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PERFORMANCE OF COMPLETE-MIX AND PLUG-FLOW SYSTEMS DURING TREATMENT OF LOW LOADED NITROGEN DEFICIENT WASTE WATER – SIMULATION WITH ASAL1 MODEL

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Abstract: *Based on Modified Ludzack-Ettinger process, the performance of biological complete-mix and plug-flow units are compared during simulative treatment of low loaded nitrogen deficient wastewater. BOD-based model ASAL1 is applied. Different variants of nitrogen deficiency, Anoxic-Aerobic volume distributions, as well as diverse $SSVI_{3.5}$ are manipulated.*
It is shown that plug-flow reactors give better effluent quality over complete-mix systems in relation to indicators: total nitrogen, total BOD and total suspended solids. Nitrogen removal is primarily diminished with the increase of Anoxic against Aerobic zone, while $SSVI_{3.5}$ up to 200 ml/g has a less pronounced effect on this parameter. However,the optimal nutrient composition gives the lowest nitrogen in the outcome stream – 95.53 % for plug-flow and 94.75 % for complete-mix series.

Keywords: *biological nitrogen removal, complete-mix, plug-flow, STOAT, ASAL1*

1.Introduction

Elevated amounts of nitrogen compounds in wastewaters have harmful influence over the life in aquatic ecosystems. To meet water quality standards different methods for nitrogen removal are applied [1,2]. Common technologies include activated sludge processes with various nitrification and denitrification steps realized as complete-mix or plug-flow reactors [3,4,5]. One of the most widespread systems is modified Ludzack-Ettinger process where nitrogen removal is carried out in pre-anoxic and aerobic zones without the necessity of easily biodegradable carbon supplementation [6].

Nevertheless beneficial effects of biological nitrogen elimination, microorganisms involved in activated sludge have special requirements on the basis of wastewater composition. Proper biomass development and effective contaminant elimination requires the BOD:N:P ratio in the secondary influent to be 100:5:1 [7]. However, many sewage and industrial waste streams are below such ratio, including food production ones with high nitrogen deficiency – brewery, fruit processing, beverage [8,9,10], which can lead to operational problems and low quality effluents [11].

Laboratory investigations of many different conditions on the behavior of wastewater treatment plant during purification of high BOD:N containing wastewater is an expensive and time-consuming work. It can be realized considerably faster with the application of mathematical modeling of biological nitrogen removal [12], where diverse initial conditions can be applied

within models for various design options and analyses.
The aim of this work is to simulate and compare the performance of complete-mix and plug-flow systems in the treatment of low loaded wastewater with diverse amounts of nitrogen deficiency.

Nomenclature

BOD – biological oxygen demand
MLSS – mixed liquor suspended solids
$SSVI_{3.5}$ – stirred sludge volume index at MLSS 3500 mg/dm^3
WRc – Independent Centre of Excellence for Innovation and Growth

2.Methods

2.1. Biological unit description

The biological wastewater treatment unit is designed graphically in the modeling and simulation environment STOAT® 5.0 [13] to purify wastewater with a constant flow-rate of 2400 m^3/d (Fig. 1).

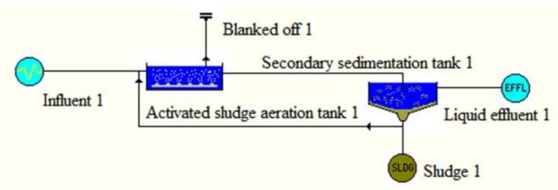


Figure 1. Schematic representation of biological wastewater treatment unit in STOAT®.

It consists of a biological activated sludge reactor with a total working volume of 1000 m^3 and a secondary sedimentation tank with a surface area of 500 m^2. Initial conditions for activated sludge reactor and secondary sedimentation tank are represented in Table 1.
Activated sludge reactor is divided into Anoxic and Aerobic zones (A/O) on the basis of modified Ludzack-Ettinger process. Three A/O percent volume ratios are investigated: 25/75, 50/50 and 75/25.

Sludge wastage and internal cycle flow-rates are 5 m^3/h and 500 m^3/h, respectively. These parameters are maintained constant in all simulation variants.

Table 1. Initial conditions in: a) activated sludge reactor; b) secondary sedimentation tank.

a)

Parameter	Anoxic stage	Aerobic stage
Soluble BOD, mg/dm^3 O_2	5	5
NH_3, mg/dm^3	1	1
Dissolved oxygen, mg/dm^3	0	2
MLSS, mg/dm^3	3000	3000
Viable autotrophs, mg/dm^3	100	100
Viable heterotrophs, mg/dm^3	1000	1000

b)

Parameter	Stages		
	1-3	4-7	8
Soluble BOD, mg/dm^3 O_2	5	5	5
NH_3, mg/dm^3	1	1	1
Dissolved O_2, mg/dm^3	2	2	2
MLSS, mg/dm^3	0	300	6000
Viable autotrophs, mg/dm^3	0	100	2000
Viable heterotrophs, mg/dm^3	0	10	200

2.2. Wastewater treatment plant modeling

WRc's activated sludge model: ASAL1 is chosen as a model for the description of bacterial growth and decay processes, both of autotrophs and heterotrophs. It is BOD-based and is recommended for normal activated sludge processes with hydraulic retention time higher than 4 h and NH_3 concentration lower than 40 mg/dm^3. The model is applied for complete-mix and plug-flow reactors according to author's instructions [13]. ASAL1 works with the respective settling tank model: SSED1.
Model ASAL1 doesn't include the growth and decay of filamentous microorganisms, solely, although these heterotrophs directly affect development of activated sludge with good settling properties in high BOD/N ratios. Activated sludge bulking as a result of nitrogen deficite in wastewater is achieved with the variation in $SSVI_{3.5}$, being higher than 150 ml/g.

2.3. Influent characterization

The wastewater characteristics include BOD-based profile for constant influent pattern, included in STOAT®. Influent indicator values are pointed at Table 2.

Table 2.

Influent characteristics

Parameter	Value
Flow, m^3/h	100
Temperature, °C	15
Soluble BOD, mg/dm^3 O_2	150
Particulate BOD, mg/ dm^3 O_2	90
Volatile solids, mg/dm^3	180
Non-volatile solids, mg/dm^3	60
NH_3, mg/dm^3	vary, according to BOD/N ratio

Assuming that free NH_3 in the influent at pH 7 and temperature 15° C is negligible small (less than 0.0027 $mole/dm^3$), nitrogen concentration is calculated on total BOD basis for BOD/N ratio: 100/5, 100/3 and 100/1, respectively, in the form of NH_4^+-N. All other parameters, included in the model, are kept at default values.

3. Results and discussion.

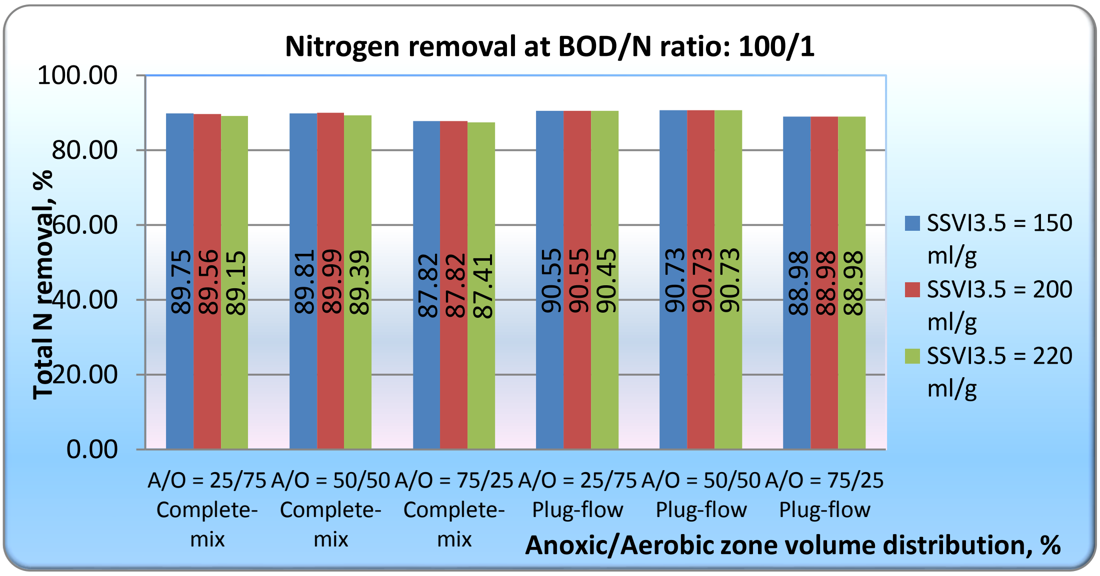
In a set of 48 h simulations the ability of complete-mix and plug-flow activated sludge units to remove nitrogen from low nutrient wastewater is investigated. In addition, 25/75, 50/50 and 75/25 A/O volume distributions and different $SSVI_{3.5}$ values are analysed. Summarized results are presented in Fig. 2a, Fig. 2b and Fig. 2c. Model data show high purification levels over 70 %. Close results are obtained for complete-mix and plug-flow reactors in all BOD/N ratios. However, plug-flow units show slightly better performance over complete-mix series which is probably due to the reactor differences in equation for steady state effluent concentration, described by [14]. Exceptions are at BOD/N ratio: 100/3 and at BOD/N ratio: 100/5, both with Anoxic/Aerobic volume relation: 75/25 in the range of 2.5 and 5.9 %, respectively higher than other variants (Fig. 2b, Fig. 2c).

Low effluent nitrogen is a result of consecutive NH_3 oxidation and NO_3^- reduction from wastewater, which can be achieved with proper Anoxic/Aerobic volume calculations. Results obtained show that lower or equal dimensions of Anoxic basin towards Aerobic give better performance of biological nitrogen removal unit, notwithstanding the reactor type. This counteracts with the conclusions, received by [15] and [16], where optimal A/O ratios are 0.75 and 0.64, respectively. However, the mentioned authors analyse processes with sufficient amount of influent nitrogen.

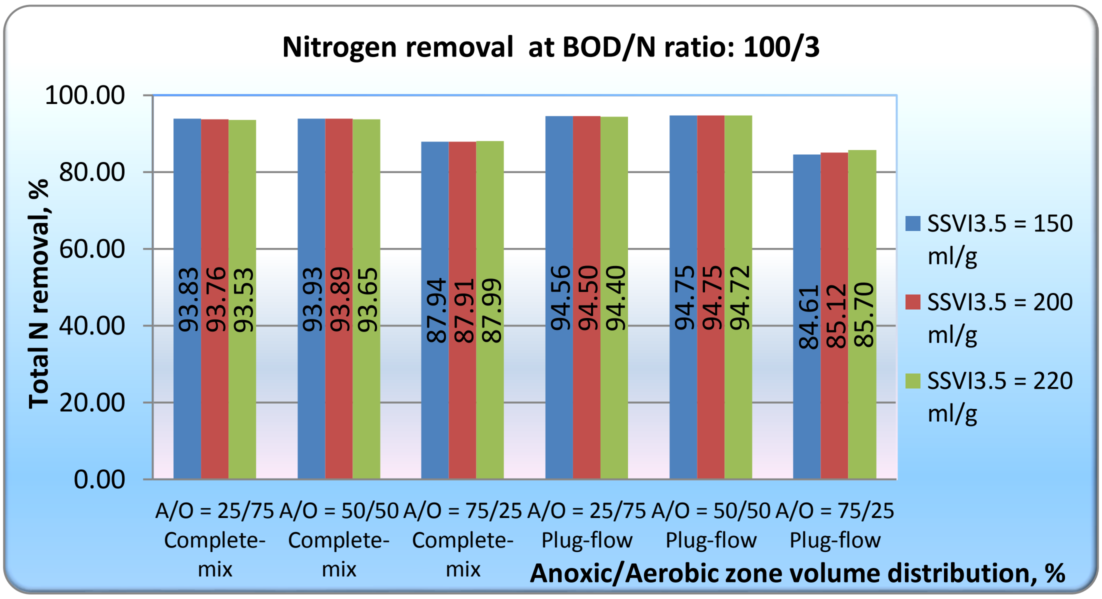
At analysed BOD/N ratios exceptions are also observed, but the differences are less of the percent (Fig. 2a, Fig. 2b, Fig. 2c). Switching to bigger Anoxic vs. Aerobic zone reflects over NH_3 transformation into NO_3^-, which rises total N in the effluent. This process is apparent at the highest BOD/N ratio with differences over 16 % for complete-mix and more than 22 % for plug-flow reactors against other two A/O zones (Fig. 2c).

To simulate the effect of sludge bulking $SSVI_{3.5}$ values of 150, 200 and 220 ml/g at which effluents fit standards for total nitrogen, total BOD and total suspended solids are explored (Fig. 2a, Fig. 2b). Obtained results show that development of filamentous organisms in large numbers doesn't reflect nitrogen removal capacity of the system for the investigated $SSVI_{3.5}$ interval and period of simulations.

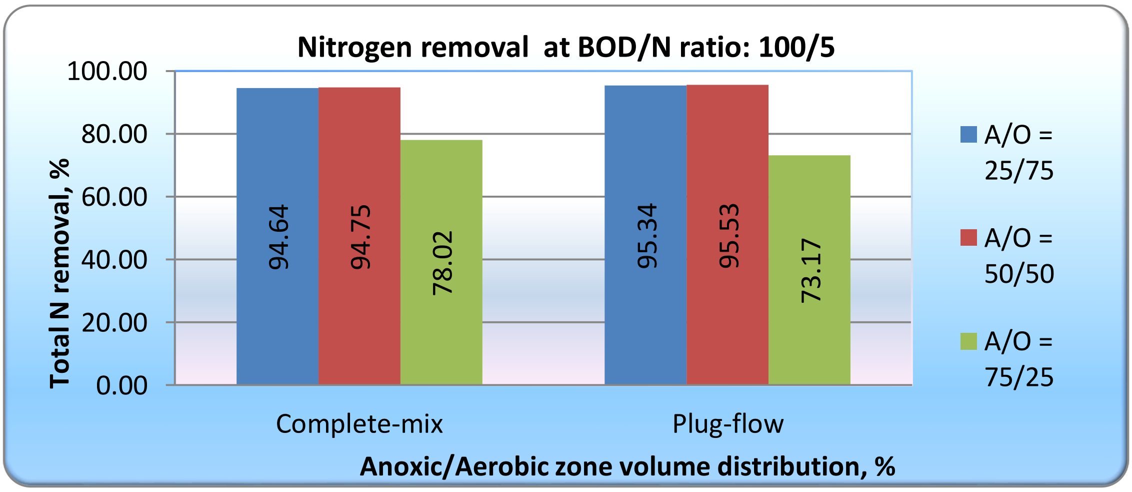
The highest nitrogen removal is achieved at optimal BOD/N ratio 100/5 and equal A/O volumes – 95.53 % for plug-flow reactor and 94.75 % for complete-mix unit (Fig. 2c).



a)



b)



c)

Figure 2. Total nitrogen removal in biological complete-mix and plug-flow unit from wastewater with BOD/N ratio: a) 100/1; b) 100/3; c) 100/5.

At BOD/N ratio 100/3 the best nitrogen reduction is the same for plug- flow reactor with A/O ratio 50/50 at $SSVI_{3.5}$ from 150 to 200 ml/g – 94.75 %. Complete-mix system gives better performance at equivalent A/O volume and $SSVI_{3.5}$ 200 ml/g – 93.89 % (Fig. 2b). At BOD/N ratio 100/1 the lowest nitrogen values are obtained with identical A/O ratios at all three $SSVI_{3.5}$ – 90.73 %. Complete-mix type achieves 89.99 % at same A/O distribution and $SSVI_{3.5}$ 200 ml/g (Fig. 2a).

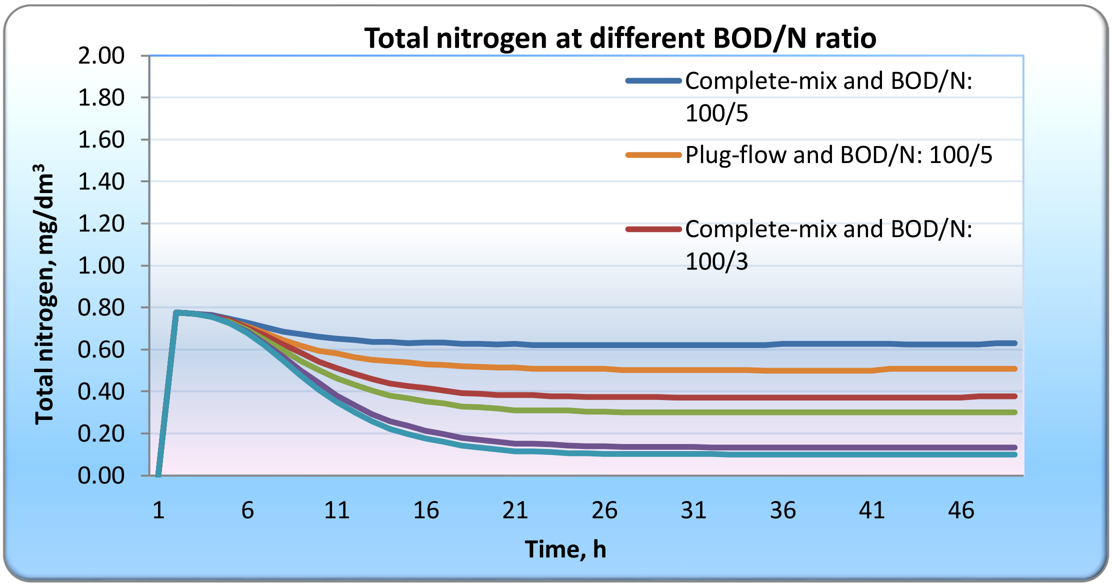


Figure 3. Total nitrogen in the effluent at different reactor system and BOD/N ratio.

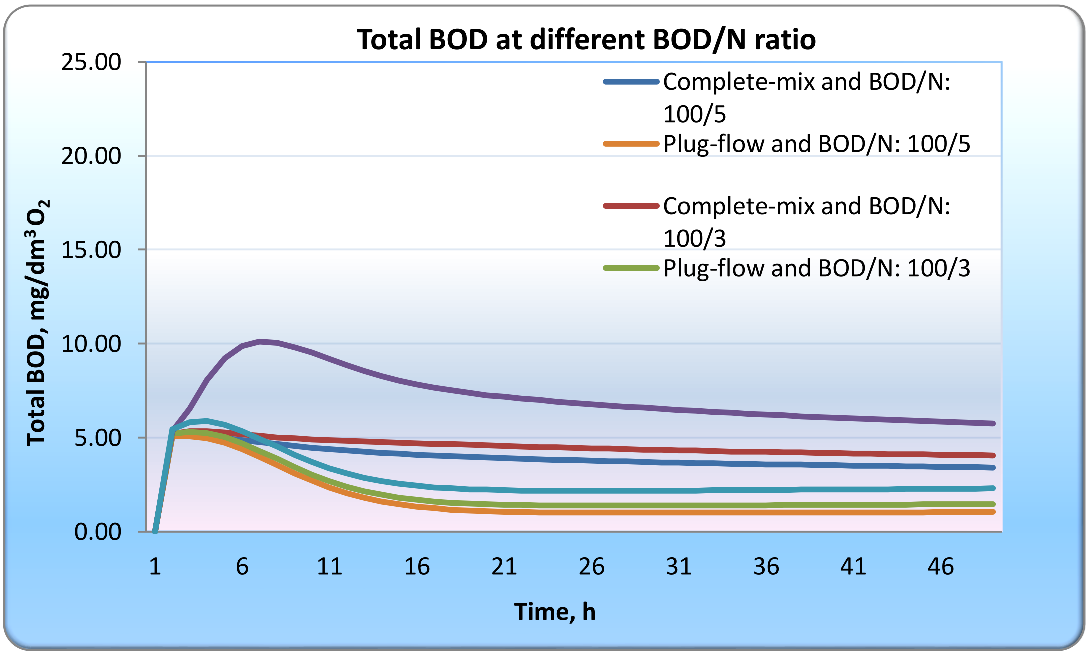


Figure 4. Total BOD in the effluent at different reactor system and BOD/N ratio.

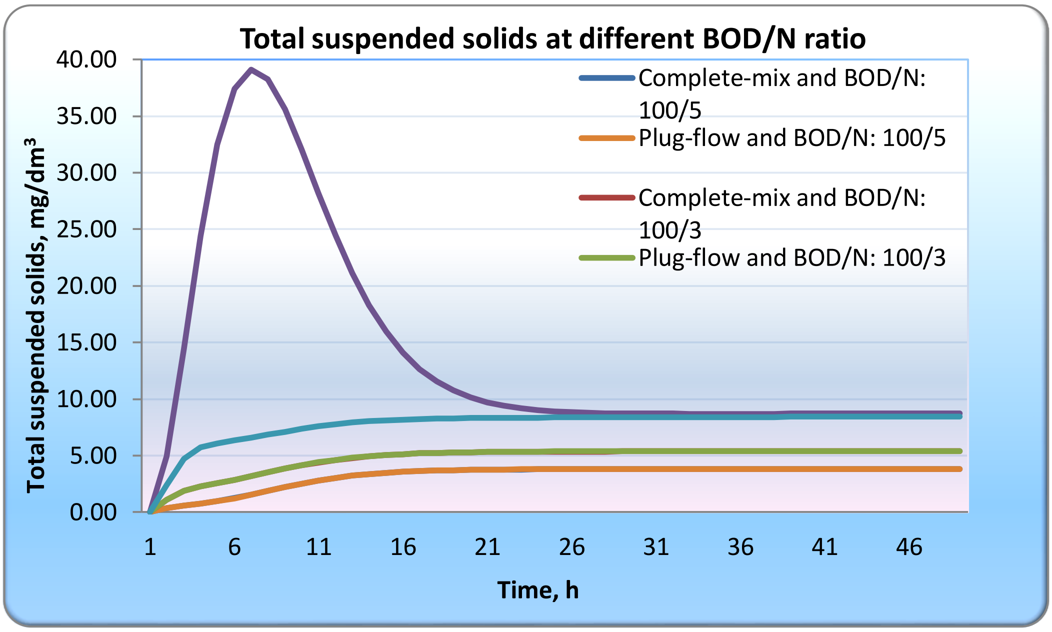


Figure 5. Total suspended solids in the effluent at different reactor system and BOD/N ratio.

A comparison between 48 h effluent profiles is done for the best obtained values from complete-mix and plug-flow reactors for all BOD/N ratios. The obtained results are represented in Fig. 3, Fig. 4 and Fig. 5. Analysed indicators: total nitrogen, total BOD and total suspended solids from all variants cover European standards for effluent quality from wastewater treatment plants – 2 mg/l, 25 mg/l O_2 and 35 mg/l, respectively [17]. Furthermore, total nitrogen concentration in the purified wastewater is less than 0.7 mg/l (Fig. 3). Nevertheless, it should be taken into account that very low effluent nitrogen under 0.5 mg/l can provoke additional sludge bulking even in well performed wastewater treatment plant [18].

Better performance of plug-flow reactors over complete-mix ones have been achieved in all simulation series, which confirms the comparative statements of the two systems, summarized by [11]. Stationary conditions in total nitrogen removal are attained after 21^{st} h. Only complete-mix system for BOD/N: 100/5 reaches earlier equilibrium – after 11^{th} h (Fig. 3). Obtained result may be explained with optimal nutrient composition of the wastewater.

Plug-flow systems don't differ too much in their effluent BODs. Faster substrate biodegradation by heterotrophs corresponds with earlier BOD balance in the outgoing stream, gained between 16^{th} and 21^{st} h (Fig. 4). Complete-mix units don't reach dynamic equilibrium for 48 h. Only the effluent at BOD/N: 100/1 has two times higher BOD loading at 7^{th} h in comparison with the other ideal-mixed reactors. The result is connected with the bulking sludge which increases particular BOD, giving higher total BOD in the effluent (Fig. 2a, Fig. 4).

Complete-mix and plug-flow series for BOD/N ratios: 100/5 and 100/3 are equal in their effluent profiles for total suspended solids. Average balance is reached around 21^{th} h. At BOD/N: 100/1 the plug-flow unit follows the same behavior. In contrast, bigger $SSVI_{3.5}$ overloads the complete-mix system – about 4 h total suspended solids are over permissible for the effluent quality – 35 mg/dm^3 (Fig. 5).

4. Conclusion

As a result of investigated analyses on the biological nitrogen removal in complete-mix and plug-flow reactors the following more important conclusions can be made:
1. Plug-flow reactors give better performance over complete-mix units with lower effluent concentrations of total nitrogen, total BOD and total suspended solids;
2. Better nitrogen removal can be achieved if Anoxic basin is smaller or equal to Aerobic;
3. Rising $SSVI_{3.5}$ up to 200 ml/g doesn't affect nitrogen elimination from wastewater;
4. The best nitrogen removal is reached in a plug-flow reactor with equal Anoxic and Aerobic zones, at optimal nutrient composition BOD:N = 100:5 – 95.53 %.

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