Pol. J. Environ. Stud. Vol. 24, No. 3 (2015), 1451-1456

Short Communication

Prospects of Domestic Wastewater Treatment for Small Settlements in Northeastern Hungary

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Received: 6 February 2013
Accepted: 15 December 2013

Abstract

In our study 14 wastewater treatment plants were investigated in Szabolcs-Szatmár-Bereg County in northeastern Hungary. The size of the plants varied between 150 and 8,500 m^3/day capacity. The treatment efficiencies were compared using parameters of COD, BOD_5, TN, and TP. Average C:N:P ratio of 50:9:1 suppressed nitrogen removal. Phosphorus removal was achieved with iron salt addition. The amount of daily influent was an appropriate scale to distinguish the technologies. SBR system efficiencies were negatively correlated with the amount of influent, which made them sufficient for small settlements. In the conventional aeration activated sludge technology full potential was only triggered in larger sized plants.

Keywords: activated sludge, small WWTP, removal efficiency

Introduction

Wastewater treatment plants (WWTPs) are key facilities for environmental management concerning hydrological and environmental aspects in modern societies. Developing the best available technology for recycling domestic sewage is constantly induced along with the ever growing demand for freshwater. Novelties like Anammox [1] are rapidly implemented worldwide. Low operating cost and promising source management are beneficial to the economy.

Developed and densely populated countries naturally tend toward centralization, prompting growing settlement sizes. In contrast, rural low-population areas have problems with domestic sewage treatment. While the technology is ready to serve these communities in terms of achieving acceptable levels of both organic and nutrient content removal, it is not as cost-effective as a centralized solution [2, 3].

The activated sludge model (ASM) by the International Water Association (IWA) task group was a great achievement, suggesting applicable models for researchers and technicians to overcome certain situations [4] and plan for the future [5]. However, integrating new findings should be done carefully. Preliminary evaluation of local conditions is important. Costs can be managed with proper up-front research. The parameters should be continuously monitored for changes after implementation [6]. For many years, constructing new and upgrading existing WWTPs were a top priority. However, there is a tendency to modify the newly constructed plants immediately after completion in order to be able to meet adequate discharge standards, because operators always require reliable performance [7].

The easternmost county of Hungary, Szabolcs-Szatmár-Bereg, is where the second largest river, Tisza, enters the country. Hydrological importance and its good ecological state are top priority. The catchment area of the river lies on the Great Plain, where most of the population is fragmented into small settlements. As a consequence, wastewater treatment facilities are scattered. WWTPs of particular settlements are drawing sewage of the surrounding smaller settlements. Settlements that are too far for joint operation are forced to cope with wastewater treatment alone using technology designated for their purpose [8].

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Table 1. Parameters of the investigated WWTPs with standard deviation.

WWTP	Technology	Capacity m^3	Average influent m^3/d
Vaja	Conventional Activated Sludge	1000	500±41
Ajak	Conventional Activated Sludge	220	213±12
Kisvárda	Conventional Activated Sludge	7000	2625±125
Mándok	Conventional Activated Sludge	400	246±16
Máriapócs	Conventional Activated Sludge	430	324±19
Mátészalka	Conventional Activated Sludge	8500	3287±135
Rakamaz	Conventional Activated Sludge	1000	645±7
Tuzsér	Conventional Activated Sludge	1000	313±25
Záhony	Conventional Activated Sludge	4100	900±41
Baktalórántháza	Activated Sludge + Oxidation Ditch	500	263±10
Csengersima	SBR	130	68±2
Kocsord	SBR	600	200±0
Porcsalma	SBR	500	345±10
Gergelyiugornya	Total Oxidation	200	165±44

This article presents the results of an independent laboratory investigation evaluating local WWTPs in order to assess their efficiency. The authors attempt to provide a regional perspective comparing the attained data of the WWTPs' effluent quality, utilized technology, and physical parameters.

Experimental Procedures

Data have been collected between 2008.01.01 and 2008.06.30 from 14 WWTPs of northeastern Hungary. All of the plants are within the county boundary of Szabolcs-Szatmár-Bereg. Developments in sewage infrastructure are rarely financed by the respective governing settlement entirely. The final recipient water river in this region is the Tisza River, and as a consequence she is severely exposed to contamination [9]. Nitrogen and phosphorus content of the effluents are strictly limited in order to suppress eutrophication.

Samples from the WWTPs were analysed in the independent and accredited analytical laboratory of Ivóvíz6 Company. The study involved the determination of chemical oxygen demand (COD – dichromatic method) and biological oxygen demand (BOD_5 – respirometric method) both used as common markers for sewage treatment evaluation. Total-nitrogen (TN – distilled calculation method) and total-phosphorus (TP – photometric method) determinations were also used as indicators of eutrophication. Statistical calculations were conducted with IBM Statistics SPSS 19.

The maximum capacity of the WWTPs ranged from 150 to 8,500 m^3/day. The majority of the plants treated sewage below the average amount of 1,000 m^3/d. The WWTPs use the biological elimination technique to achieve regulation standards. None of them are enhanced with biological phosphorus removal technology; only iron salts are injected. We have found a range of technologies falling into the 'activated sludge' definition. The conventional activated sludge (CAS) method was dominating (9 plants, 40 samples); we have encountered a few sequencing batch reactors (SBR) (3 plants, 12 samples), there was a plant using total oxidation (TO) (1 plant, 4 samples) and one using a combined system incorporating activated sludge technology with additional oxidation ditch (CT) (1 plant, 4 samples). We have found both single- and multi-reactor configurations. The theoretical maximum capacity of investigated WWTPs along with the average amount of influent sewage and the utilized technologies are shown in Table 1.

Results

General influent water characteristics are summarised in Table 2. COD values varied in a wide range and overall qualified as semi-high. Three of the observed WWTPs had influent water above 500 COD mg O_2/L. One of them is Csengersima, which has the lowest treatment capacity and receives the lowest amount of daily influent sewage. These circumstances challenged the operators.

BOD_5/COD average ratio was 0.33. The low BOD_5 concentration was readily available for microbial metabolism. No impact of industrial activities were reported to affect the investigated settlements. Average BOD_5 and COD ratio values for domestic wastewater are between 0.60-0.70. However, in practice a much wider range exists [10], for example ratios of 0.40-0.44 were also found to be accepted [11]. Smaller plants purified sewage with higher

Table 2. Characteristics of raw wastewater (average values) with standard deviation.

WWTP	COD (mg/L)	BOD_5 (mg/L)	TN (mg/L)	TN-inorg. (mg/L)	TN-org. (mg/L)	TP (mg/L)
Vaja	397±286	133±97	91±48	79±42	12±6	9±4
Ajak	241±88	87±23	85±15	74±13	11±2	10±2
Kisvárda	195±41	65±13	60±13	52±11	8±2	11±1
Mándok	236±64	80±22	46±16	40±14	6±2	7±4
Máriapócs	433±196	144±64	86±20	75±17	11±3	8±3
Mátészalka	316±230	100±80	61±13	53±12	8±2	10±3
Rakamaz	577±26	190±14	57±37	50±32	8±5	18±7
Tuzsér	430±176	143±57	67±19	59±17	9±2	7±2
Záhony	373±190	120±62	69±10	60±9	9±1	7±3
Baktalórántháza	409±85	138±29	76±27	66±24	10±3	9±5
Csengersima	575±217	188±71	74±42	64±37	10±5	8±3
Kocsord	351±243	123±86	59±9	52±8	8±1	9±3
Porcsalma	539±105	180±38	80±19	69±17	10±2	8±4
Gergelyiugornya	223±81	75±30	77±1	67±1	10±0	12±1

nutrient loads. Concentrations of nutrients – mostly nitrogen – in the sewage of rural areas are higher. Households in these areas have lower rates of connection to the sewer system in comparison to bigger towns. TN influent comes with an average 87% inorganic component, from which NH_4-N was dominant. TN and TP influent concentrations averaged 77.9 and 9.4 mg/L, respectively, with a peak of TP 18 mg/L at Rakamaz.

COD removal efficiencies were moderate (Table 3). Highest values were found at the plant of Rakamaz. The removal efficiency of this plant was above 85% using conventional activated sludge technology. Only two other plants were able to perform above 80% of COD removal, the WWTP of Tuzsér and Porcsalma. An SBR system was used at Porcsalma, while the WWTP at Tuzsér only used an aerating reactor for biological treatment. The low hy-

Table 3. Average removal efficiencies (%) of the investigated WWTPs with standard deviation.

WWTP	COD %	BOD_5 %	TN %	TN-inorg. %	TN-org. %	TP %
Vaja	72±14	73±13	62±25	62±26	61±25	50±16
Ajak	62±12	68±8	75±11	74±13	83±6	76±7
Kisvárda	66±5	66±4	83±19	83±19	83±18	81±3
Mándok	58±19	60±20	59±34	59±35	58±33	34±29
Máriapócs	79±10	78±13	57±33	57±33	57±33	59±22
Mátészalka	69±16	67±18	84±11	85±11	81±15	75±7
Rakamaz	85±3	87±2	54±36	54±36	54±35	88±6
Tuzsér	81±10	81±10	81±10	81±10	81±10	42±5
Záhony	65±24	64±25	87±14	87±14	87±14	38±11
Baktalórántháza	70±5	76±10	56±28	56±29	52±23	48±34
Csengersima	79±17	80±16	73±25	73±25	72±22	37±57
Kocsord	69±10	71±9	44±29	44±29	44±29	61±8
Porcsalma	80±7	80±7	35±35	35±35	35±34	33±34
Gergelyiugornya	63±20	62±21	73±7	73±7	78±13	60±15

draulic load of the influent water at Tuzsér poorly satisfies the normal operational condition of maximum 1,000 m^3/d wastewater.

It was impossible to operate WWTPs in the optimal C:N:P=100:5:1 ratio [12]. The best ratio was achieved at Rakamaz with 50:3:1. On average, Rakamaz had a C:N:P ratio of 50:9:1. Larger treatment plants theoretically should have provided proper BOD_5/NH_4-N ratio. However, carbon deficiency was a general issue [13, 14] causing the BOD_5/NH_4-N ratio to fall to 3.8. Throughout the investigation, there were only two times when BOD_5/NH_4-N ratio was above 6.0 (Fig. 1). Microbial processes demand readily available carbon sources to eliminate high nitrogen concentrations. The built-in anoxic phase of the conventional activated sludge method is a standard industrial solution for this phenomenon. Operational dissimilarities existed between the SBR technologies. Carbon source in the anaerobic phase was at the same level, and their utilized capacities (between 52-69%) also supported the hypothesis.

TN removal efficiencies show moderate levels in both organic and inorganic content. In the raw sewage NH_4-N levels were reduced by 87% at the plant of Záhony. Systems at Mátészalka, Kisvárda, and Tuzsér were above 80%. These plants used conventional activated sludge technology with proper nitrification and denitrification available. Statistical evaluation of investigated TN concentrations are assessed in Fig. 2.

The probability of the resulting influent TN concentration was normally distributed in 96% of the samples. 13% of the TN concentration was organic nitrogen. Average TN concentration was 71.1 N mg/L with a standard deviation of 24.1 N mg/L. However, the initial part of the normal distribution between 25 and 50 N mg/L did not affect the WWTPs as negatively. TN concentrations above 100 N mg/L had a significant effect. The effluent average TN concentration was 24.1 N mg/L with a 24.3 N mg/L standard deviation. The ratio of organic nitrogen concentration changed to 15%. The effluent TN concentrations showed a significant bend at 81% of probability at 29.4 N mg/L (Fig. 2). There was a positive correlation between the influent and effluent TN concentrations in all the observed WWTPs.

R=0.5773 (Pearson parametric probe, n=60, p=0.01), suggesting that the influent TN concentration above 83.4 N-mg/l was to be considered as a potential risk inhibiting good TN removal efficiencies (Fig. 3). A high concentration of nitrogen was utilized if the influent sewage contained high concentrations of nitrogen, but removal efficiencies did not increase accordingly. This is in line with the previous findings of other authors [15]. The oxidative zones in the aerobic reactor fed microbial processes and were being completed at the reductive anoxic reactors for

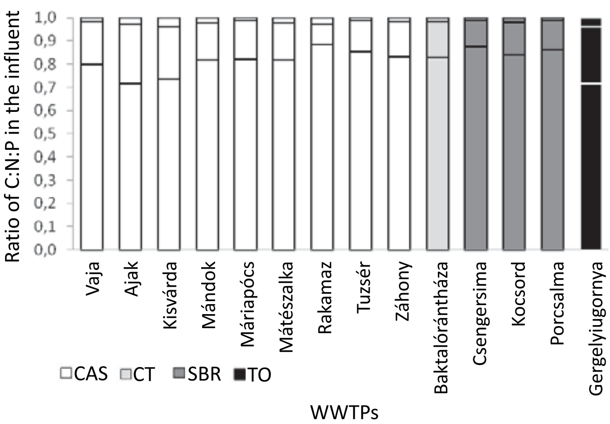

Fig. 1. General C:N:P ratio in the influents at the investigated WWTPs.

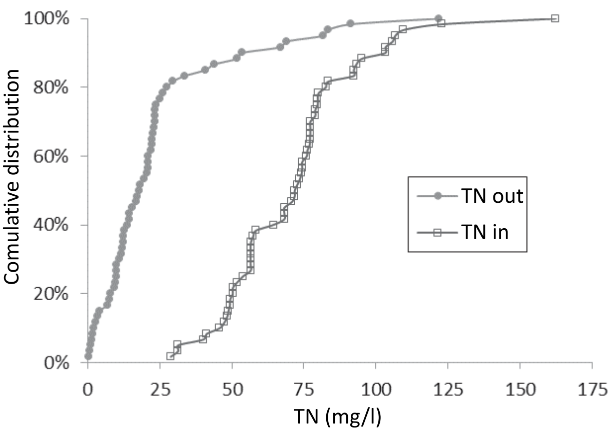

Fig. 2. Cumulative distribution of TN influent and effluent.

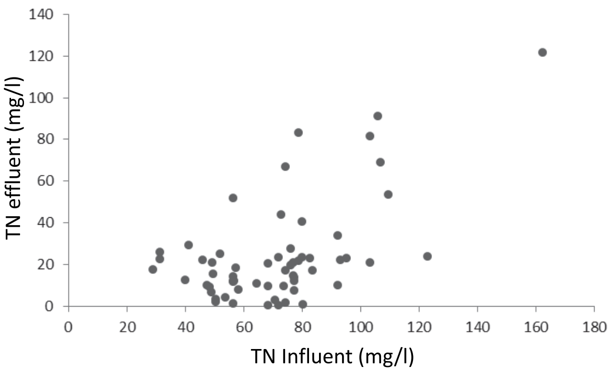

Fig. 3. Total Nitrogen (TN) concentration variation.

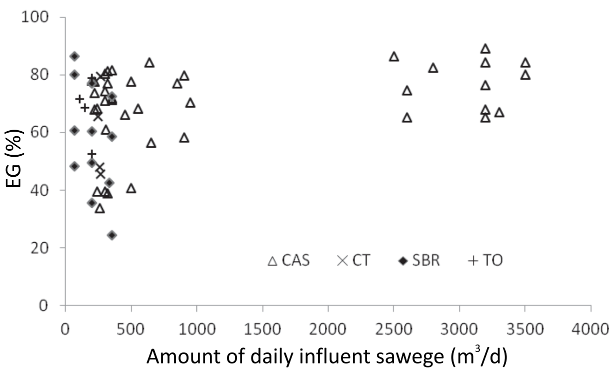

Fig. 4. General efficiencies versus daily influent sewage flow.

successful nitrogen elimination. The plants of Máriapócs and Ajak have smaller maximum capacities, but they are also equipped with similar reaction zones. The plant of Ajak had a nitrogen removal efficiency of 75% at nearly full load. At this plant, the nitrogen removal technology was enhanced with a reductive anoxic and aerobic zone after primary nitrification and denitrification. This reductive anoxic zone allowed for a preliminary reduction before recirculation into the primary anoxic reactor, while the second aerobic zone served for microbial stabilization before settling.

The TP removal efficiencies varied in a broad range (Table 3). Average TP concentration in the effluent was 3.5 P mg/L with 1.7 P mg/L standard deviation. The investigated plants were designed without biological phosphorus removal. Despite the promising prospects [16], biological phosphorus removal methodology was excluded due to simultaneously low COD/TP, COD/TN ratio. Chemical precipitation is available as a low-cost solution using ferric chloride [11]. Activated sludge systems in continuous flow layouts are compatible with iron salts. Reliable phosphorus removal efficiencies can be achieved above 90%, according to a previous study [17]. The plant of Rakamaz achieved a phosphorus removal efficiency above 88% efficiency: 2 mg/L phosphorus concentration in the effluent. The lowest TP removal efficiency of 33% was observed at Porcsalma.

15% of the effluent wastewater TP concentrations were above the standard deviation error. TP concentration removal did not depend directly on influent wastewater quality. This may suggest that the non-reliability is coming from operational management.

We used the general efficiency (EG) indicator [18] to summarize the investigated WWTP performance. This allowed us to compare efficiencies of the different plants and technologies using the interpretation BOD_5, COD, TN, and TP data as the following:

$$EG = \frac{1}{4} (EBOD_5 + ECOD + ETN + ETP)$$

- EG general efficiency indicator %
- $EBOD_5$ average efficiency of BOD_5 removal %
- ECOD average efficiency of COD removal %
- ETN average efficiency of TN removal %
- ETP average efficiency of TP removal %

In Fig. 4 the efficiencies of the WWTPs are expressed with the general efficiency indicator. General efficiencies varied between 24% and 89%. The total oxidation system yielded an average of 68% removal efficiency with 72% of the maximum capacity in use.

The medium level of TN and TP concentration removal caused the combined technology to achieve 60% of the average removal efficiency. Capacity not fully utilized would allow sufficient hydraulic retention time for proper functionality.

The average removal efficiencies of 69%, 56%, and 50% decreased with the average daily amount of influent of 70, 200, and 350 m^3/d, respectively, in the case of SBR systems. This remained unexplainable because the technology proved to have no limitations on a large scale [19].

The conventional activated sludge technology performed the opposite way. The results of the WWTPs varied between 33% and 81% until 500 m^3/d, and resulted between 56% and 89% above 500 m^3/d. The average removal efficiency increased with the increasing amount of daily average influent sewage. This suggests improved reliability with higher amounts of influent sewage.

Conclusions

An independent evaluation based on the performance of 14 WWTPs in Szabolcs-Szatmár-Bereg county resulted in the following conclusions:

- The characteristics of the influent sewage varied in a broad range. In certain cases small-sized plants treated high-strength sewage. TN ratio dominated by the inorganic NH_4-N content of 87%. The readily available carbon source in the form of BOD_5 was low compared to the amount COD. General C:N:P ratio at 50:9:1 inhibited proper pollutant removal.
- Low BOD_5/NH_4-N allowed incomplete TN concentration removal. Influent TN concentration above of 83.4 N mg/L limited good removal efficiencies.
- The plants utilized chemical precipitation as an adequate TP concentration removal, because enhanced phosphorus removal technology was not available. Operational dissimilarities existed among plants. 15% of the average removal efficiencies yielded over standard error.
- The feasibility of SBR technology was greatly suppressed above 100 m^3/d average amount of influent. The design achieved acceptable levels of purification only at small plants.
- The conventional activated sludge method resulted in better average removal efficiencies for larger plants treating above 500 m^3/d average amount of influent. Upgrading the plants seems necessary in order to maintain reliable performance in settlements already using the small-sized conventional active sludge method.
- Intensification and optimization of the operations in these WWTPs requires continuous effort.

Acknowledgements

The authors gratefully acknowledge the funding for this study by the DU scientific educational Project (TÁMOP-4.2.2./B-10/1-2010-0024) and Ivóvíz6 Company.

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