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ADVANCED TECHNOLOGIES IN BIOLOGICAL WASTEWATER TREATMENT PLANTS

211.03 – ENGINEERING NETWORKS IN CONSTRUCTION

Summary of the PhD thesis in technical sciences

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CONTENTS

CONCEPTUAL LANDMARKS OF RESEARCH

Timeliness and importance of the issue addressed. The Republic of Moldova's accession to the European Union implies the necessity of solving the problems of the protection of the environment through the modernization of existing technologies, through to implementation and putting into operation of new installations, performances, and by providing services tailored to the requirements of the environment.

By creating mini treatment plants, in compact form, with autonomous operation, the aim is to reduce the environmental impact of human or industrial activities in rural and isolated areas where there is no possibility of collecting wastewater and their treatment in municipal treatment plants. The use of modern treatment technologies can significantly reduce the amount of sludge resulting from the treatment, make efficient use of existing free spaces, increase reliability and simplify maintenance operations.

Description of the situation in the field of research and identification of research objectives. The study of technologies applied in small capacity treatment plants is required by the objectives assumed by our country towards the European Union. According to the latest estimates, in the Republic of Moldova, there is an increase to the "Extending and upgrading the water system and the sewer system," and has the following objectives: provision of water and sewerage services at affordable rates, ensuring the adequate quality of drinking water in the country, the improvement of the quality of the water courses, to improve the management of sludge from sewage treatment plants waste water treatment plants.

Wastewater treatment represents different processes and technologies used in compact small capacity wastewater treatment plants and emphasizes the retention of nitrogen and phosphorus compounds in wastewater in order to achieve outstanding performance in terms of effluent quality.

The use of compact treatment plants is imposed by the need to treat wastewater produced in use with a small number of equivalent inhabitants such as: schools, camps, hotels, filling stations, recreational areas, private homes, industrial parks, localities up to 10,000 inhabitants and which are not incorporated into agglomerations that have municipal treatment plants.

Small treatment plants are based on mechanical-biological treatment. Biological purification in compact plants is carried out either with suspended biological mass (active sludge) or with fixed biological mass (biological film). The biological purification step is aimed at the removal of biodegradable organic substances (BOD), nitrogen by nitri-denitrification processes and phosphorus by biological processes.

Aim of the thesis: obtaining a process and a modern installation for domestic and industrial with characteristics of pollutants close to those of the domestic wastewater treatment, obtaining a biological reactor with a small volume and with plug flow movement of the fluid with minimal excess sludge and low energy consumption.

Main objectives are:

- study of biological treatment methods;
- study of the composition of wastewater;
- study on the hydrodynamic regime in different bioreactors;
- elaboration of an experimental bioreactor and observance of the algorithm of scientific researches of domestic wastewater treatment with the help of solid support;
- obtaining positive results regarding the hydrodynamic regime and the quality of the treated wastewater in the experimental bioreactor.

Scientific novelty and originality: for the first one in the Republic of Moldova have been developed studies on the hydrodynamic regime of wastewater in the biological reactor. Obtaining the flow of wastewater - air in the biological reactor near the plug flow.

The results obtained that contribute to the solution of an important scientific problem: it has been proposed to reduce the retention time distribution (RTD) of wastewater in the hybrid biological reactor (MBBR). Through different experiments it has been shown that the dispersion of wastewater - air is very small and approaches the plug flow.

The theoretical significance: based on the experiments, new knowledge was obtained regarding the movement of wastewater - air in the hybrid biological treatment reactor (MBBR).

Applicative value of the work: obtaining a high degree of wastewater treatment.

The implementation of scientific results: through the obtained results it was proposed the implementation of the Vavibloc type wastewater treatment plants for domestic and industrial wastewater. For this type of treatment plants (Vavibloc) was obtained sanitary opinion, ecological opinion and technical evaluation.

Research hypothesis. For carrying out various experiments, a pilot plant for biological treatment of domestic wastewater was designed and installed.

The technology/treatment process in this pilot plant is plug flow type with hybrid biomass, i.e. both suspended biomass (active sludge) and fixed biomass growing on permanently moving parts/elements (mobile solid support) – MBBR.

The pilot plant is made of sheet metal with dimensions 4,5 x 1,0 x 3,0 m (L x b x h), H_{water}=2.8 m, divided into 4 compartments: anoxic bioreactor – aerobic bioreactor – aerobic bioreactor – lamellar decanter.

Publications. 11 scientific articles were published on the topic of the thesis. At the same time, based on the results obtained, an invention patent was obtained.

Structure and volume of the thesis: The thesis includes the following sections: annotation in Romanian, Russian and English, list of tables, list of figures, list of abbreviations, introduction, four chapters, general conclusions and recommendations, bibliography from 71 titles, annexes, 122 pages of basic text, including 101 figures and 56 tables, statement on taking responsibility, CV of the author.

Keywords: wastewater treatment, bioreactor, biological film, hydrodynamic regime, pilot treatment plant, plug flow water movement, mobile solid support, hybrid treatment, tracer.

This thesis contains 4 basic chapters, namely:

Bibliographic summary. This chapter describes the qualitative characteristics of domestic wastewater, the characteristics of wastewater from small communities, the characteristic of wastewater movement regimes. A brief history of wastewater treatment is presented. At the same time, current methods and procedures for wastewater treatment were studied.

Program and methodology of investigations of scientific research of wastewater treatment with mobile solid support (hybrid process). This chapter presents the advantages of the hybrid process. Also here is described in detail the pilot plant with the help of which the necessary experiments were carried out. The chapter also describes in detail the program of conducting experiments in the pilot wastewater treatment plant.

At the same time, analytical methods of analysis of raw waste water composition and methods of measurement of water purification efficiency were described.

Study of the hydrodynamic regime in biological reactors. This chapter presents the types of biological reactors used for wastewater treatment. Biological reactors with ideal movement of the water flow and the bases of non-ideal movement of the waste water flow are presented. Particular attention is shown on the dispersion model and the distribution of retention time.

Results and applications of investigations in practice. This chapter presents the results of the experiments on the basis of the pilot plant. Here the influence of mobile solid support on the efficiency of water purification is described. The results of the study of raw wastewater are presented in graphic form. The results obtained from the biological purification of wastewater for different flow rates with different conditions are presented. At the same time, calculations and results on the hydrodynamic regime in the biological reactor are presented.

CONTENT OF THE THESIS

In **INTRODUCTION** the actuality of the problem addressed is argued, the main purpose and objectives of the paper are formulated, the scientific originality of the applied approaches is described, the applicative and theoretical value of the paper are exposed, the main results submitted for support are presented.

1. BIBLIOGRAPHIC SUMMARY

1.1. Qualitative characteristics of domestic wastewater

The main quality indicators are classified into 4 categories:

- physical (turbidity, colour, smell, temperature);
- chemical (SS, dissolved oxygen, BOD_5, COC, detergents, oils, fats, etc.);
- bacteriological (different types of bacteria);
- biological (bacteria, larvae, worms, etc.).

1.2. Characteristics of domestic wastewater from small communities

Wastewater from temporary uses (tourist areas, camps, sanatoriums, etc.) generally has differentiated characteristics, depending on the type of use and the degree of comfort. It is found that this organic load has values in the range of 10 g BOD_5/inh-day and 100 g CBO_5/inh-day.

1.3. Natural biological treatment

The constructions necessary for natural biological treatment are: irrigation and filtration fields, sand filters, biological ponds, phytofilters (constructed wetlands).

1.4. Artificial biological treatment

Classic biological wastewater treatment processes

Suspended microflora bioreactor/active sludge aeration tank. This process is the most widespread and is known as the active sludge process [38].

Process with hybrid microflora cultures (elements/supports for biomass fixation)

The hybrid wastewater treatment process (MBBR) uses the principle of aerobic biofilm and combines the advantages of the biological treatment process with active sludge and those of other biofilm systems without being strongly influenced by their disadvantages. The basis of this process is the mobile biofilm support elements made of polyethylene [38].

Biological purification process using aerobic granular sludge

The technology of biological wastewater treatment with the help of aerobic granular sludge is a relatively new one. According to the studies carried out by the researchers, aerobic granular sludge ranks between active sludge and biofilm, since there are very great similarities with biofilm growing on a mobile solid support element of small size.

Biological membrane purification process

The development and application of membrane bioreactors for wastewater treatment is recent. Membrane bioreactors are an active sludge treatment system using microporous membranes to separate the solid from the liquid phase instead of secondary decanters [38].

Biological purification process in cyclic sequential bioreactors (SBR)

Sequencing Batch Reactor (SBR) are a variety of activated sludge aeration tanks, in which all phases of wastewater and activated sludge treatment take place in one and the same bioreactor.

1.5. Technological schemes for nitrogen and phosphorus removal

Because European Directive no. 91/271/EEC of 30.05.1991 requires that both biodegradable matter (BOD) and nitrogen and phosphorus be eliminated in the treatment plants, in this thesis an analysis has been made on the technological schemes for the elimination of these components.

Biological nitrogen removal technologies

Preanoxic scheme

a. Ludzack-Ettinger

This scheme was developed by Ludzack-Ettinger. According to this scheme, the influent is introduced into an anoxic zone, which is followed by an aerobic zone [25, p. 60].

b. Ludzack-Ettinger modified

The basis of this treatment scheme is the Ludzack-Ettinger scheme with the distinction that nitrates are supplied to the anoxic zone directly downstream of the aerobic zone, by providing for an internal recirculation. This resulted in both increased nitrogen retention efficiency and increased denitrification rate [25, p. 60].

c. Fractional feeding

The preanoxic design is used in fractional feed treatment schemes. This project is used in existing multi-pass aeration basins [25, p. 62].

Postanoxic scheme

a. Single stage with sludge

In the single-stage sludge process developed by Wuhrmann, nitrogen removal is carried out in the active sludge process by adding an anoxic basin with mixing after the aerobic nitrification basin [25, p. 65].

b. Bardenpho (4 steps)

The 4-stage Bardenpho purification process is characterized by having both preanoxic and postanoxic denitrification incorporated into it [25, p. 65].

Biological phosphor removal technologies

a. Procedure A/O

The A/O process involves the removal of phosphorus on the water line, in the biological step simultaneously with the oxidation of carbon - based organic substances [28, p. 20].

b. Phostrip process

The Phostrip process involves the removal of phosphorus on the sludge line. In this process, part of the recirculated active sludge is routed to an anaerobic phosphor stripping tank [28, p. 20].

Biological technologies for combined nitrogen and phosphorus removal

a. Procedure A^2/O

This process is based on the A/O system for the removal of phosphorus, the initial system has been improved to be able to remove nitrogen as well. The classical system introduced new anoxic zones, in which the denitrification of waste water is carried out [25, p. 81].

b. Bardenpho process

The Bardenpho process is an improvement of an elaborate nitrogen retention system, the modification consisting of its adaptation to reduce phosphorus. This was achieved by the introduction of a fifth step - a compartment with anaerobic environment [25, p. 81].

c. UCT process

The UCT process is based on process A^2/O, with two modifications: the recirculated active sludge is introduced into the anoxic zone and not into the anaerobic zone, and the internal recirculation is made from the anoxic zone to the anaerobic zone. By recirculating the active sludge in the anoxic zone, the introduction of nitrate into the anaerobic zone is avoided [25, p. 82].

d. VIP procedure

The waste water enters the anaerobic tank where it is mixed with the recirculated flow from the downstream anoxic zone. The resulting mixture subjected to anaerobic conditions then enters the anoxic tank, where it is combined with the recirculated nitrified mixture from the downstream aerated area and the recirculated activated sludge [25, p. 83].

2. PROGRAM AND METHODOLOGY OF INVESTIGATIONS OF SCIENTIFIC RESEARCH OF WASTEWATER TREATMENT WITH MOBILE SOLID SUPPORT (HYBRID PROCESS)

2.1. Advantages of domestic wastewater treatment by the hybrid process

Compared to the active sludge process, the hybrid one has the following advantages:

- higher biological activity;
- purification efficiency increases by recirculating water with sludge;
- fast film restocking after film detachment;
- simple operation.

2.2. Pilot plant for domestic wastewater treatment

For the development of the experiments, a pilot plant for biological treatment of domestic wastewater was built and installed. The treatment process in this pilot plant is hybrid, i.e. with suspended biomass (active sludge) and fixed biomass that grows on the permanently moving parts (mobile solid support) – MBBR (Mobile Bed Biofilm Reactor). The pilot plant has dimensions 4,5 x 1,0 x 3,0 m (L x b x h), H_{water}=2,8 m, divided into 4 compartments: anoxic bioreactor – aerobic bioreactor – aerobic bioreactor – lamellar decanter. According to the calculations this pilot plant has the capacity to treatment a flow of 25,0 m^3/ day.

Technological scheme of the proposed pilot facility for research

According to European Directive no. 91/271/EEC of 30.05.1991 requires that a technological scheme be approved in the treatment plants not only for the disposal of biodegradable matter (BOD) but also for the disposal of nitrogen and phosphorus, which is why the experimental plant also includes this in the technological scheme.

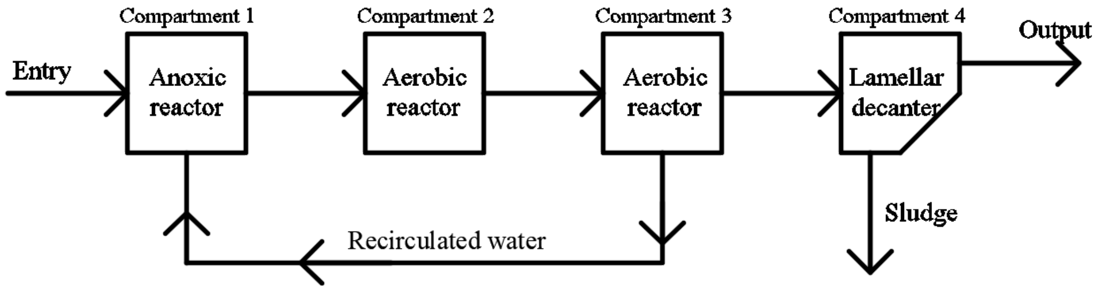

Fig. 2.1. Proposed technological scheme for research in the pilot facility

Sizing calculation of the pilot biological wastewater treatment plant

The sizing calculation of the pilot biological wastewater treatment plant (hybrid process) proposed for research is carried out for a daily flow of wastewater Q_{day}=25 m^3/day, or 150 E.I., with a consumption of 150 l/inh-day according to table C. 1 of NCM G. 03.03.2015 [53, p. 49].

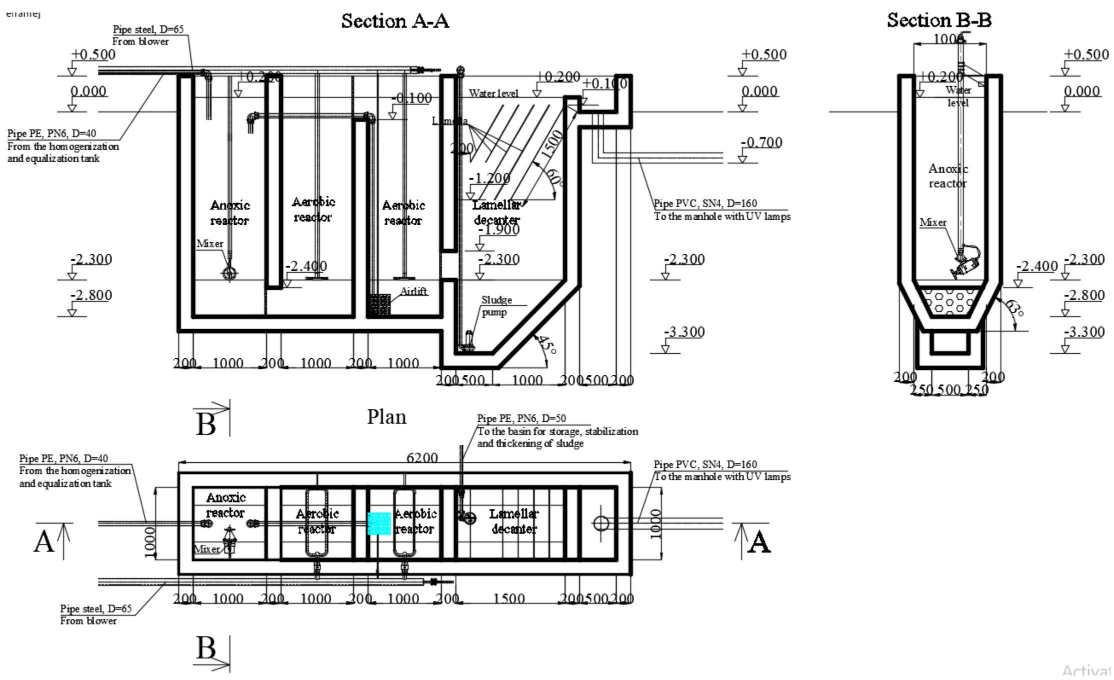

Fig. 2.2. Pilot wastewater treatment plant proposed for research

2.3. Description of the pilot plant for domestic wastewater treatment

The biological treatment process takes place in four compartments: anoxic bioreactor – aerobic bioreactor – aerobic bioreactor – lamellar decanter.

Compartment no. 1 (anoxic reactor). It contains mobile solid support elements, but not being aerated achieves anoxic reduction of nitrogen (denitrification) by stirring with a mixer.

Compartment no. 2 (aerobic reactor). It contains mobile solid support elements, but is aerated with medium bubbles with a diameter of 2-3 mm. Here occurs the oxidation of biodegradable organic matter and the elimination of biodegradable substances (BOD_5).

Compartment no. 3 (aerobic reactor). It also contains mobilr solid support elements and is aerated with medium bubbles with a diameter of 2-3 mm. Complex nitrification phenomena occur here, leading to the oxidation of ammonia nitrogen. At the same time in this compartment is installed an aerlift that recirculates water with nitrate content in the anoxic bioreactor.

In compartment no. 4 (lamellar decanter), containing the lamellar block, the separation of the sludge from the purified wastewater by gravity sedimentation is carried out. Purified, clarified wastewater is discharged from the lamellar decanter through the purified wastewater pipe.

Fig. 2.3. Pilot wastewater treatment plant on which the experiments took place

2.4. Algorithm of conducting experiments in the pilot plant of domestic wastewater treatment

There was an ordered series of repeated experiments, by controlling one or more initial parameters, in order to obtain new knowledge, leading to the economic validation of the model. An algorithm has been proposed to carry out the experiments in the pilot wastewater treatment plant. The algorithm for conducting experiments is presented below.

The transit regime of raw non-purified wastewater in the absence of the treatment process (hydrodynamic/hydraulic study)

1. Determination/study of retention time distribution in the range of variation of pumped flow (0,5; 1,0; 2,0) m^3/h.
2. Study of the composition of raw wastewater (variation during the day/month).

Operating regime of the pilot installation with active sludge

1. Supply flow variation from Q_{min} up to Q_{max}, with complete recirculation of the active sludge settled in the secondary decanter (in the absence of evacuation of excess active sludge);
2. The study of the treatment efficiency obtained at different loads (mass and volume), retention times, doses of active sludge (by excess activated sludge discharge).
3. Analysis:
    a. pollutant loads (mass, volume);
    b. physico-chemical (COC-Cr, BOD_5, $N\text{-}NH_4^+$, P_{total}, dissolved oxygen, temperature).

Operating mode in the presence of the mobile solid support

1. Biofilm growth (duration, thickness, moisture, sludge index);
2. Supply flow variation;
3. Hydrodynamic study;
4. Treatment efficiency study;
5. Analysis.

Long-term stabilised operating regime of the pilot plant in hybrid microflora system (with mobile solid support)

After the development of all the experiments, the pilot wastewater treatment plant was allowed to operate in a stable regime for a long time. The pumped water flow from the pumping station/homogenization and equalization basin was 1,25 m^3/h. The time of stable operation was around 3 months. This flow was chosen because according to the results of the hydrodynamic regime, the retention time for this flow and the results obtained after biological treatment are the most successful.

2.5. Study of the composition of raw domestic wastewater

In the present thesis a study was made on the concentrations of raw wastewater parameters over a period of one year.

3. STUDY OF THE HYDRODYNAMIC REGIME IN BIOLOGICAL REACTORS

3.1. Types of biological reactors

Wastewater treatment involves physical, chemical and biological processes that are carried out in different containers generally known as biological reactors. The main types of biological reactors used for wastewater treatment, shown in figure 3.1, are:

- batch reactor - Sequencing Batch Reactor;
- complete mixing reactor (continuous flow stirring/mixing reactor);
- plug flow reactor (also known as tubular flow reactor);
- reactors with complete mixing in series;
- fixed biological filling reactor (biological filter);
- moving bed biofilm reactor (MBBR).

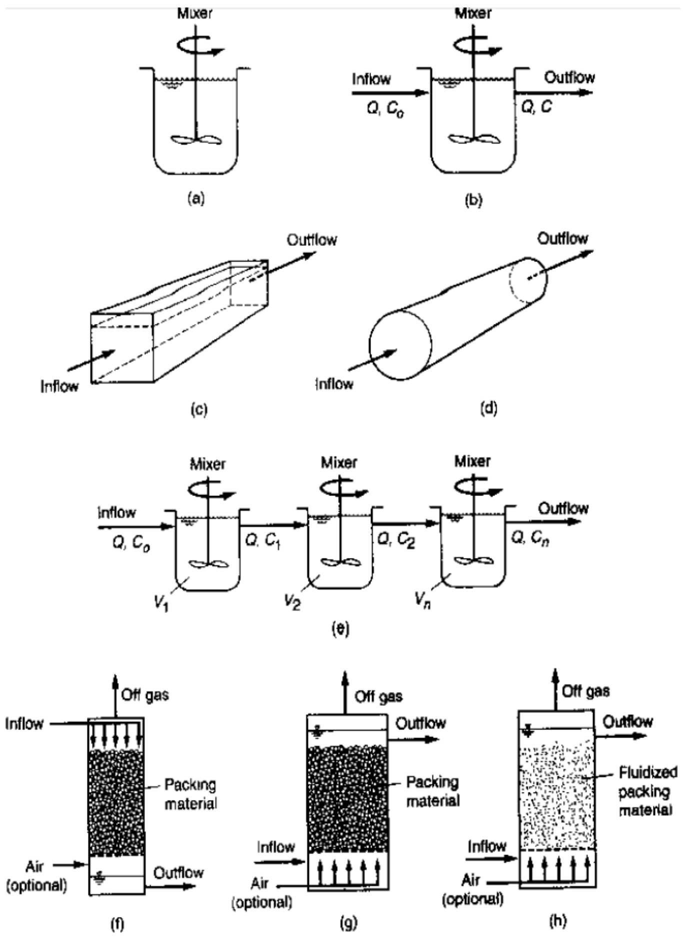

Fig. 3.1. Types of biological reactors. (a) batch reactor, (b) complete mixing reactor, (c, d) plug flow reactors, (e) reactors with complete mixing in series, (f, g) fixed biological filling reactor, (h) moving bed biofilm reactor [20, p. 219]

3.2. Biological reactors with ideal movement of the flow of domestic waste water

Biological reactors with ideal movement of the wastewater flow are: batch reactor, plug flow rector, complete mixing reactor.

These types of ideal reactors are relatively easy to operate. In addition, they are usually the best way to contact reactants - regardless of the operation. [5, p. 91].

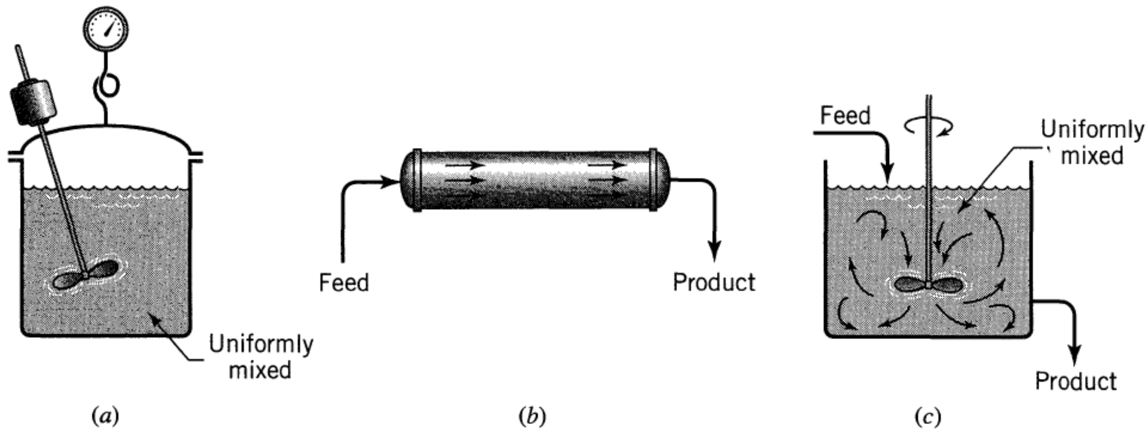

Fig. 3.2. Three types of ideal reactors. (a) batch reactor, (b) plug flow reactor, (c) complete mixing reactor [5, p. 90]

3.3. The foundations of the non-ideal movement of the flow of household waste water

In general, three somewhat interrelated factors form the contact or pattern of movement of the fluid inside the reactor:

- retention time distribution of fluid (waste water - air) passing through the reactor;
- the state of aggregation of the flowing fluid, its tendency to clump and for a group of molecules to move together;
- maturity and delay of fluid mixing in the reactor [5, p. 257].

<u>Retention time distribution</u>

Deviations from those models with ideal flow of motion can be caused by chaotic mixing of the fluid or by the creation of standing regions (dead zones) in the reactor. If it is precisely known what is happening inside the reactor, then in principle we should be able to predict the behavior (movement) of the fluid inside the reactor. This information can be easily and directly determined by a large-scale research method, called the impulse-response experiment [5, p. 258].

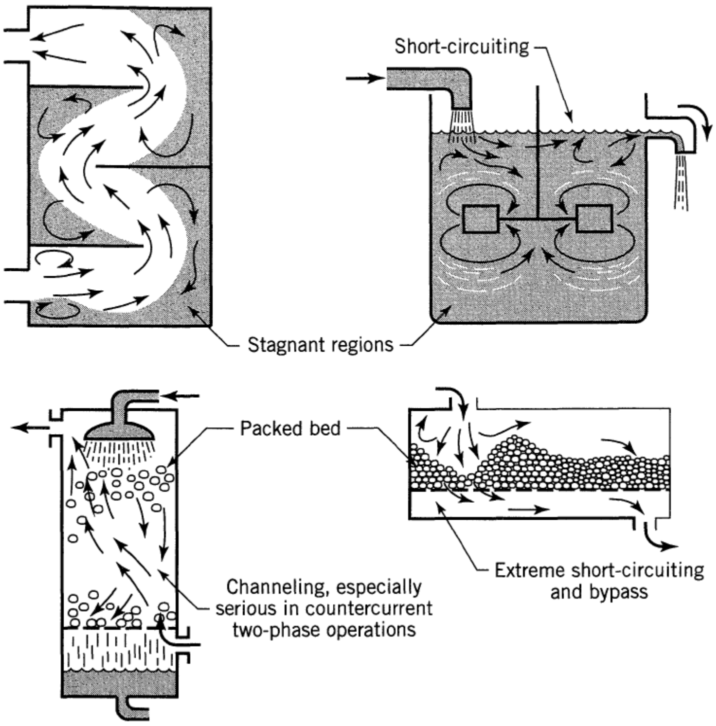

Fig. 3.5. Models of non-ideal flows that may exist in process equipment [5, p. 258]

<u>E curve, fluid age distribution, retention time distribution</u>

It is obvious that fluid elements taking different paths through the reactor may have different lengths of time to pass through the reactor. The distribution of these times for the flow of fluid leaving the reactor is called the distribution of the exit ages, **E**, or the fluid Residence Time Distribution (RTD).

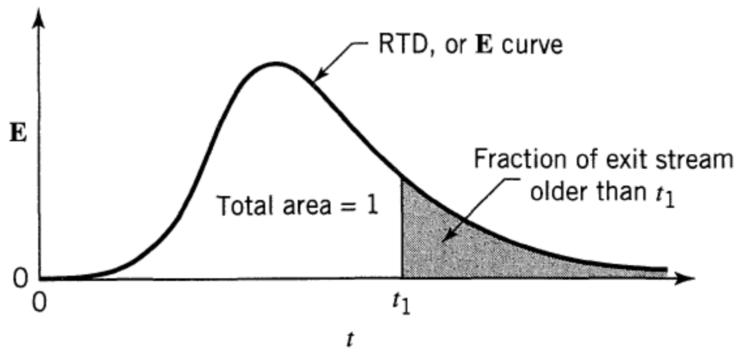

Fig. 3.6. The output age distribution curve E for the fluid flowing through a reactor, also called the retention time distribution [5, p. 261]

3.4. Dispersion model

The hydraulic characteristics of non-ideal reactors can be modeled by taking into account dispersion. For example, if the dispersion tends to infinity, the movement of the fluid in the axial dispersion reactor is equivalent to the fully mixed reactor. However, before examining nonideal flow/movement in reactors, it will be useful to examine the distinction between molecular diffusion coefficient, turbulent diffusion and dispersion applied in the analysis of reactors used for wastewater treatment [20, p. 245].

Choice of dispersion models

Suppose that an ideal pulse of the tracer is introduced into the fluid entering a reactor. The pulse spreads as it passes through the reactor, and to characterize the spread according to this pattern (see figure 3.15), we assume that a diffusion-like process is superimposed over the plug flow. This is called dispersion or longitudinal dispersion to distinguish it from molecular diffusion. Dispersion coefficient **D** (m^2/s) represents this scattering process.

Therefore:

- the high value of **D** means fast scattering/mixing of tracer curve;
- the small value of **D** small means the slow spread of the tracer curve;
- **D** = 0 means that it does not spread, so the flow/movement of the fluid is plug flow type.

Also (**D**/*uL*) is the dimensionless relationship that characterizes the spread of fluid throughout the reactor.

His assessment **D** or **D**/*uL* it occurs by recording the shape of the tracer curve as it passes through the reactor outlet. In particular, it is measured:

- $\bar{t}$ - average passing time or when the curve passes to the exit;
- σ^2 - variation or a measure of the spread of the curve.

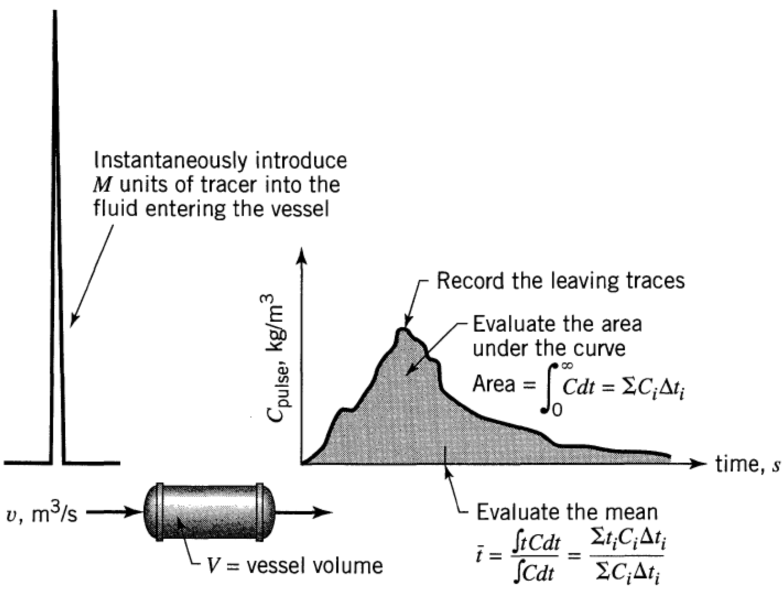

Fig. 3.15. Tracer spread according to the dispersion model [5, p. 294]

4. RESULTS AND PRACTICAL APPLICATIONS OF INVESTIGATIONS

4.1. Influence of mobile solid support/floating load of the treatment efficiency

Biological treatment using the mobile solid support is used to increase the efficiency of wastewater treatment. The biological film that forms on this mobile solid support, which contains biomass, can be at rest or trained in motion. Plants of this type are also referred to as fixed crop biological treatment plants [13, p. 101].

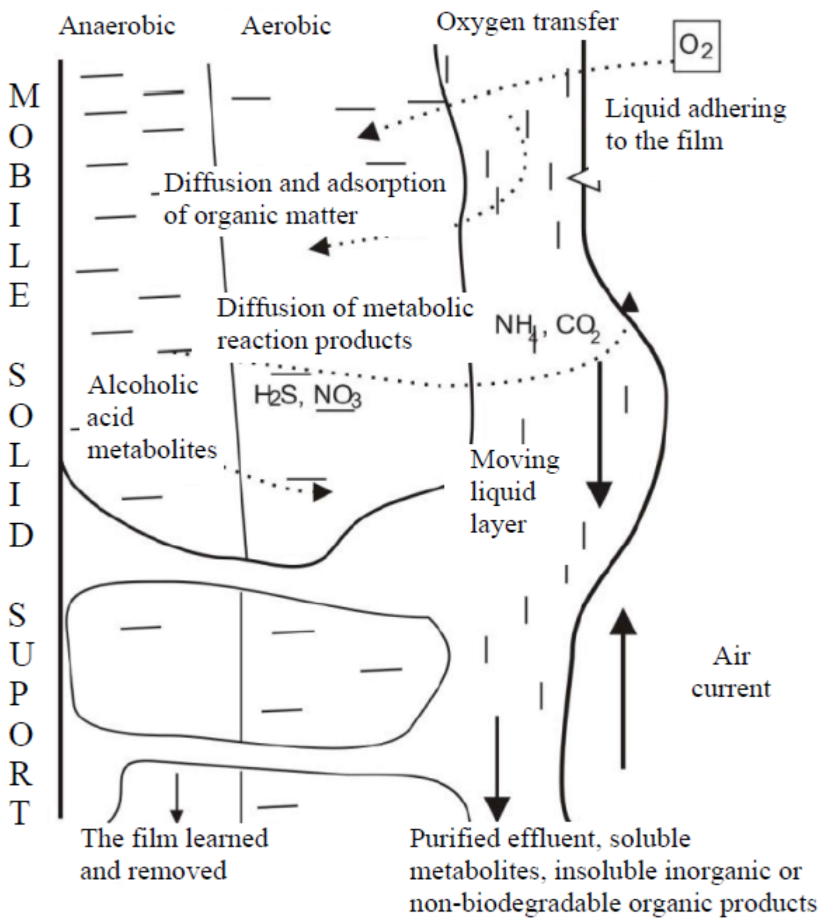

Fig. 4.1. Physical, chemical and biological processes in the biological film [13, p. 101]

4.2. Results obtained in the study of raw domestic wastewater

According to the algorithm of conducting experiments in the pilot wastewater treatment plant described above, a series of investigations of raw wastewater was carried out each month and for different hours. The centralising results on the quality of raw waste water over a period of one year are presented in table 4.1.

Table 4.1. Change in the composition of raw waste water during the year

No.	Months	SS, mg/l	COC-Cr, mg/l O	BOD_5, mg/l O	$N\text{-}NH_4^+$, mg/l	P_{total}, mg/l	Temp., °C
1	January	96,4	240,4	112,4	46,4	5,3	16,3
2	February	90,1	337,1	162,1	59,4	10,1	16,3
3	March	275,3	515,6	243,4	34,6	6,8	17,3
4	April	420,2	730,9	296,7	31,7	11,5	18,4
5	May	223,2	419,8	187,9	40,6	11,7	18,6
6	June	73,8	320,7	154,6	34,8	8,0	19,8
7	July	101,6	242,8	115,3	8,6	4,7	19,9
8	August	90,2	267,4	128,4	51,6	5,6	19,2
9	September	359,3	591,5	270,5	13,6	4,3	19,3
10	October	491,8	574,7	268,0	39,7	14,9	18,7
11	November	395,5	406,7	334,2	22,3	9,0	17,5
12	December	348,7	428,0	342,7	25,5	12,4	17,8
13	Average	247,17	422,96	218,01	34,06	8,69	18,3

4.3. Calculations and results obtained in the experimental/pilot biological reactor

Table 4.2. Results obtained after wastewater treatment, without mobile solid support

No.	Parameters	Entrance (annual average)	Output (pumped flow/recirculated flow, m^3/ h)					
			0,5/1,0	0,5/1,5	1,0/2,0	1,0/3,0	2,0/4,0	2,0/6,0
1	SS, mg/l	247,17	16,4	26,0	21,6	20,2	39,2	16,0
2	COC-Cr, mg/l O	422,96	78,5	82,1	108,1	41,1	136,8	129,6
3	BOD_5, mg/l O	218,01	19,7	26,1	24,6	16,4	26,5	30,0
4	$N\text{-}NH_4^+$, mg/l	34,06	10,3	1,8	12,8	21,2	3,3	2,6
5	P_{total}, mg/l	8,69	1,8	1,2	4,0	4,3	1,5	1,9

Tabelul 4.3. Rezultatele obținute după epurarea apei uzate, cu suport solid mobil

No.	Parameters	Entrance (annual average)	Output (pumped flow/recirculated flow, m^3/ h)					
			0,5/1,0	0,5/1,5	1,0/2,0	1,0/3,0	2,0/4,0	2,0/6,0
1	SS, mg/l	247,17	13,2	12,8	19,6	16,2	36,8	34,5
2	COC-Cr, mg/l O	422,96	74,6	71,2	78,8	76,3	138,9	122,9
3	BOD_5, mg/l O	218,01	14,3	12,6	16,2	14,9	28,5	26,3
4	$N\text{-}NH_4^+$, mg/l	34,06	6,0	5,6	8,0	7,2	6,4	6,2
5	P_{total}, mg/l	8,69	0,9	0,9	1,0	0,8	1,8	1,4

The best results are for the condition with mobile solid support (hybrid system) for an average hourly flow of 1,0 m^3/ h (25 m^3/ day) with recirculation of 3,0 m^3/ h. In order to reduce the retention time of the waste water and as an attempt is made to obtain a plug flow of movement, the experimental plant was allowed to work for 3 months with a constant flow of waste water equal to 1,25 m^3/h (30 m^3/ day) and with a recirculated flow equal to 3,75 m^3/ h.

Table 4.6. Results obtained, condition with mobile solid support, duration regime, with treatment flow 1,25 m^3/h, recirculated flow rate 3,75 m^3/h

No.	Parameters	Ent.	Out.	Ent.	Out.	Ent.	Out.	Ent.	Out.
1	SS, mg/l	514,0	29,8	487,5	28,9	395,9	28,7	333,2	26,8
2	COC-Cr, mg/l O	705,5	110,4	715,9	110,2	601,2	109,8	419,7	107,9
3	BOD_5, mg/l O	383,7	22,6	391,5	22,7	381,2	22,4	282,0	20,2
4	$N\text{-}NH_4^+$, mg/l	27,1	1,9	24,2	1,6	21,2	1,5	22,2	1,8
5	P_{total}, mg/l	11,3	0,8	10,6	0,9	10,7	1,2	10,6	1,2

4.4. Hydrodynamic regime on the performance of the purification process

Experimental method for determining the hydrodynamic regime

For the evaluation of age distribution functions (hydrodynamic regime), the impulse – response technical method was used, which consists in introducing a signal into the influent and measuring the response in the effluent. To make such a signal, the tracer is inserted into the fluid path (in the first compartment). The Tracer is inserted into the influent in a very small interval of time, basically t = 0 (all the mass at once). Due to the dispersion that occurs as a result of mixing during flow, the tracer pulses change their shape after introduction into the reactor, the more the dispersion is greater. For experiments as a tracer used sodium chloride (kitchen salt), NaCl.

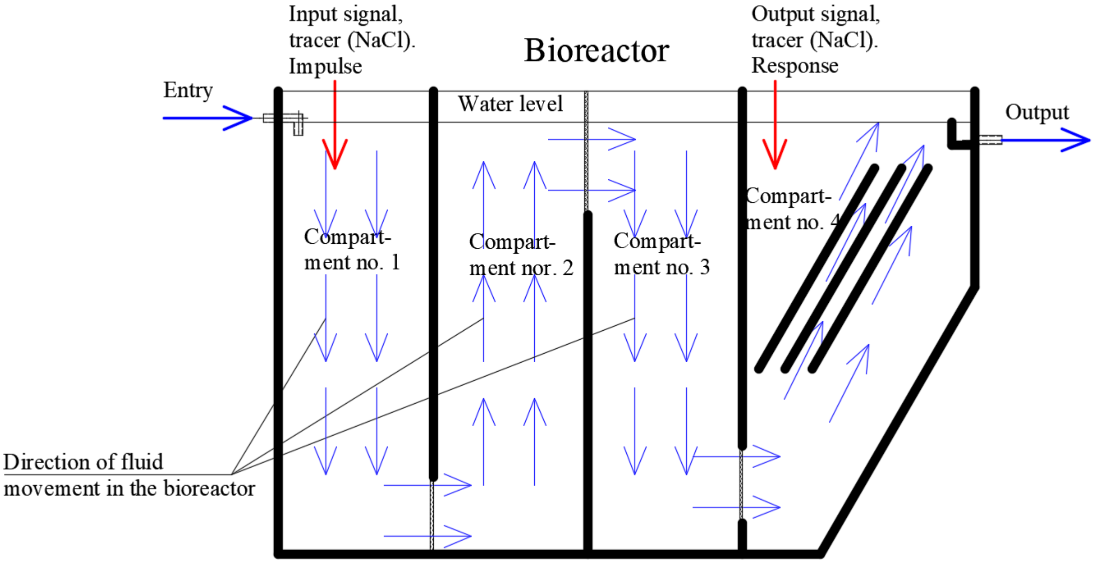

Fig. 4.15. Flow diagram of the fluid in the pilot/experimental biological reactor

Experiments were carried out for different wastewater flows namely 0,5 m^3/h, 1,0 m^3/h and 2,0 m^3/ h, for different conditions according to the algorithm of conducting experiments. In total, 21 experiments were conducted.

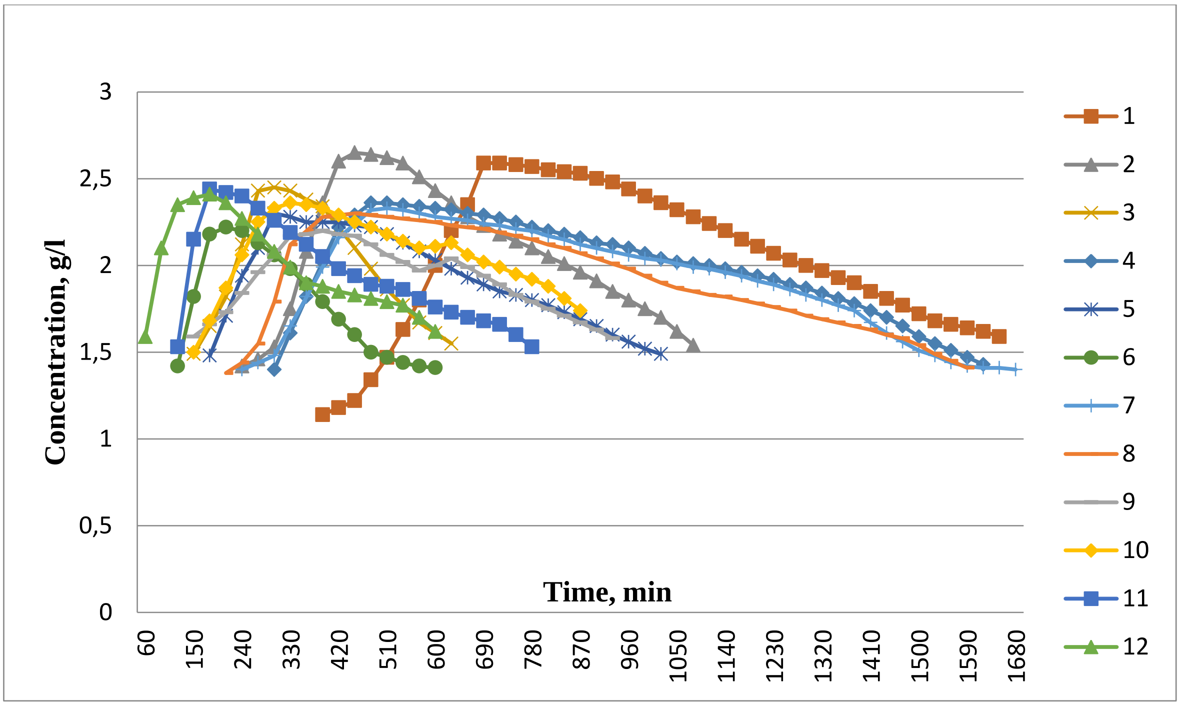

Fig. 4.28. Cetralizer graph for curve $C_{impulse}$ no support, conditions: 1, 2, 3 - no aeration, no recirculation, flow 0,5 m^3/h, 1,0 m^3/h, 2,0 m^3/h; 4, 5, 6 - with aeration, with mixing, no recirculation, flow 0,5 m^3/h, 1,0 m^3/h, 2,0 m^3/h; 7 - 12 - with aeration, mixing, recirculation, flow 0,5 /1,0 m^3/h, 0,5 /1,5 m^3/h, 1,0/2,0 m^3/h, 1,0/3,0 m^3/h, 2,0/4,0 m^3/h, 2,0/6,0 m^3/h

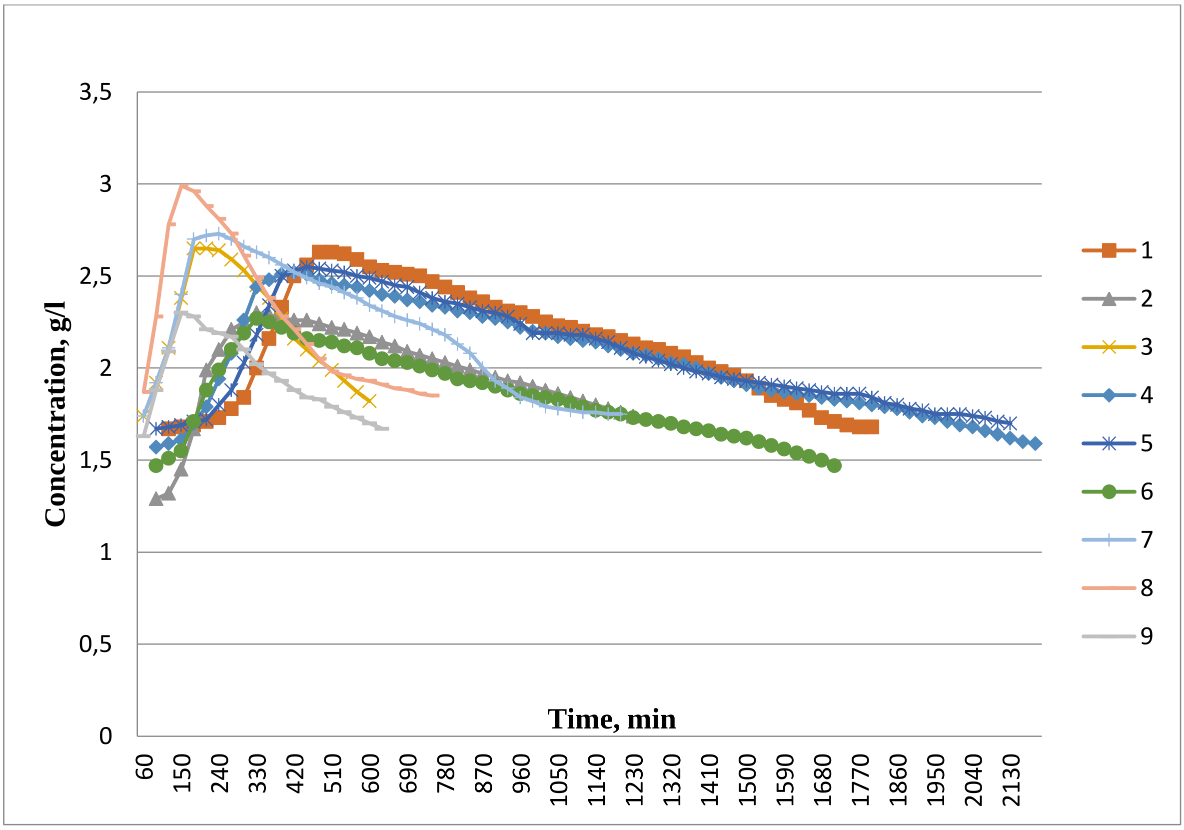

Fig. 4.38. Cetralizer graph for curve $C_{impulse}$ with support, conditions: 1, 2, 3 - with aeration, mixing, no recirculation, flow 0,5 m^3/h, 1,0 m^3/h, 2,0 m^3/h; 4 - 9 - with aeration, mixing, recirculation, flow 0,5 /1,0 m^3/h, 0,5 /1,5 m^3/h, 1,0/2,0 m^3/h, 1,0/3,0 m^3/h, 2,0/4,0 m^3/h, 2,0/6,0 m^3/h

Calculation of the dispersion model, D/uL

After obtaining curves $C_{impulse}$ the calculation of the dispersion model (**D**/*uL*) to determine the degree of dispersion of the fluid (waste water - air) in the experimental plant.

Table 4.29. Dispersion model results obtained for condition number 1. Without mobile solid support

No.	Conditions	$\bar{t}$, hours	δ^2	δ^2_θ	D/*uL*
9	Flow - 1,0 m^3/h, recirculated flow rate 2,0 m^3/h, without mobile solid support, with aeration, with mixing/stirring, with recirculation	8,22	27357,44	0,112	0,046
10	Flow - 1,0 m^3/h, recirculated flow rate 3,0 m^3/ h, without mobile solid support, with aeration, with mixing/stirring, with recirculation	8,11	30197,20	0,127	0,051

Tabelul 4.30. Rezultatele modelului de dispersie obținute pentru condiția numărul 2. Cu suport solid mobil

No.	Conditions	$\bar{t}$, hours	δ^2	δ^2_θ	D/*uL*
6	Flow - 1,0 m^3/ h, recirculated flow rate 2,0 m^3/h, with mobile solid support, with aeration, with mixing/stirring, with recirculation	11,94	133212,7 5	0,259	0,094
7	Flow - 1,0 m^3/h, recirculated flow rate 3,0 m^3/h, with movable solid support, with aeration, with mixing/stirring, with recirculation	7,67	50864,11	0,239	0,088

According [20, p. 249], for his values **D**/*uL* the values of the dispersion are also assigned:

- **D**/*uL* = 0, no dispersion (ideal fluid movement);

- **D**/*uL* < 0,05, small dispersion;

- **D**/*uL* = 0,05 – 0,25, moderate dispersion;

- **D**/*uL* > 0,25, large dispersion;

- **D**/*uL* → ∞, , complete mixing.

The results obtained for conditions with mobile solid support (hybrid treatment process), are close to 0,05, which demonstrates that the movement of the fluid inside the reactor tends to a small dispersion movement, i.e. the biological reactor is close to plug flow type.

For flow rate of 1,0 m^3/h and recirculated flow rate of 3,0 m^3/h, with support, with aeration, with mixing, with recirculation we obtain an average retention time equal to 7,67 hours for the compartments of the experimental installation which results in a time of 1,91 h for each compartment. Given that the experimental plant was left to work for 3 months with a flow rate of 1,25 m^3/h, and the results obtained were quite good the whole plant can be resized for a flow of 1,25 m^3/h = 30 m^3/day. This results in an average wastewater transit time of around 1,71 hours per compartment. As a result, it is proposed for the design of these types of treatment plants to adopt the waste water retention time of 3,6 hours for aerobic reactors (1,8 hours for each of the 2 aerobic compartments). For compartment number 1 (anoxic bioreactor) a retention time equal to 1,0 hours is proposed. At the same time, for each project, the volume of the entire plant will be checked depending on the organic load of BOD and ammonia nitrogen. Refers to industrial and/or high concentration domestic wastewater.

<u>**Obtaining the E curve, the retention time distribution**</u>

Above were presented the curves $C_{impulse}$, but for greater clarity on the retention time distribution it is necessary to obtain the curve **E**.

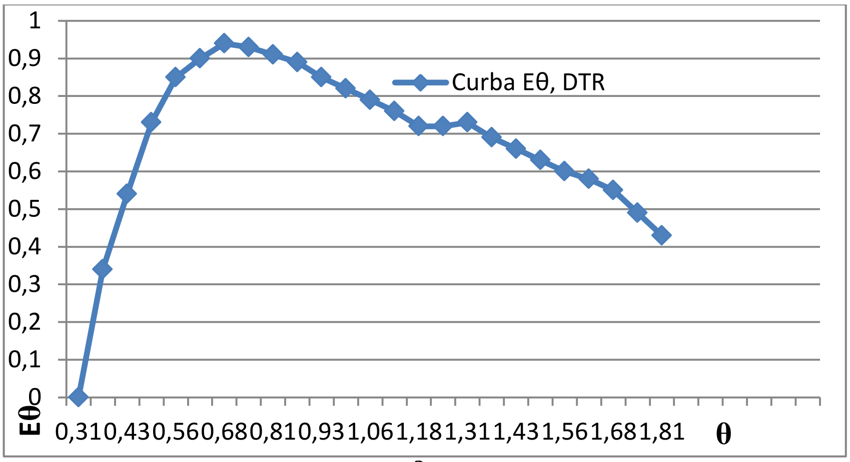

Fig. 4.46. Curve E_θ for pumped flow of 1,0 m^3/h, with the conditions - without support, with aeration, with mixing stirring, with recirculation, recirculated flow rate 3,0 m^3/h

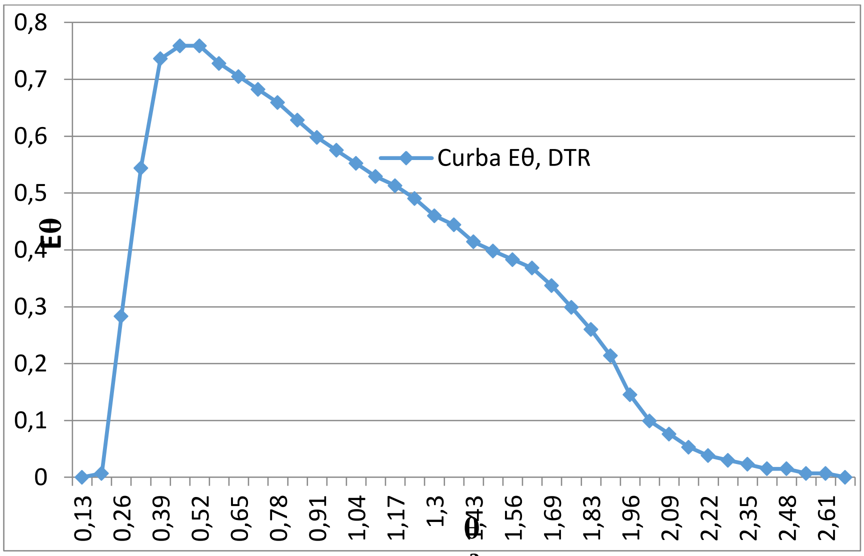

Fig. 4.49. Curve E_θ for pumped flow of 1,0 m^3/h, with conditions - with support, with aeration, with mixing/stirring, with recirculation, recirculated flow 3,0 m^3/h

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- for the removal of nitrogen and phosphorus compounds, it is necessary to compartmentalize the bioreactors for different treatment conditions (anaerobic, anoxic, aerobic) and with the recirculation of water with sludge;
- the concentrations of raw waste water vary during the day, so before biological purification it is necessary to include a reservoir for homogenizing the concentrations;
- the results obtained on the dispersion model of the fluid inside the biological reactor for the conditions of the biological reactor with mobile solid support (hybrid treatment) are close to 0,05 which demonstrates that the movement of the fluid inside this reactor tends to a small dispersion movement, i.e. the biological reactor is close to plug flow type;
- by using the mobile solid support, the air bubbles that come into contact with the water subjected to purification will have a chaotic movement, dispersing into smaller bubbles, thus the contact time with the waste water and the microflora will be much longer which will lead to the decrease of the air flow and, respectively, to the decrease of the electricity consumption;
- the results obtained in the treatment of waste water in the experimental treatment plant are of a high degree and meet the national and European design regulations, thus the sanitary opinion, the ecological opinion and the technical evaluation were obtained.

Recommendations

- for the design of these types of treatment plants (the hybrid process) the adoption of waste water retention time is equal to 3,6 hours for aerobic reactors (1,8 hours for each of the 2 aerobic compartments);
- for compartment number 1 (anoxic bioreactor) a retention time equal to 1,0 hours is proposed;
- for compartments 1 and 2 (anoxic and aerobic no. 1) to use 50% of the support of the volume of bioreactors, and for compartment 3 (aerob no. 2) to be used 60% of the support of the reactor volume, with an support area of at least 650 m^2/m^3;
- implementation of wastewater treatment plants type Vavibloc (according to the results obtained on the basis of the pilot wastewater treatment plant) to be carried out on the territory of the Republic of Moldova.

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ADNOTARE

Vîrlan Vasili, **„Tehnologii avansate în stațiile de epurare biologică a apelor uzate”**, doctor în științe tehnice, Chișinău, 2021. Teza de doctor include: adnotare în limbile română, rusă și engleză, lista tabelelor, lista figurilor, lista abrevierilor, introducere, patru capitole, concluzii generale și recomandări, bibliografie din 71 titluri, 6 anexe, 122 pagini de text de bază, inclusiv 101 figuri și 56 tabele, declarația privind asumarea răspunderii, CV-ul autorului. Rezultatele obținute sunt publicate în 11 articole științifice. Pe baza rezultatelor obținute s-a obținut un brevet de invenție.

Cuvinte cheie: epurarea apei uzate, reactor biologic, film biologic, regim hidrodinamic, instalație-pilot de epurare, mișcarea apei tip piston, suport solid mobil, epurare hibridă, trasor.

Domeniul de studiu: 211.03 – Rețele inginerești în construcții.

Scopul lucrării: obținerea unui procedeu și a unei instalații moderne de epurare a apelor uzate menajere și industriale cu caracteristicile poluanților apropiate de cele menajere, obținerea unui reactor biologic cu un volum mic și cu mișcare de tip piston a fluidului cu cantități minime a nămolului în exces și consum redus de energie.

Obiectivele cercetării: studierea metodelor de epurare biologică, studiul componenței apei uzate brute, studiul privind regimul hidrodinamic în diferite reactoare biologice, elaborarea unui reactor biologic experimental și respectarea algoritmului cercetărilor științifice ale epurării apelor uzate menajere cu ajutorul suportului solid mobil, obținerea rezultatelor pozitive privind regimul hidrodinamic și calitatea apei uzate epurate în reactorul biologic experimental.

Noutatea și originalitatea științifică: în premieră în Republica Moldova s-au efectuat studii privind regimul hidrodinamic a apei uzate în reactorul biologic. Obținerea fluxului apei uzate – aer în reactorul biologic apropiat de cel piston.

Rezultatele obținute care contribuie la soluționarea unei probleme științifice importante: a fost propus micșorarea timpului de retenție a apei uzate în reactorul biologic de tip hibrid (MBBR). Prin diferite experimente (experimental) s-a demonstrat că dispersia apei uzate – aer este foarte mică și se apropie de tip piston.

Semnificația teoretică: pe baza experimentelor au fost obținute noi cunoștințe cu privire la mișcarea apei uzate – aer în reactorul de epurare biologică de tip hibrid (MBBR) și eficiența mai înaltă a reactoarelor tip piston precum și a microflorei hibride.

Valoarea aplicativă a lucrării: obținerea unui grad înalt de epurare a apei uzate.

Implementarea rezultatelor științifice: prin rezultatele obținute s-a propus implementarea stațiilor de epurare a apelor uzate menajere și industriale tip Vavibloc în baza brevetului obținut. Pentru acest tip de stații de epurare s-a obținut aviz sanitar, aviz ecologic și evaluare tehnică.

АННОТАЦИЯ

Вырлан Василий, **„Передовые технологии в установках биологической очистки сточных вод”**, доктор технических наук, Кишинёв, 2021. Диссертация состоит из: аннотацией на румынском, русском и английском, список таблиц, список рисунков, список сокращений, введение, четырёх глав, общие выводы и рекомендации, библиография из 71 названий, 6 приложений, 122 страниц основного текста, в том числе 101 рисунков и 56 таблиц, заявление об ответственности, резюме автора. Результаты опубликованы в 11 научных статьях. На основании полученных результатов был разработан патент.

Ключевые слова: очистка сточных вод, биологический реактор, биологическая плёнка, гидродинамический режим, экспериментальная очистная установка, движение воды идеального вытеснения, подвижная биозагрузка, гибридная очистка, трассер.

Область исследования: 211.03 – Инженерные сети в строительстве.

Цель диссертацией: получение современной технологического процесса и установки очистки бытовых и промышленных сточных вод с характеристиками загрязняющих веществ близких к бытовых, получение биореактора с небольшим объемом и идеального вытеснения с минимальным количеством избыточного ила и низким энергопотреблением.

Задачи исследования: изучение методов биологической очистки, исследование состава сточных вод, исследование гидродинамического режима в различных биореакторах, разработка экспериментального биореактора и соблюдение алгоритма научных исследований очистки бытовых сточных вод с помощью мобильная биозагрузка, получение положительных результатов по гидродинамическому режиму и качеству очищенных сточных вод в экспериментальном биореакторе.

Научная новизна и оригинальность: впервые в Молдове были проведены исследования гидродинамического режима сточных вод в биологическом реакторе и получение потока сточной воды - воздуха идеального вытеснения.

Решенная научная задача: было предложено сократить время удерживания сточных вод в гибридном биологическом реакторе (MBBR). Посредством различных экспериментов было показано очень маленькая дисперсия сточных вод – воздуха, которая приближается к идеального вытеснения типу.

Теоретическая значимость: в результате экспериментов были получены новые знания о движении сточных вод - воздуха в биореакторе очистки гибридного типа (MBBR).

Практическая важность работы: высокая степени очистки сточных вод.

Внедрение научных результатов: благодаря полученным результатам было предложено внедрение очистных сооружений бытового и промышленного типа Вавиблок, для которых было получено санитарное, экологическое и техническая заключение.

ABSTRACT

Vîrlan Vasili, **„Advanced technologies in biological wastewater treatment plants"**, PhD thesis in technical sciences, Chisinau, 2021. The thesis comprises: abstract in romanian, russian and english, list of tables, list of figures, list of abbreviations, introduction, four chapters, general conclusions and recommendations, bibliography of 71 titles, 6 annexes, 122 pages of basic text, including 101 figures and 56 tables, the statement of liability, author CV. The research results were published in 11 scientific papers. Based on the results obtained, has been developed a patent.

Keywords: wastewater treatment, biological reactor, biological film, hydrodynamic regime, experimental treatment plant, plug flow water movement, fluidized packing material, hybrid treatment, tracer.

Research field: 211.03 – Engineering networks in construction.

Aim of the thesis: obtaining a process and a modern installation for domestic and industrial with characteristics of pollutants close to those of the domestic wastewater treatment, obtaining a biological reactor with a small volume and with plug flow movement of the fluid with minimal excess sludge and low energy consumption.

Objectives: study of biological treatment methods, study of the composition of wastewater, study on the hydrodynamic regime in different bioreactors, elaboration of an experimental bioreactor and observance of the algorithm of scientific researches of domestic wastewater treatment with the help of solid support, obtaining positive results regarding the hydrodynamic regime and the quality of the treated wastewater in the experimental bioreactor.

Scientific novelty and originality: for the first one in the Republic of Moldova have been developed studies on the hydrodynamic regime of wastewater in the biological reactor. Obtaining the flow of wastewater - air in the biological reactor near the plug flow.

The solved scientific problem: it has been proposed to reduce the retention time (RTD) of wastewater in the hybrid biological reactor (MBBR). Through different experiments it has been shown that the dispersion of wastewater - air is very small and approaches the plug flow.

The theoretical significance: based on the experiments, new knowledge was obtained regarding the movement of wastewater - air in the hybrid biological treatment reactor (MBBR).

Applicative value of the work: obtaining a high degree of wastewater treatment.

The implementation of scientific results: through the obtained results it was proposed the implementation of the Vavibloc type wastewater treatment plants for domestic and industrial wastewater. For this type of treatment plants (Vavibloc) was obtained sanitary opinion, ecological opinion and technical evaluation.

VIRLAN VASILI

ADVANCED TECHNOLOGIES IN BIOLOGICAL WASTEWATER TREATMENT PLANTS

211.03 – ENGINEERING NETWORKS IN CONSTRUCTION

Summary of the PhD thesis in technical sciences

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