

Original Research

Evaluation of Anaerobic-Aerobic Wastewater Treatment Plant Operations

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Abstract

Seven small wastewater treatment plants were chosen for evaluation. These WWTPs work on the principle of anaerobic pre-treatment and aerobic post-treatment and were made with the cooperation of Slovak Technical University with ASIO-SK s.r.o. Bytča and ASIO s.r.o. Brno. Wastewater treatment plants are made for 5-600 PE. When operated at suitable conditions, the results match the directive water discharge from small wastewater treatment plants in the Slovak Republic.

Keywords: domestic wastewater, small wastewater treatment plant, anaerobic pre-treatment, aerobic post-treatment

Introduction

The wastewater issue is not only important but is difficult to resolve. This is the situation not only in Slovakia, but also in other countries. Large WWTPs present composite technological units with high efficiency. This is because of the qualified operation and long-time experiences. The character of settlements in Slovakia does not allow many people to connect the sewage system. That is one of the reasons for the raising interest of people for small WWTPs.

Small WWTPs differ from large ones, especially in wastewater quality and quantity. The volume and quality of wastewater from one PE are different and depend first of all on the type of the facility for which the WWTP serves (restaurant, hotel, single household, etc.).

The market with small WWTPs has expanded in the last few years. Producers offer WWTPs as an option to the standard cesspool or septic tank. Low investment and maintenance costs should be beneficial. Small WWTPs

should operate quietly without bad smell, with simple operation and long durability [1]. Excess sludge does not smell and is liquidated in solid form. Treated wastewater can be discharged into a recipient such as a stream.

Aerobic technologies are used in most of the cases for wastewater treatment from small sources. Research was forced to find new technologies with lower energy requirements because of the problems with energy cost.

Anaerobic reactors have been used mainly for industrial wastewaters, but more often can be found also in municipal wastewater treatment. High-rate anaerobic systems represent low cost and sustainable technology for domestic sewage treatment, because of its low construction, operation and maintenance costs, small land requirements, low excess sludge production and production of biogas. Although anaerobic wastewater treatment plants for municipal wastewater have been successfully operated in tropical countries such as Mexico, Columbia, India and China [2-5], the process until now has not been applied in countries with moderate and low temperatures. At such temperatures, chemical oxygen demand (COD) removal is limited and long hydraulic retention time is

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needed for one-step systems to provide sufficient hydrolysis of particulate organics [6]. Despite the advantages of the anaerobic treatment, the anaerobic effluent needs post treatment for removing the remaining COD, nutrients and pathogens. The post treatment system for the anaerobic effluent should, like the anaerobic pre-treatment, be a high-rate, low-cost and sustainable technology. Various aerobic systems have been proposed for post-treatment, such as submerged aerated biofilters [7], aerobic fluidized beds [8], rotating biological contactors [9], down-flow hanging sponge cubes [10], and activated sludge [11].

Anaerobic Pre-Treatment with Aerobic Post-Treatment

A few new technologies have appeared in the field of biological wastewater treatment during the last few years. Combined anaerobic and aerobic wastewater treatment can be considered one of them. Such an integrated system appears to be one of the possible ways for treatment of wastewater from small sources.

One of the possibilities to underline the advantages and fight back the disadvantages (Table 1) of both (anaerobic and aerobic) technologies is to combine them into one integrated system with anaerobic pre-treatment and aerobic post-treatment. That technology should have the following characteristics:

- high efficiency for the removal of organic matter as well as for the nutrients
- low specific energy requirements
- a relatively short detention time (due to the relatively small volume of the tanks)
- biogas production
- low specific production of excess sludge

The small-scale gappei-shori Johkasous (anaerobic bed reactor with constant flow-rate control system followed by aerobic biofilm reactor) used for domestic wastewater, showed good performance of BOD removal with effluent BOD below 20 mg/l in 70% of surveyed data. BOD and N_{total} decreased with the recycle operation. The effluent N_{total} seemed to be controlled below 15 mg/l with recycle ratio of 3Q-10Q (Q – influent flow quantity). The BOD removal performance in the facilities treating wastewater from restaurants and hotels was largely influenced by the influent n-Hex (oil) concentration. It was likely to have a risk of failing the performance if the influent n-Hex was over 30 mg/l [12].

In the anaerobic-aerobic biofilm process, nitrification presents a limiting phase in nitrogen removal. The effect of VFAs produced in anaerobic biofilm reactors under various flow-rate and recirculation ratio on nitrifying bacteria were also investigated in Johkaso. As a result, at a temperature of 10°C, nitrification activity could be increased about 65% by recirculation. High concentrations of VFAs were found in anaerobically treated effluent, especially at 10°C without recirculation, and inhibition of nitrite oxidation and nitrite accumulation was observed in

Table 1. Comparison of anaerobic and aerobic processes.

Comparing parameter	Anaerobic processes	Aerobic processes
energy consumption	low	high
construction	simple	complex
biomass production	low	high
nutrition demand	low	high
reaction speed	low	high
nutrient removal	minimal	very good
starting period	long	short

the aerobic biofilm reactor. It was concluded that recirculation was indispensable to promote nitrification-denitrification activity and biodegradation of VFAs in the small-scale anaerobic-aerobic biofilm process [13].

Since 1996 an intensive research focusing on the anaerobic technology utilization for domestic wastewater [14] has been in progress at the Department of Environmental Engineering STU Bratislava. This research showed that it is necessary to add a post-aerobic step to meet the requirements of directive.

Material and Methods

The presented work can be divided into two basic parts: laboratory research done in reactors AN-I and AN-II and research done with evaluation of real working WWTP AS-ANAcmb.

Two pilot-scale reactors were used in the experiment with aerobic post-treatment. Reactor AN-I (consisting of a primary settling tank, an anaerobic baffled system, an aerobic part and a secondary settling tank, as can be seen in Fig. 1.), seeded with anaerobic sludge (≈ 200 l with SS concentration of 18-22 g/l). Reactor AN-II was designed identically to AN-I, but was started-up without inoculation. Both experimental plants were installed at the municipal wastewater treatment plant in Bratislava – Devínska Nová Ves ($\approx 40,000$ PE). The pilot scale experiments with both reactors were running from September 1999 till August 2001. The basic wastewater parameters (COD, BOD₅, pH, SS, NH₄-N, NO₃-N, NO₂-N) of the influent and effluent were monitored according to Standard Methods [15].

In the second part, seven real WWTPs working on anaerobic – aerobic principles were chosen for evaluation, one for 10 PE, three for 20 PE, two for 200 PE and one for 250 PE. WWTPs from which the samples were taken are situated in the north of Slovakia. The samples were taken five times during the period between August 2003 and October 2003 from the effluent of the WWTP and all were grab samples. COD, BOD₅, pH, SS, NH₄-N, NO₃-N and PO₄-P analyses were done on the samples according to Standard Methods [15].

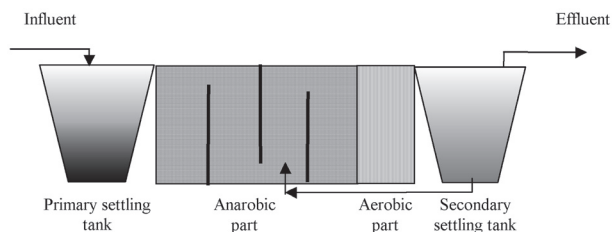


Fig. 1. Schematic drawing of AS-ANAcomb.

Results and Discussion

Pilot Scale Experiments

In the experiments with AN-I and AN-II a very quick start-up process was obtained in a few weeks. The HRT in the anaerobic part was 15.2 h, in the aerobic part about 3.8 h. All results exhibited not only good organic removal but also good initial nitrification in the first weeks of reactor operations. No sludge was removed from the reactors during the start-up period. In spite of unfavourable temperature conditions the removal efficiencies were very high in all monitored parameters during the winter periods. Effluent values and removal efficiencies for both COD and BOD₅ parameters were comparable with the low loaded aerobic sludge systems. Intensive nitrification was observed during the first month of the winter period in both tested systems. The nitrification activity was partially reduced during the days with extremely low temperatures, and this phenomenon lasted to the end of the winter period. A denitrification process in the anaerobic baffled system ran parallel with nitrification. Due to sufficient anaerobic sludge, the average removal efficiency by denitrification in AN-I was between 75 and 80%. The amount of anaerobic sludge had not been too high in the anaerobic compartment of AN-II during the first winter period, which caused lower denitrification rates. During the summer period the minimal changes in COD values were registered compared to the winter conditions in both tested systems. The slight improvement was registered in both reactors in the parameter BOD₅. In the process of nitrification a decided increase of effluent NH₄-N concentration was observed. The high production of ammonia in consequence of decay and hydrolysis of the sludge in the anaerobic part of reactors caused the decrease. During the summer period the partial removal of sludge from primary settler and from anaerobic compartment of AN-I was realized twice. The yearly operation of AN-II was absolutely without sludge waste. The second year of the operation can be evaluated like the first one. All results exhibited good organics removal. The concentration of SS increased in a few months after sludge removal. The slight change of the HRT ratio in favour of the aerobic part led to better conditions for nitrification in the AN-II during the second year. The results obtained by two years monitoring of the models working on anaerobic-aerobic principles are summarized in Table 2.

The results obtained by the operation of these reactors are quite encouraging not only for countries with a hot climate, but also indicate the possibility for wastewater treatment under real conditions in our country. The organic removal was high and stable during the whole monitored time. The process of nitrification was also observed, but it was dependent on temperature and sludge decay. SS removal was also obtained with good efficiencies [16,17].

The construction of real WWTPs was realized in cooperation with ASIO-SK s.r.o. Bytča and ASIO s.r.o. Brno. AS-ANAcomb can be found in the range of 5-600 PE. AS-ANAcomb reached the market at the end of 1999 and there were about 800 of them in operation by the end of 2003 throughout the Slovak and Czech republics. Most of them were for 5-50 PE, but large ones are also operating.

Real WWTPs Evaluation

The main purpose of the second part of this study was to analyze the operation of various size types of AS-ANAcomb. According to directive No. 491/2002 the main concern was BOD, COD and SS removal. However, nutrient concentrations in the effluent were also monitored.

AS-ANAcomb 10

This WWTP (AS-ANAcomb A) is situated inside the area of a saw mill that has approximately 20 employees working in two shifts. The WWTP has operated for more than a year and the sludge was removed three months before the first sampling. Only the wastewater from sanitary facilities is treated.

The experimental results indicate that the AS-ANAcomb A operated properly during monitoring. The effluent organic pollution was around 85 mg/l (26-119 mg/l) for COD and 25 mg/l (14-43 mg/l) for BOD on average. The concentration of SS was 38 mg/l (15-61 mg/l) on average, which is almost twice as high as the guarantee (20 mg/l) by ASIO-SK s.r.o. The higher presence of SS can be explained by the lengthy polluted pipeline. The low NH₄-N concentration, which was 7.5 mg/l on average (2.4-20.9 mg/l), indicates that the process of nitrification was also in progress, while denitrification was not.

This WWTP does meet the directive, because only BOD has to be monitored for this largeness type and has to be less than 40 mg/l.

AS-ANAcomb 20

Three WWTPs of this size were investigated.

The first one (AS-ANAcomb B) is situated in the garden of a retirement home and has operated only 6 months. The sludge was removed only three weeks before the sampling. There is a problem with the size of the WWTP for this retirement home. An AS-ANAcomb 30 was designed for this purpose, but only an AS-ANAcomb 20 was realized. After removing the sludge the WWTP was in the start-up period, and this was not without problems.

Table 2. The results obtained during two years operation of AN-I and AN-II.

Parameter [mg/l]	Influent Mean	Effluent AN-I		Effluent AN-II	
		Mean	% rem.	Mean	% rem.
COD	410 (140 - 915)	78.1 (18-185)	78.0	78.9 (18 - 227)	78.3
BOD ₅	202 (54 - 420)	14.9 (3.0 - 59)	91.2	13.8 (3 - 43)	92.4
SS	226 (30 - 760)	29.5 (2 - 100)	85.3	26.5 (0.5 - 120)	82.5
NH ₄ -N	44.2 (20.8 - 48.6)	15.8 (0.2 - 48.6)	62.4	18.2 (0 - 48)	59.7
NO _x -N	-	14.7 (0 - 45.1)	-	10.9 (0 - 46.3)	-

Table 3. Characteristics of effluent wastewater from AS-ANAcComb.

AS-ANAcComb	COD [mg/l]	BOD ₅ [mg/l]	SS [mg/l]	NH ₄ -N [mg/l]	NO ₃ -N [mg/l]	PO ₄ -P [mg/l]
A	85 (26-119)	25 (14-43)	38 (15-61)	7.5 (2.6-20.9)	58 (27-70)	1.8 (1.5-2)
B	430 (332-580)	179 (81-250)	111(87-145)	60.7 (54.1-69.8)	-	1.6 (1.3-2.3)
C	153 (136-165)	32 (27-35)	40 (20-48)	38 (28.9-52.3)	42 (10-74)	2.7 (2.5-2.9)
D	140 (30-240)	26 (5-43)	42 (3-93)	26 (6.9-52.1)	54 (12-159)	1.4 (0.3-2.1)
E	108 (70-194)	27 (10-70)	32 (10-54)	67 (49.8-72.4)	0.5 (0-2.6)	1.3 (1-1.7)
F	52 (44-58)	23 (15 -30)	17 (14-19)	48 (46.1-49.8)	0.2 (0-0.7)	1.4 (1.3-1.7)

The second WWTP (AS-ANAcComb C) can be found in the area of the company, where 10-15 employees work in the office and only a few more workers use the sanitary facilities. An oily film was present on the top of the aerated part and the secondary settling tank. The owner said that none of the workers poured oil into the sink.

The third WWTP (AS-ANAcComb D) treats wastewater from a restaurant situated in a small village. The secondary settling tank was filled with denitrificant sludge at the time of the first sampling. This problem did not appear after our interference with the operation of the WWTP.

The running of these WWTPs presented some possible problems.

There was a problem with the high organic pollution on the effluent of the AS-ANAcComb B as seen from Table 3. The high COD and BOD effluent concentrations as well as SS concentration are due to the incorrect operation of the WWTP. The primary settling tank was full of grease and kitchen waste even after the staff of the retirement home was warned not to throw it into the sink. The accumulation of these can lead to the failure of the process. Another problem may arise, that of the air blower, which is used for oxygen delivery to the aerobic part of the WWTP. The air blower is inside the plastic tank of the WWTP. The air circulates there and no fresh air gets inside, which means that there is not enough oxygen for the aerobic post-treatment.

In spite of the oily film the results of the analyzed samples from the AS-ANAcComb C are quite promising. Only the COD concentration is a bit higher, which is presumably due to the presence of oil.

The AS-ANAcComb D pointed out the problems with the fluctuation of quantity and quality of the wastewaters. Such a fluctuation is natural for such facilities as restaurants. Low NH₄-N and NO₃-N concentrations, which were 19.5 mg/l and 27.3 mg/l, respectively (on average), indicate that the processes of nitrification and denitrification were also in progress.

AS-ANAcComb 200

Two WWTPs of this size were chosen for this study.

The first one (AS-ANAcComb E) lies on the border between the Slovak and Czech republics. There was a requirement from the investor that the character of the countryside should not change, so the WWTP is inside a building. The sampling point is at a location where the effluent flows into a stream.

The second WWTP (AS-ANAcComb F) was designed for 400 PE, but because of financial restrictions only one part as AS-ANAcComb 200 was realized. AS-ANAcComb 200 was designed for wastewater flow of 60-62 m³ per day with influent BOD about 150 mg/l.

COD and BOD effluent concentrations in the AS-ANAcComb E were 110 mg/l and 30 mg/l, respectively, on average. The fifth sampling indicates that a problem could occur, because the COD and BOD concentrations increased. The average effluent COD and BOD concentrations without this measurement are even lower, 86 mg/l and 17 mg/l, respectively. SS concentration was at a limit of 30 mg/l. It is interesting, that by these conditions the process of nitrification as well as denitrification were not in progress.

Table 4. Characteristic of wastewater.

	COD [mg/l]	BOD ₅ [mg/l]	SS [mg/l]	NH ₄ -N [mg/l]	pH
influent	557 (395 – 807)	292 (255 – 450)	267 (183 – 354)	45.1 (17.9 – 61.1)	7.7 (7.2 – 8.05)
effluent	83 (33-122)	16 (6.5 – 25)	29 (6 – 78)	23.6 (2.9 – 41.9)	7.5 (7.13 – 8.22)

The operation of AS-ANAcomb F can be divided into two phases. The first one can be characterized by hydraulic overloading (the wastewater flow was 100 m³ per day on average) with a higher BOD concentration as designed (the real effluent BOD concentration was approximately 250 mg/l). The increase of flow can be caused by percolation of ground water as well as by the possibility that some people living in the village are using water from their wells. Other problems with the operation of WWTP could be caused by the presence of filamentous bacteria in the aerated part and the secondary settling tank. During this start-up period the average effluent concentrations of COD and BOD were 200 mg/l and 60 mg/l, respectively. High NH₄-N concentration stands for poor nutrient removal, but it was foreseeable. For the verification of the WWTP operation a second phase has been suggested. A part of influent wastewater was by-passed during this phase, so the wastewater flow was about 40 m³ per day. The effluent quality improved significantly after this interference. All parameters, which have to be monitored according to directive No. 491/2002, did meet this directive. The bypass of the wastewater is not a definitive solution, it is only a demonstration of the proper operation of the WWTP. The realization of the missing part (AS-ANAcomb 200) would be the proper solution to the problem with the WWTP overloading.

AS-ANAcomb 250

The WWTP is situated in the area of a company, which is treating metal materials. The representatives of the company assured us only that the wastewater from the sanitary facility is treated in the WWTP. The WWTP consists of two lines, but only one is in operation. The second part will be set in operation after the company enlargement. The WWTP has operated for more than six months without sludge removal. More attention has been paid to this WWTP, as it was one of the first ones of this size set in operation. Samples for analyses were taken from the influent, the effluent but also from the WWTP's compartments.

The start-up was without larger problems and the WWTP operated in steady state by sampling time. The treatment process showed good efficiencies for the removal of organics. Effluent COD and BOD₅ concentrations were 89 mg/l and 24 mg/l on average, respectively. Relatively high NH₄-N concentrations indicate only partial process of nitrification.

The results obtained by the real WWTP operation supported the results from the lab-scale as well as the pilot-scale operation. The efficiencies of COD and SS removal

at the effluent of the anaerobic compartment were 51% and 58%, respectively.

Conclusions

An integrated system originated from the combination of anaerobic and aerobic technologies was studied. Following operational experiences it can be said that the properly operated two-stage technology is effective for the removal of organic pollution and suspended solids, while under optimal conditions even nutrient removal can be achieved. Energy consumption decreased at about 25-40% compared to the small WWTP working on aerobic principles. The operation of AS-ANAcomb validated the lowering of the specific sludge production by 40%. The repeated start-up of the WWTP is without larger problems by proper operation.

The operation of AS-ANAcomb showed some problems which led to a decrease of treatment efficiency. This can be caused by the accumulation of things that should not get into the WWTPs (grease, oil, solvents, cleaning agents) in many cases. The fluctuation of the wastewater flow can also be a perturbing influence.

The operation of chosen AS-ANAcomb WWTPs can be evaluated positively. The majority of the chosen WWTPs were efficient in the removal of the organic pollution without professional operation, which is one of the most important requirements for small wastewater treatment plants. The results obtained from WWTP operation confirmed the viability of an integrated anaerobic-aerobic system for municipal wastewater treatment, even in a country with a temperate climate.

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