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Analysis concerning the biological treatment of wastewater with high concentrations of ammonia nitrogen

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Abstract. The treatment of the domestic wastewaters in one biological treatment step with active sludge is limited by the practical treatment efficiency, which is max. 93%. This efficiency can provide satisfactory treatment when the wastewaters do not exceed the values from NTPA 002/2005. In case of the wastewaters that extensively exceed the values from the regulation standards and especially at the ammonia nitrogen indicator, the total efficiency called for tends to be 98% and cannot be optimally provided in one biological step, irrespective of the process applied. In this paper we set out a treatment technology in two biological steps, for domestic wastewaters with high concentrations of ammonia nitrogen, which provides an up to 98% total treatment efficiency, alongside a reduction of the specific oxygen demand from 4.3 kg O_2/kg CBO_5, as necessary for one treatment step, to 1.4 kg O_2/kg CBO_5, as needed in the two steps variant, and a reduction of the constructive equivalent total volume to 50%. The first step of biological treatment chosen is with high load aeration, where the sludge organic load ranges between 1.5 and 2 kg CBO_5/kg dry matter/day, and the second step of biological treatment with a full mixture, where the sludge organic load is between 0.2 and 0.6 kg CBO_5/kg dry matter/day. We will highlight the resemblances and the differences versus the known treatment processes, as well as the advantages and the disadvantages of the method on a practical application.
Key Words: biological treatment, organic load, efficiency, ammonia nitrogen.

Zusammenfassung. Die Reinigung von Haushaltsabwässern in einer einzigen biologischen Stufe mit Belebtschlamm wird durch die praktische Wirksamkeit der Reinigung eingeschränkt, die höchstens 93 beträgt. Dieser Wirksamkeitsgrad kann eine zufriedenstellende Reinigung sichern unter Vorbehalt, dass die Haushaltsabwässer die NTPA 002 Wertenicht überschreiten. Für Abwässer, die die Normwerte, insbesondere die des Ammoniumstickstoffes stark überschreiten, hat die Wirksamkeit sich an99% zu nähern und kann in einer rinzigen biologischen Stufe nicht gesichert werden, egal welches Verfahren angewandt wird. In dieser Studie stellen wir eine Reinigungtechnologie für Haushaltsabwässer in zwei biologischen Stufen dar, die hohe Ammoniumstickstoffgehalte aufweisen und die eine Gesamtwirksamkeit an Reinigung von bis zu 99% sichert, wobei der spezifische Verbrauch an Sauerstoff von 4,3 kg O_2/kg CBO_5, der für eine Stufe notwendig gewesen wäre, im 2-Stufen System auf 1,4 kgO_2/kg CBO_5sinkt; somit sinkt auch das bauliche Gesamtvolumen. Die erste Reinigungsstufe, für die man sich entschieden hat, ist eine stark belastete Belüftung, wobei die organische Belastung des Schlammes zwischen 1,5 und 2 kg CBO_5/kg TS/Tag, liegt. Die zweite biologische Reinigungsstufe ist ein komplettes Gemisch und die organische Belastung des Schlammes liegt zwischen 0,2-0,6 kg CBO_5/kg TS/Tag. Des Weiteren werden wir anhand einer praktischen Anwendung die Ähnlichkeiten und Unterschiede im Vergleich zu den bekannten Verfahren sowie auch die Vor- und Nachteile der Methode beschreiben.
Schlüsselworte: biologische Behandlung, organische Belastung, Wirksamkeit, Ammoniumstickstoff.

Introduction. The aim of this paper is to analyse two wastewater treatment plants with a high concentration of ammonia nitrogen having identical flow rates, loads; their total purification efficiency lies up to 98% but having different ways of construction: one works with two biological steps and the other with one biological step. Adequate technologies are to be chosen depending on the final cleaning degree that will bring the parameters of the cleared water to a quality acceptable in legal provisions. We shall calculate the volumes that are necessary. In the following we compute the volumes that are necessary with the aerobe biological steps and how much air there is to be blown and thus get an idea about the applied technologies, the constructive advantages and the stability during operation. We are also going to show a practical application that will confirm the theoretical results.

Theoretical calculation. Biological treatment is a technological process where the organic impurities of wastewaters are transformed by means of a culture of microorganisms into inoffensive degradation products, namely CO_2, mineral salts, etc. The process takes place in the presence of dissolved oxygen diffused in water by means of an air ventilation system (Robescu et al 2000).

In compliance with the legal document NP 133/2013 we calculate the dimensions of a system depending on the organic load of the sludge (I_{oN}), the organic load of the tanks (I_{oB}) and their efficiency:

$$I_{oN} = C_b/V$$

where:

C_b - quantity of biodegradable organic substance that influences the active sludge in the basin;

V - usable volume of the airing basin.

$$I_{oN} = I_{oB}/C_n$$

where:

C_n - concentration of the active sludge kg MTS/m^3;

I_{oB} - organic loading of sludge; kg CBO_5/m^3·day

$$C_b = X_{5uz} \text{ x } Q_c$$

where:

X_{5uz} - concentration in CBO_5 for the influent of the station;

Q_c – $Q_{uz\ max\ day}$.

One can get a total efficiency E_t = 98% of a biological wastewater treatment plant by using a two-step biological treatment with the following efficiencies E_1 = 80% for step one and E_2 = 91% for step 2, with $C_b = C_{b1} + C_{b2}$.

The quantity of biodegradable organic substance that is eliminated in step one (C_{b1}) is:

$$C_{b1} = C_b - C_{ev1} = 0.8\ C_b$$

where:

C_{ev1} - quantity of biodegradable organic substance eliminated in step one.

$$C_{b2} = C_{ev1} - C_{ev} = 0.2\ C_b$$

where:

C_{b2} - quantity of biodegradable organic substance eliminated in second step;

C_{ev} - quantity of biodegradable organic substance that is eliminated in the emissary.

Total efficiency is:

$$E_t = E_1 + E_2$$

where:

$E_1 = [C_b - (1\text{-}0.8)\ C_b]$;

$E_2 = [C_b(1\text{-}0.8) - (1\text{-}0.8)\ (1\text{-}0.91)\ C_b]$

This makes:

$E_1 + E_2 = [C_b - (1\text{-}0.8)\ (1\text{-}0.91)\ C_b] = C_b(1\text{-}0.02) = 98.2\%\ C_b$

In connection with these efficiencies we have the following organic loads, according to the diagram in Figure 1 (STAS 11566-91).

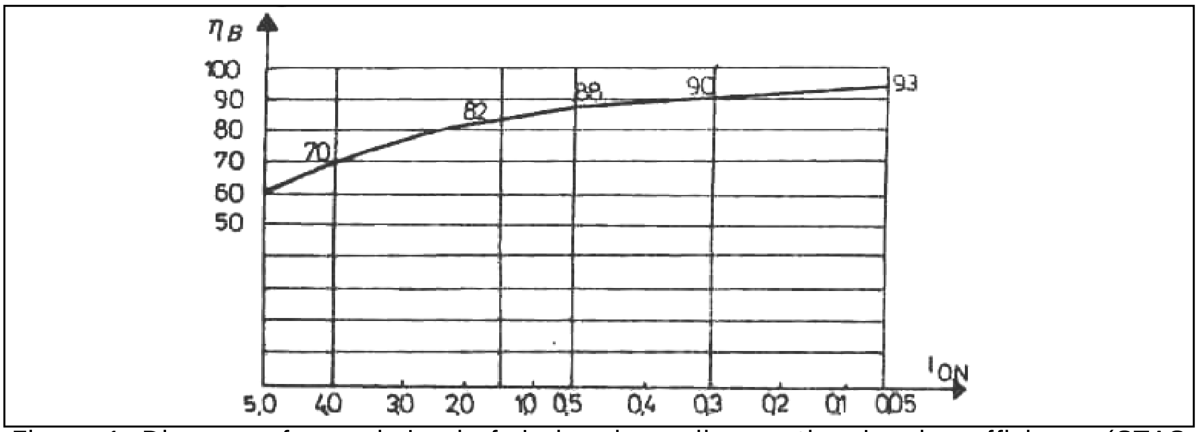

Figure 1. Diagram of organic load of sludge depending on the cleaning efficiency (STAS 11566-91 Sewerages).

$I_{oN} = I_{oB}/C_n$, where C_n is chosen between 1000-5000 mg L^{-1}. For the first step we choose 1200 mg L^{-1} and for the second step 3000 mg L^{-1}. With a one-step wastewater treatment plant we take C_n = 5000 mg L^{-1}. That means for 2 steps I_{ob1} = 3 kg/m^3 (E_1 = 80%), I_{ob2} = 0.6 kg/m^3 (E_2 = 91%) sand for step I_{oBt} = 0.2 kg/m^3 (E_t = 98%).

Changing into the volume formula we will get:

$V = C_b/I_{oB} = C_b/0.2 = 5\ C_b$ for the one-step variant;

$V_1 = C_{b1}/I_{oB1} = 0.8\ C_b/3 = 0.27\ C_b$;

$V_2 = C_{b2}/I_{oB2} = 0.2\ C_b/0.6 = 0.33\ C_b$;

$V_1 + V_2 = 0.27\ C_b + 0.33\ C_b = 0.6\ C_b$ for the two-step variant.

That means that for the two-step variant compared to the one-step variant the ratio of the volumes is:

$V/(V_1 + V_2) = 5\ C_b/0.6\ C_b = 8.3$.

These are the advantages what volumes concerns.

For the supply of oxygen (O_n) we have:

$O_n = O_{ns} \times V$ (kgO_2/day), there from:

O_{ns} = specific supply of oxygen – taken in compliance with Table 1.

Table 1

Specific supply of oxygen according to the type of biological treatment

O_{ns} (kg O_2/m^3 b.a.,day)			
Type of biological treatment			
Conventional treatment		Nitrification	Prolonged airing
$X_{5uz}^{adm} \leq 20$ mg L^{-1}	$X_{5uz}^{adm} \leq 30$ mg L^{-1}		
1.12	1.44	0.79	0.47

$O_{n2} = 1.44V_1 + 0.79\ V_2 = 1.44 \cdot 0.27 \cdot C_b + 0.79 \cdot 0.33 \cdot C_b = 0.64\ C_b$

$O_{n1} = 0.47\ V = 0.47 \cdot 5 \cdot C_b = 2.35\ C_b$

It follows from this that the supply of oxygen necessary is $O_{n1}/O_{n2} = 3.67$.

This calculation shows that for the two-step purification technology one needs basins with volumes up to 8.3 smaller and an oxygen supply of 3-4 smaller.

The first biological treatment step that was chosen for an efficiency of 80% has a high aeration load where the organic load of the sludge lies between 0.5 and 2 kg CBO_5/kg dry matter/day and the organic load of the basin is between 1.2 and 3 kg CBO_5/m^3/ day; the second biologic treatment step that was chosen for an efficiency of 91% is with a complete mixture, where the organic load of the sludge lies between 0.2-0.6 kg CBO_5/kg dry matter/day and the organic load of the basin between 0.3 and 1.6 kg CBO_5/m^3/ day. We are going to highlight the advantages of this plant compared to the one-step plant where, for an efficiency of 98%, we shall choose the prolonged airation treatment where the organic load of the sludge is 0.04 kg CBO_5/kg dry matter/day and the organic load of the basin lies between 0.1 and 0.3 kg CBO_5/m^3/day.

Practical application

1. Wastewater treatment plant with two aerobe biological steps

Entrance data. The wastewater treatment plant is designed to process a flow of wastewater $Q_{uz\ max}$ = 54 m^3/day and is made up of a entrance pit, an anoxic basin (that is in the same time a basin for equalization and a water homogenizer), the aerobe basin step 1, the aerobe basin step 2, a secondary decanter, a flow measurement device and a pit to evacuate waste water (Technical Project 287/2013).

Characteristics of waste water. The maximum loads of polluting elements at the entry of the treatment plant are usually compliant to NTPA 002/2005 – quality indicators of waste water poured into the sewerage nets of communities. As the values obtained through sample taking in the case of ammonia nitrogen exceed a great deal the maximum tests of pollutants according to NTPA 002/2002, we will take into account the medium values we got through sample taking for the entrance water, thinking of the accumulation possibilities of the homogenizing and uniformisation tank of the flow (Table 2). The content of carbon was rectified in order to equilibrate the C:N:P ratio, that is needed to clear the ammonia nitrogen in excess.

Table 2

Entrance characteristics of the waste water

Parameter	*Value (mg L^{-1})*	*Value after adding the nutrient (mg L^{-1})*
CCO-Cr	550	1530
CBO_5	390	1370
TSS	350	350
NH_4^+	70	70
P_{tot}	4	4

The discharge conditions into the emissary that are settled in ***NTPA 001/2002- limit values of the loading values of pollutants of waste water poured into natural receptors (Table 3).

Table 3

Characteristics of the treated water

Quality indicator	*Unit.*	*Acceptable limit values*	*Analysis method*
pH	pH units	6.5-8.5	SR ISO 10523-97
Suspension matters (MS)	mg/dm^3	35	STAS 6953-81
Biochemical oxygen consumption at each 5 days CBO_5	mg O_2/dm^3	25	STAS 6560-82
Biochemical oxygen consumption CCO-Cr	mg O_2/dm^3	125	SR ISO 6060-96
Ammonia nitrogen (NH_4^+)	mg/dm^3	2	STAS 8683-70
Total phosphorus (P)	mg/dm^3	1	SR EN 1189-99

Clearing load of the plant. The data concerning waste water quality, loads and efficiency of the plant on each clearing step are shown in Table 4.

In the mechanical step the load of the wastewater treatment plant slightly diminishes through the grid basket, as there is no primary decantation. The main objects of the plant are placed according to the technological schedule in Figure 2.

Table 4

The waste water quality, loads and efficiency of the plant on each clearing step

Parameter	*Value Step 1 (mg L^{-1})*	*Load of waste water step 1 (kg day^{-1})*	*Efficiency Step 1 (%)*	*Value Step 2 (mg L^{-1})*	*Load of waste water step 2 (kg day^{-1})*	*Efficiency Step 2 (%)*
CCO-Cr	1530	82.60	75.0	382.50	20.65	68.0
CBO_5	1370	74.00	80.0	274.00	14.80	91.0
MTS	350	18.90	0.0	350.00	18.90	83.0
NH_4^+	70	3.80	77.0	16.10	0.87	87.5
P_{tot}	4	0.2	60.0	1.6	0.09	37.5

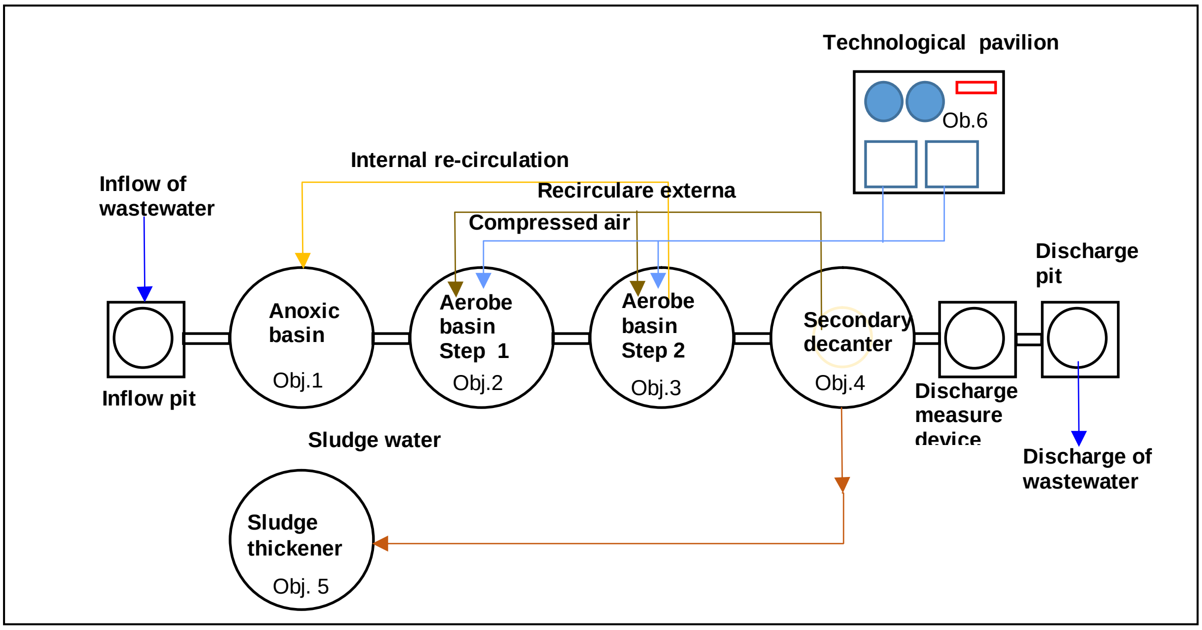

Figure 2. Technological schedule.

The main phases of the clearing process (Technical Project 287/2013) are:

- accumulation, equalization, compensation, homogenization and pumping;
- biological treatment – mitigation of organic carbon, nitrogen and phosphor;
- measuring of cleared water;
- thickening of the remaining sludge.

Object 1 is made up of:
- *anoxic basin* – a basin where wastewater flows and where it is separated from gross suspension by means of a grid basket that is cleaned manually; then the water is homogenized with a submersible mixer, the basin has also the role of an anoxic step.
Objects 2 and 3 are aerobe biological steps functioning successively and are made of:
- *aerobe step 1*, aeration compartment with active sludge that is equipped with an aeration network of fine bubbles;
- *aerobe step 2*, aeration compartment with active sludge and an air-lift pump for the re-circulation of water in the anoxic step in order to eliminate nitrites and nitrates.
Object 4 is a basin made up of:
- *vertical secondary decanter* – the basin having re-circulation pumps of the active sludge in the biologic compartments of lines 1 and 2 and for the discharge of the excess sludge in the sludge thickener compartment.
- *flow measurement step* **–** is a pit where they mount an electromagnetic discharge measure device.
Object 5 is made up of a basin where the sludge is thickened.

Object 6 is a container with dosage devices for reagents, compressed and the automation control of the plant.

Functioning principle of the modular wastewater treatment plant. The wastewater flows through a grid basket into an accumulation-homogenization basin. In this basin they make the dosage of organic substances that contribute to CCO-Cr, in this case technical alcohol. Here the water is mixed with the re-circulated water in aeration basin 2 and after that it enters the aeration basin 1. From the grid basket the solid matters are withheld and taken from time to time and poured directly in a waste container.

The aeration basins that make up the two steps are endowed with aeration diffusors with fine bubbles with oxygen controlled and sensor regulated flow. The air is supplied by blowers that are placed in the technologic pavilion. A part of the water that is loaded with nitrates from the aeration basin 2 and is re-circulated in the anoxic basin. An aeration period of about 9.5 hours can be granted. In order to ensure dissolved oxygen, that is necessary for the biologic processes, they planned a flow of air of e 150 m^3 air/h.

In the following the mixture of water with active sludge flows under the influence of gravitational force into the secondary decanter where the solid separates from the liquid by sedimentation. The sludge is taken from the secondary decanter by a re-circulation pump and a pump for excess sludge. The excess sludge is driven to the storage and sludge thickener basin. The water flow is measured by means of an electromagnetic discharge measure device after it comes out from the secondary decanter and after that the water is poured out in the emissary of the discharge pit.

2. The wastewater treatment plant with one aerobe treatment step. With the wastewater treatment step with a single aerobe treatment step we chose the same entrance data and the same outflow conditions. The main objects of the plant are placed according to the technological schedule in Figure 3.

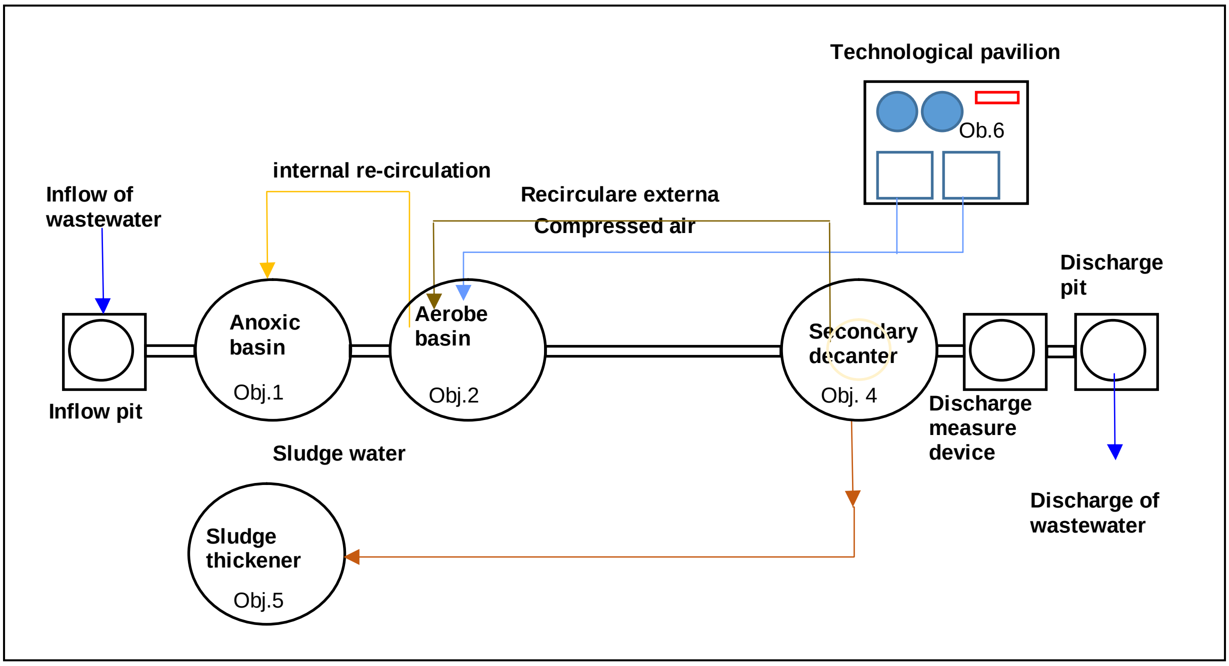

Figure 3. Technological schedule of a plant with one biological step.

Analysis of the treatment efficiency

A) With the two-steps wastewater treatment plant. For the first treatment step we take *the heavy load aeration* having a smaller efficiency. When choosing the technology we take into account the fact that the load of wastewater is heavy after carbon is brought from the exterior. The dimensioning calculation (Dima 2005) for the first step is:

- organic load of the sludge step 1: I_{ON} = 2 kg CBO_5/kg MTS_V.day;
- the concentration of the sludge in the aeration of step 1: C_N 1.5 kg s.v./m^3 (is chosen);
- organic load of the basin of step 1: I_{OB} = I_{ON} x C_N = 2x1.5 = 3 kg CBO_5/ m^3·day;
- quantity of organic substance entered with step 1: L_{5B} = 74 kg CBO_5/day
- the volume of the biological aeration basins step 1: V = L_{5B}/I_{OB} V = 24.6 m^3;
- we choose a volume of 2x16 m^3;
- total quantity of active sludge in the aeration basin: G_{NV} = L_{5B}/I_{ON} = 37 kg;
- the aeration time with step 1 is: t = V/Q med/h = 16 mc/1.67 m^3/h = 9.58 h;
- oxygen necessary for biological processes in step 1:

$$ON = a\frac{\eta_B}{100_{5B}} + bG_{NV} + c(N_i - N_e) = 0.5\text{x } 59.2 + 0.15 \text{ x } 37 + 3.4 \text{ x } 2.93 = 45.11 \text{ kg day}^{-1}$$

where:

a - breathing coefficient of the substrate (0.5 for household wastewater);
$\eta_B/100_{5B}$ – efficiency of the biological step;
b - endogen breathing coefficient (interval 0.15-0.17);
c - breathing coefficient of the substrate with the nitrification process;
N_i - the influent quantity of ammonia nitrogen;
N_e - the enfluent quantity of ammonia nitrogen.

- oxygenation capacity with step 1: CO = ON x 1.43 = 64.5 kg day^{-1};
- quantity of air necessary when using aeration with fine bubbles in step 1: $Q_{air\ T1\ L1}$ = 64.5x1000/(17x3.7) = 1025 mc day^{-1}.

For step two of the treatment we choose the complete mixture technology. The dimensioning calculation for step two is:

- organic load of the sludge step 2: I_{ON} = 0.2 kg CBO_5/kg MTS_V.day;
- the concentration of the sludge in the aeration of step 2: C_N 3 kg s.v./m^3 (is chosen);
- organic load of the basin of step 2: I_{OB} = I_{ON}xC_N = 0.2.x 3 = 0.6 kg CBO_5/ m^3·day;
- quantity of organic substance entered with step 2: L_{5B} = 15.12 kgCBO_5/day;
- the volume of the biological aeration basins step 2: V = L_{5B}/I_{OB} V = 25.2 m^3;
- total quantity of active sludge in the aeration basin: G_{NV} = L_{5B}/I_{ON} = 75.6 kg;
- the aeration time with step 2 is: t = V/Q med/h = 25.2 mc/1.67m^3/h = 15.1 h;
- oxygen necessary with step 2: ON = 0.5 x 13.8 + 0.15 x 75.6 + 3.4 x 0.76 = 20.8 kg day^{-1};
- oxygenation capacity with step 2: CO = ON x 1.43 = 29.7 kg day^{-1};
- quantity of air necessary when using aeration with fine bubbles in step 2: $Q_{air\ T2\ L1}$ = 330.6 m^3/h.

B) With the wastewater treatment plant of a single step. For the wastewater treatment plant with a single step we choose the *prolonged aeration* technology. We calculated the following dimensions:

- organic load of the sludge: I_{ON} = 0.04 kg CBO_5/kg MTS_V.day;
- the concentration of the sludge in the aeration: C_N = 5 kg s.v./m^3 (choose maximum);
- organic load of the basin: I_{OB} = I_{ON}xC_N = 0.2;
- quantity of organic substance: L_{5B} = 74.0 kgCBO_5/day;
- the volume of the basin step: V = L_{5B}/I_{OB} V = 370 m^3;
- total quantity of active sludge: G_{NV} = L_{5B}/I_{ON} = 1850 kg;
- aeration time: t = V/Q med/h = 352 m^3/2.25m^3/h = 221 h;
- oxygen necessary for biological processes: ON = 0.5 x 72.5 + 0.15 x 1850 + 3.4 x 3.69 = 276.3 kg day^{-1};
- oxygenation capacity: CO = ON x 1.43 = 395.1 kg day^{-1};
- quantity of air necessary when using aeration with fine bubbles in step:
$Q_{aer\ T2\ L1}$ = 395.1 x 1000/17 x 3.7 = 6281 m^3/day.

The total volume of the wastewater treatment plant with two steps is of 50 m^3, and the air needed is 1355.6 m^3/day.

The volume needed for the biological step of the wastewater treatment plant is of 370 m^3, the air needed is of 6281 m^3/day.

We can state that the ratio of volumes of the biological steps in the two cases is 7.4 in favour of the wastewater treatment plant in two steps; the ration of the air needed for oxygenation is 4.6 in favour of the 2 steps wastewater treatment plant.

Compared to the theoretic calculation we found that the practical application showed an even better ratio for oxygen consumption due to the important loads with CBO_5 that results in the compensation of the quantity of organic carbon, so that the C:N:P ratio of waste water should be at its best (to draw close to 100:5:1).

For the wastewater treatment plant with two steps we got the following characteristics of treated water (we checked in the time January – March 2014) (Figures 4-7).

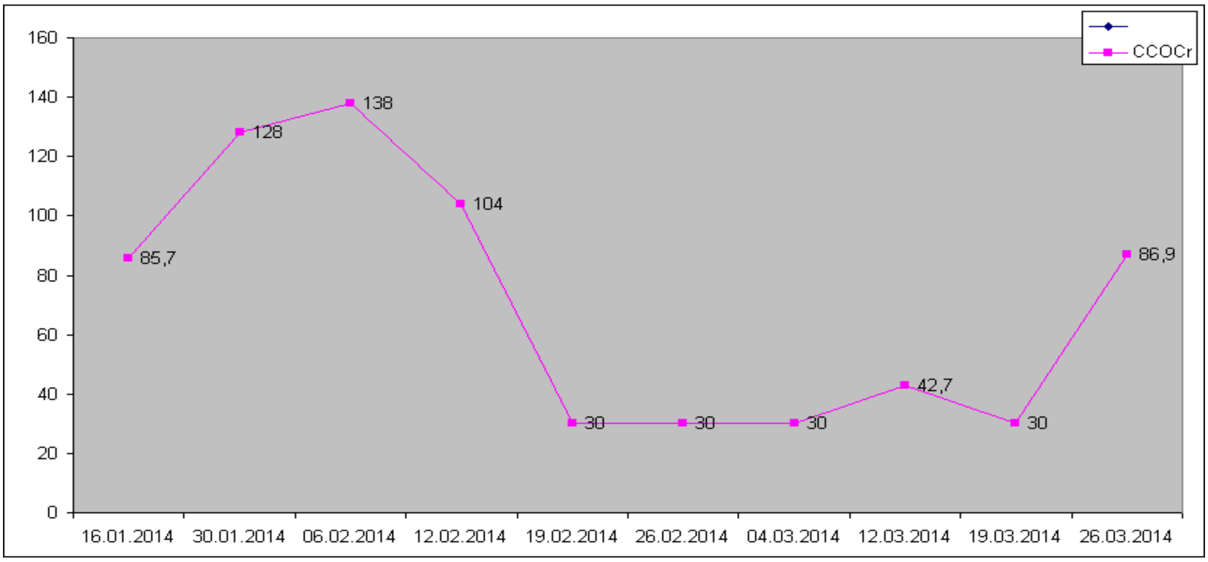

Figure 4. Variation of the CCO-Cr parameter between January and March 2014.

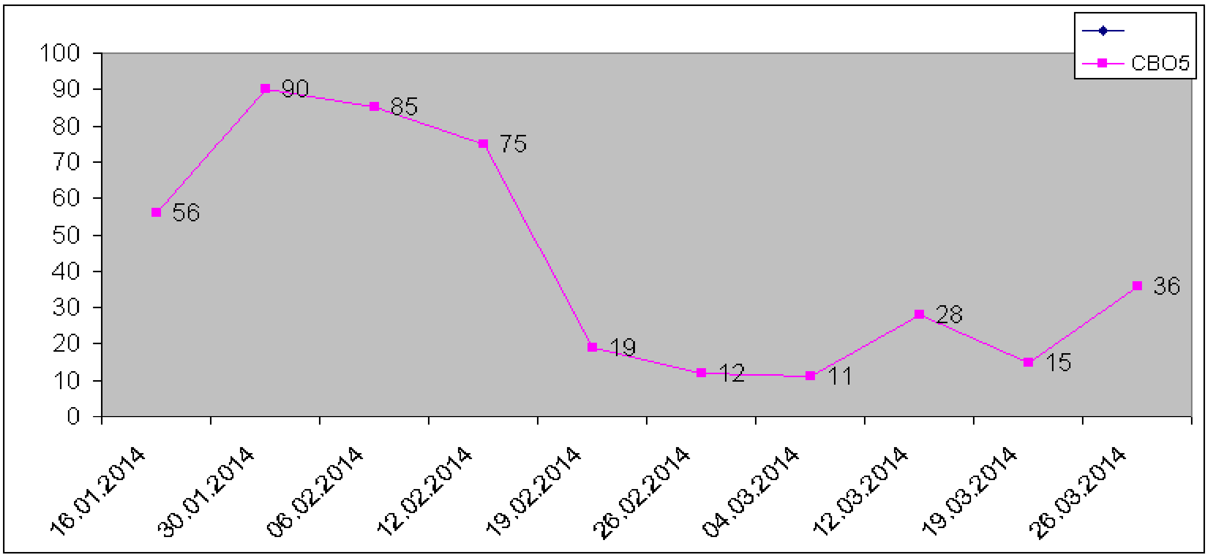

Figure 5. Variation of the CBO_5 parameter between January and March 2014.

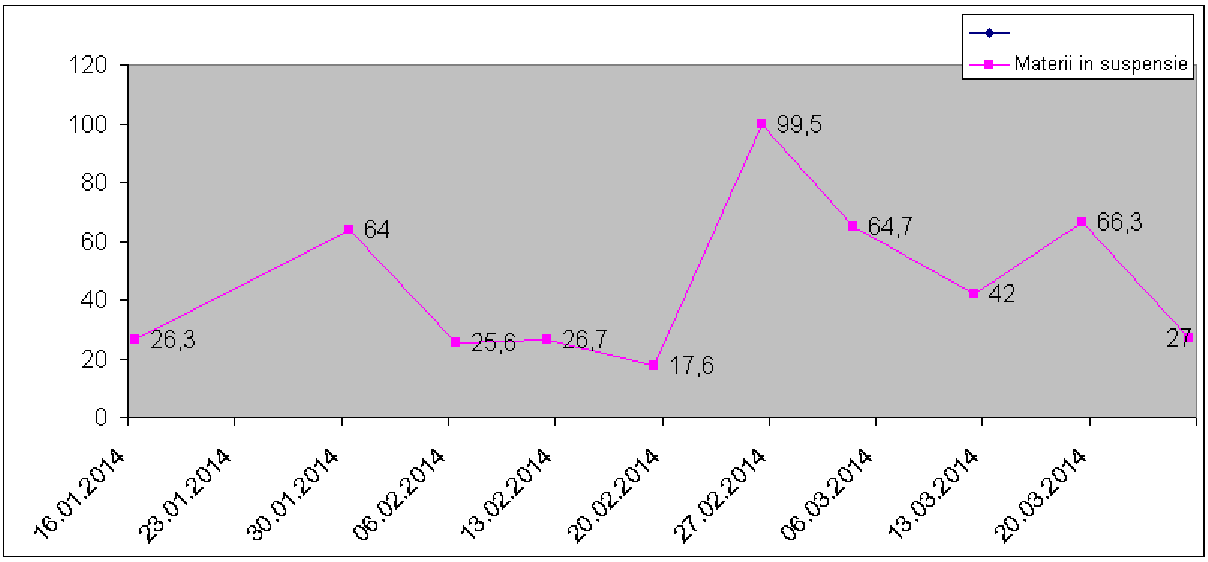

Figure 6. Variation of the suspension matter parameter between January and March 2014.

Conclusions. In the case of household waste water with a high load of ammonia nitrogen we could prove theoretically and check in practice that a wastewater treatment plant in two steps is more advantageous from the point of view of technology, construction and economy. As in rural areas the ammonia nitrogen in the waste water exceeds the limits as per NTPA 002/2005, on the basis of which 1-step wastewater treatment plants are projected and built, after they have been commissioned they do not reach the purification grade that is necessary to pour the water into an emissary. This situation means that major construction changes should be carried out with the 1-step wastewater treatment plants or reduced should they choose the 2-step biological wastewater treatment.

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*** Legal regulation NP 133/2013 – Legal regulation concerning the design, execution and running of water supply systems and sewerage of localities.

*** Standard STAS 11566/91 – Active sludge basins.

*** Standard STAS 11566/91 – Sewerages. Activated sludge basins- General design specifications

***Standard SR ISO 10523-12 Determination of pH.

*** Standard STAS 6953-81 Determination of suspended solids.

*** Standard SR EN 1899-1 Determination of biochemical oxygen demand after 5 days.

*** Standard SR ISO 6060-96 Determination of chemical oxygen demand.

*** Standard SR ISO 7150-1 Determination of ammonium content.

*** Standard SR EN ISO 6878-8 Determination of determination of phosphorus.

*** Legal regulation NTPA 002/2005 – Concerning the conditions of evacuating wastewater into the sewage net of localities or directly into treatment plants

*** Technical Project 287/2013 – Extention of the wastewater treatment plant of S.C. REXROTH BOSCH GROUP S.R.L. – Blaj.

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