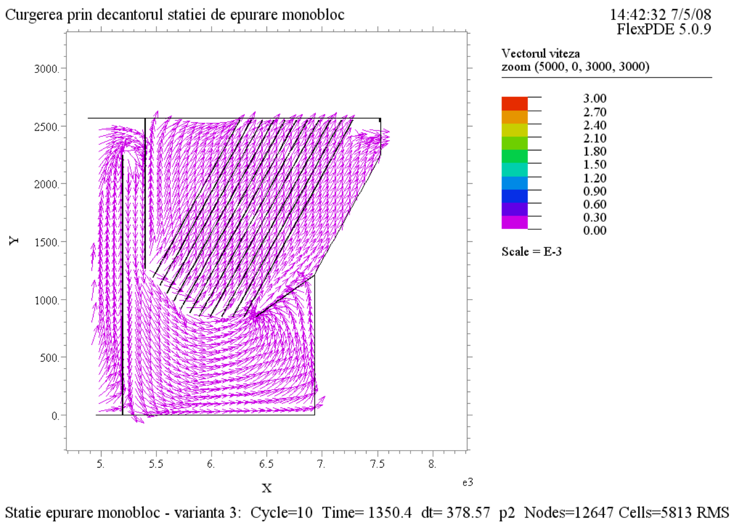

Fig. 6. Results obtained during numerical simulations

In figure 6, the first's lamellas were cut and the wastewater flows normally between lamellas. A wall was conceived in order not to occur the by pass. As it can be observed the flow inside the settling was improved.

In figure no. 7 it was desired to see what is happening if the entrance is situated at a lower level. In figure no. 8 the lamellar settling was flattered. In the last 2 cases the by-pass also occurs.

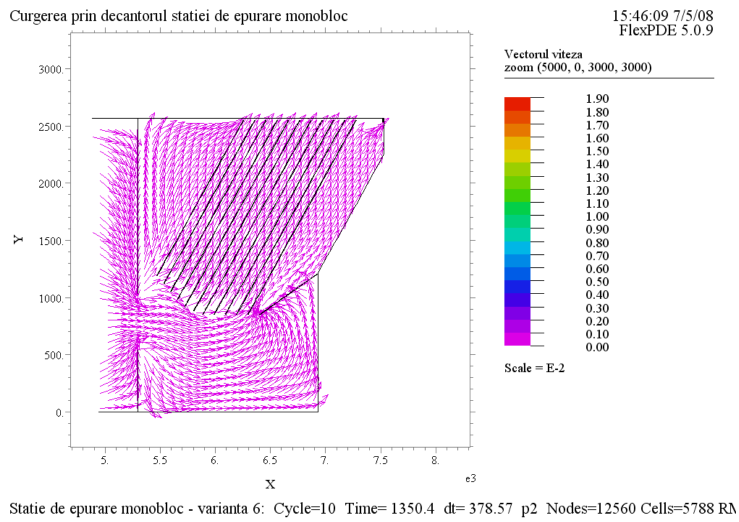

Fig. 7. Results obtained during numerical simulations

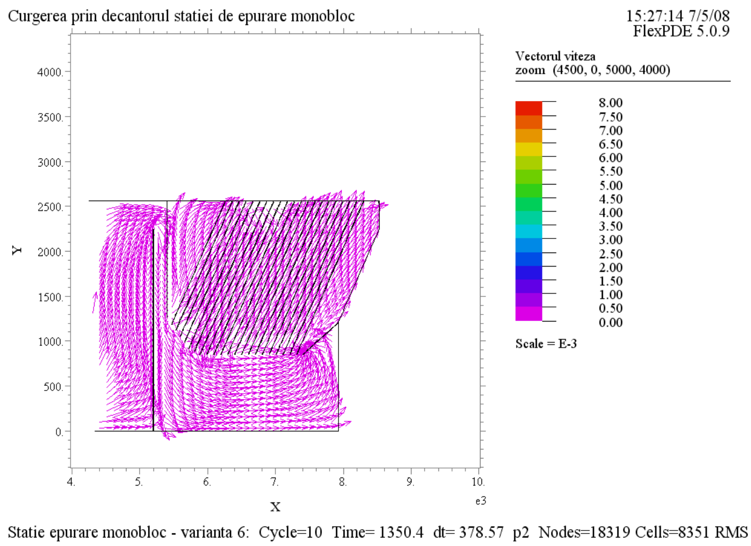

Fig. 8. Results obtained during numerical simulations

After some other numerical simulations the final shape was chosen and it is represented in figure no. 9. Here, the water will not by-pass the lamellas and the flow inside the settling is normal, from the bottom of the lamellas to the discharged area.

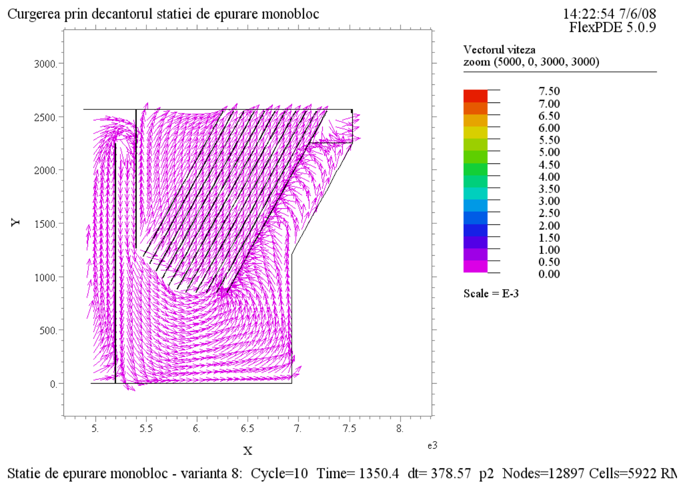

Fig. 9. Results obtained during numerical simulations

4. Conclusions

Mathematical modeling and numerical simulation is 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, has been reached the optimum shape for the lamellar settling. 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 from the station accomplish the NTPA regulations.

R E F E R E N C E S

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