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Operation of a Small Wastewater Treatment Facilities in a Scattered Settlement

Magdalena Gajewska, Łukasz Kopeć,
Hanna Obarska-Pempkowiak
Gdańsk University of Technology, Poland

1. Introduction

The disproportion between water supply and newly constructed sewer systems have been still increasing. Although, the number of people connected to the sewer system is still increasing but compare other EU countries it is unsatisfying.

The latest report of Environmental Protection Inspection about the condition of Polish waters indicates that the protection of waters against eutrophication is one of the most significant issues. In order to solve the problem of the eutrophication of waters in Poland, strategies not only for big agglomerations but, first of all, for rural areas with dispersed farms and buildings have to be developed. Surface waters are especially exposed to eutrophication due to the way land is used in rural areas. The integrated management of water resources in such areas is also a difficult task. According to the projects of new administration regulations, building of sewerage systems is not profitable if there are less than 120 inhabitants per 1 km of newly constructed system (including the main collectors and the pressure conduits transporting the sewage to WWTP) (CE guidelines).

The problem that the owners of houses located in rural areas face is the lack of a sewerage systems. At present the number of wastewater treatment plants in rural areas is over 50 000 (and is increasing with about 7 000 WWTP per year). According to Central Statistical Office at present there are 1636 agglomerations, with 23 million of people connected to sewerage systems (GUS, 2008). It means that the other 15 million of people in Poland do not use sewerage systems. Only 1% of people is equipped with individual waste water treatment plant (IWWTP). In consequence, in the nearest future, great interest and increase of number of IWWTP will be observed. It is estimated that up to year 2015 about 1 mln of IWWTP, will be built and they will treat sewage from 10% of inhabitants in Poland.

Thus there is an urgent need to create a new, cheep and simple in operation forsolution of sewage sludge management in rural areas.

The objective of this paper is to demonstrate the experiences of operation and monitoring results from WWTP working in different technologies serving wastewater treatment for individual household and units less than 2 000 inhabitants.

2. Experience from using Bioclere® treatment plants

Bioclere® treatment plants are based on low-rate trickling filter technology. There is Hufo® media inside the reactors. Media is made of polypropylene (PP) and it has great specific surface about 120 m^2/m^3. Biofilm, consisteing of many kinds of organisms, grows on media surface. In biofilm specific reactions of pollutants removal proceed.

In recent years, the number of new Bioclere® treatment plants systematically rise and average about 500 objects in Poland. The Biocleres are good solution for rural areas and work with applications like: schools, hotels, restaurants and mountain refugees. It can work in following configurations (the loading is refer to volume of bed as kg BOD_5/m^3 d):

1. one-stage unit (basic unit) – run with 0.4 kg $BOD_5/m^3 \cdot d$ and enable to reduce 90% organic loading (Fig. 1a).

2. two-stage unit without nitrification – I° trickling filter works with 0.8 kg $BOD_5/m^3 \cdot d$ and II° trickling filter works with 0.4 kg $BOD_5/m^3 \cdot d$. This solution enable to reduce 95% organic loading (Fig. 1b).
3. two-stage unit with nitrification – I° trickling filter works with 0.4 kg $BOD_5/m^3 \cdot d$ and II° trickling filter with 0.1 kg $BOD_5/m^3 \cdot d$ (nitrification bed). This system can secures organic concentration below 15 mg O_2/dm^3, nitrogen concentration below 6 mg/dm^3 and phosphorus loading below 1 mg/dm^3 (with chemical precipitation).

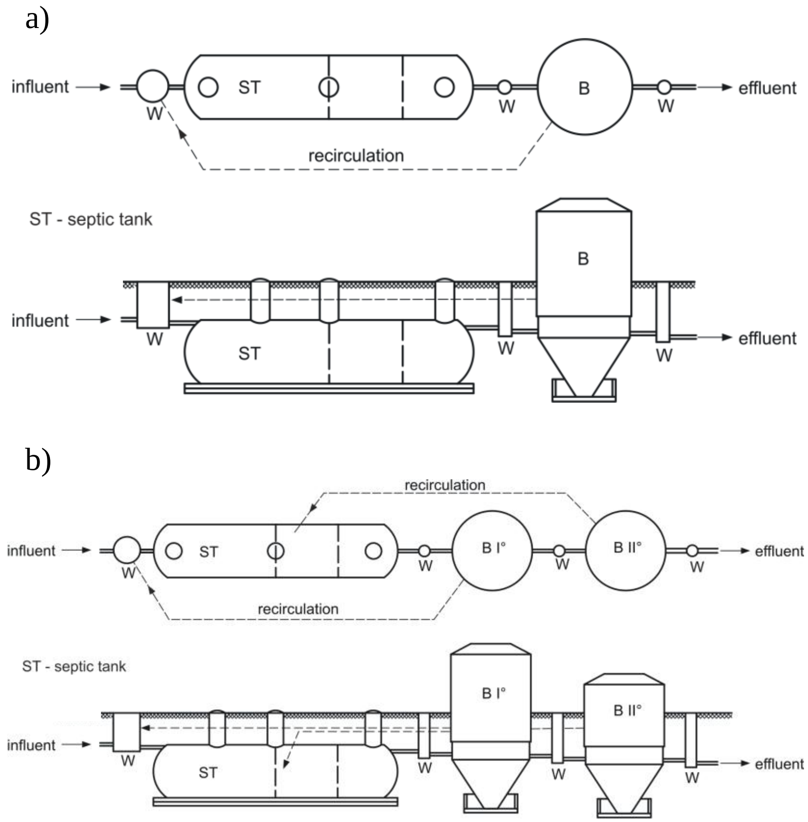


Fig 1. One-stage (a) and two-stages (b) unit applied in plant Bioclere®
W – inspection chambers; B I°, B II° – trickling filters; ST – septic tank [14]
Rys. 1. Układ jednostopniowy (a) i dwustopniowy (b) stosowany
w oczyszczalniach Bioclere® W – studzienki rewizyjne; B I°, B II° – złoża zraszane; ST – osadnik wstępny; [14]

In the years 2006÷2009 eight Bioclere® objects have been selected and analyzed in respect of efficiency pollutants removal. From among to researched objects are both one and two-stage units (Tab. 1). Every Bioclere® installation is assigned for service different number of inhabitants, (from 10 to 500 people). If the number of people exceed 500 then parallel systems are used (for example: 4 × Bioclere® type 500 to 2000 inhabitants).

Table 1. Characteristic of selected Bioclere® plants (ST – septic tank, TF1 – trickling filter I°, TF2 – trickling filter II°, SCh – chemical stage, UDCh – chemical feeding system
Tabela 1. Charakterystyka wybranych oczyszczalni typu Bioclere (ST – osadnik wstępny, TF1 – złoże biologiczne I°, TF2 – złoże biologiczne II°, SCh – stopień chemiczny, UDCh – urządzenie dozowania chemikaliów)

No. of object	Name of plant	pe	$Q_{av.}$[m^3/d]	Unit System
1.	Świecice	100	16.3	ST-TF1
2.	Lubno	260	31.1	ST-TF1
3.	Stare pole	156	17.6	ST-TF1
4.	Małkowo	140	9.9	ST-TF1
5.	Guzowy Piec	128	20.0	ST-TF1-TF2-SCh
6.	Subkowy*	230	26.4	ST-TF1-TF2-SCh
7.	Klekotki*	82	11.0	UDCh-ST-TF1-TF2
8.	Gronowo Górne*	350	19.9	UDCh-ST-TF1-TF2

* – plants with the necessity of biogenic substances removal (phosphorus removal proceed by chemical precipitation)

Bioclere® treatment plants are appropriated to purify domestic wastewater. The chemical constitution of sewage, except special cases, is: BOD_5: 200÷600 mg O_2/dm^3; COD: 700÷1200 mg O_2/dm^3; SS: 200÷400 mg/dm^3.

From carried research result, that pollutants concentration in influent doesn't differ from value in literature [5].

Achieved results show that Bioclere trickling filters are able to effective removal of pollutants from wastewater to the allowable values in the effluent. The exceptions to the common trickling filter plants are objects, which kind of wastewater isn't specific. According to Heidrich et al., (2008) efficient removal is possible when $COD/BOD_5 \geq 2.2$; $BOD_5/TN \geq 4$ and $BOD_5/TP \geq 25$.

Table 2. The mean values of pollutant concentration in influent and effluent from selected Bioclere® plants
Tabela 2. Zestawienie średnich wartości zanieczyszczeń w dopływie i odpływie w badanych oczyszczalniach. Bioclere®

No. of object	Parameter	Concentration in influent [mg/dm^3]	Concentration in effluent [mg/dm^3]	Maximum allowed value in effluent [mg/dm^3]
1.	BOD_5	632	24	25
	COD	1233	111	125
	TSS	311	32	35
2.	BOD_5	635	18	40
	COD	1438	114	150
	TSS	401	11.8	50
3.	BOD_5	405	32	40
	COD	757	270	150
	TSS	167	51	50
4.	BOD_5	262	23	25
	COD	367	73	125
	TSS	345	27	35
5.	BOD_5	346	20	25
	COD	818	53	125
	TSS	51	10	35
6.	BOD_5	359	2	40
	COD	1011	85	150
	TSS	251	24	50
	TN	28	1	30
	TP	40	2	5
7.	BOD_5	404	35	40
	COD	757	323	150
	TSS	275	67	50
	TN	65	11	30
	TP	28	3	5
8.	BOD_5	175	8	40
	COD	399	81	150
	TSS	237	24	50
	TN	116	66	30
	TP	15	4	5

Bioclere® treatment plant in Gronowo Górne is an analyzed object. It treats sewage from furniture factory. Raw wastewater comes from sanitary facilities and exceeds allowed parameters in total nitrogen concentration. A ratio BOD_5/TN is very low (about 1,5) and causes problems with treatment processes. At present, research to maximize nitrification processes are continued.

The other reason that some Bioclere® objects exceed environmental requirements is presence of fraction of hardly degradable compounds. This situation happens in Bioclere® treatment plant in Klekotki (7) which treats wastewater from hotel with restaurant. The hardly degradable fraction of COD comes from laundry which works every day. In spite of a value of COD which was in standard range (757 mg O_2/dm^3) in influent, that there was 323 mg O_2/dm^3 COD in effluent. In the same wastewater BOD_5 is removed to allowed level.

Difficulties with COD removal can also emerge when there is delivered putrid sewage to Bioclere® installation. In new treatment plant in Stare Pole (3) there was wastewater flowing through old chambers – residues past old treatment plant.

Concluding, it was found that removal processes in Bioclere® trickling filters are difficulted in cases when raw wastewater is characterized by disproportionate composition or presence of hardly degradable fraction of COD [9]. The average concentration of pollutants in the influent and effluent in monitored facilities are present in the Table 2.

3. Experience from treatment wetland operation in Poland

Nowadays more than 1000 treatment wetlands are in operation in Poland. Most of them are one stage facilities with horizontal flow of sewage (SS HF), which from many different reasons didn't ensure stable removal of nitrogen compounds. Since 2005 more popular become one stage facilities with vertical flow of wastewater (SS VF) and multistage systems (MTW) with at least two beds with horizontal and vertical flow. Although, the experience proved that technological units for wastewater treatment consisting of septic tank and vegetated subsurface bed (willow or reed) could be recommended for treatment of wastewater in rural areas the efficiency removal of pollutants is unstable [4]. Organic removal matter in different types of treatment wetlands (TWs) varied significantly from 25.6 to 99.1%. Similar the efficiency of nitrogen removal varied from 23.4 to 78.0% in the loadings range: 0.14÷4.6 g N/m^2·day.

Mass removal rates from 1 m^2 (of the TWs) varied from 1.8 to 6.3 g/m^2·d (on average 2.0) for BOD and from 0.4 to 0.7 g/m^2·d for TN [4, 11].

Within the research project *Innovative Solutions for Wastewater Management in Rural Areas* (financed by Polish Ministry of Science and Higher Education E033/P01/2008/02 and EOG Financial Mechanism and Norwegian Financial Mechanism PL0271) the conception of wastewater treatment and sewage sludge utilization at the TWs for individual households at a rural area was created. The project has been launched in the catchment area of the river Borucinka in the Municipality of Stezyca, Pommerania Region. The idea was to work out a ready-to-implement solution for community in a rural area through using TWs serving individual households. Local terrain configuration and dispersed development in the selected area do not justify building a sewerage system. Domestic sewage is collected at cesspools, which often leak to groundwater. After the review of existing TWs in Poland and in Europe, three configurations of hydrophyte beds are proposed. These facilities were constructed in summer 2009.

Three configurations were proposed: two with vertical flow (VF) beds and the third one with a horizontal flow (HF) bed preceded by a prefilter (Fig. 2):

- Configuration I: primary sedimentation tank with elongated detention time (5,6 days), followed by a single VF bed (the unit area of 4 m^2/pe) and a pond.
- Configuration II: existing primary sedimentation tank (with short retention time up to two days), then two sequential VF beds followed by a pond.
- Configuration III: primary sedimentation tank, prefilter (pre-treatment), HF bed.

The proposal of an innovative sanitary system is basing on an idea of a closed cycle of matter in the environment. The nutrient substances: N, P, K compounds present in sewage should be used as soil fertilizers.

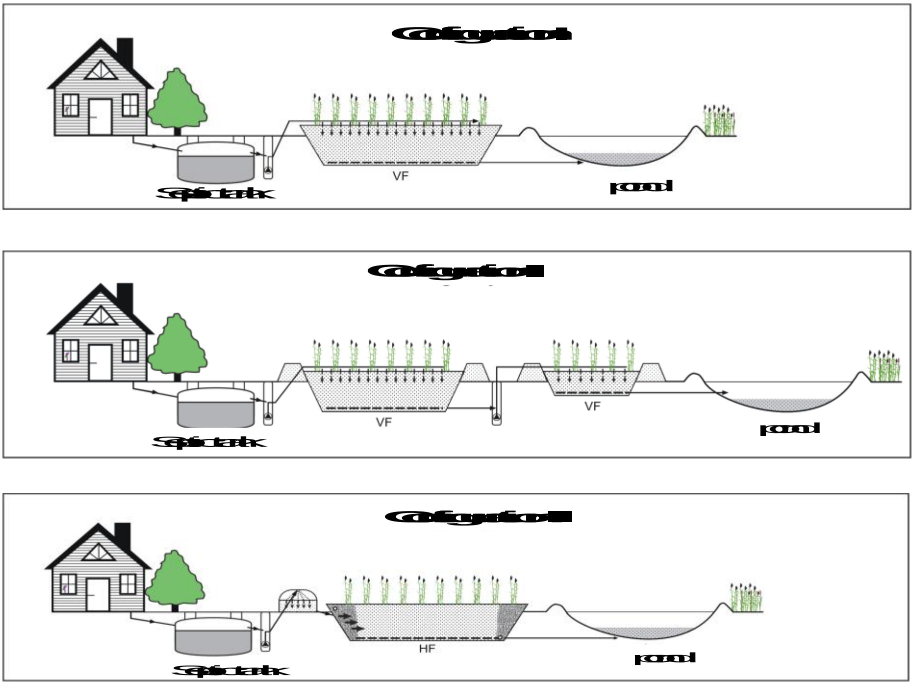


Fig. 2. Layout of three single-farm TW configurations
Rys. 2. Schematy konfiguracji elementów przydomowych oczyszczalni ścieków

Thus, the nutrient substances should be recycled to soil in the form of compost or humus, or can be used as an alternative, renewable energy source. It is assumed that the sewage could also be used for watering of the crops (for instance energetic crops or the plants used for co-composting with sludge and organic fraction of domestic wastes) during the vegetation season. In the Fig. 3 the concept of proposed solution is presented.

The samples were collected from four finished TWs, briefly charaxcterized in the Table 3. One of the TWs (at the Bronk farm) was working in the first configuration (1st). Three other were working at the second configuration (2nd). No facilities working in the third configurations were finished [13].

The concentration of pollutants discharged in analysed period did not fluctuated in time for each single-family TW (standard deviation below 20%) (Table 2). The concentration of pollutants discharged to four facilities varied significantly among each other. Also the achieved concentrations were much higher in comparison with the date given by Vymazal, 2005; Heistad et al., 2006 or Kayser et al., 2001 and Jenssen et al., 2005.

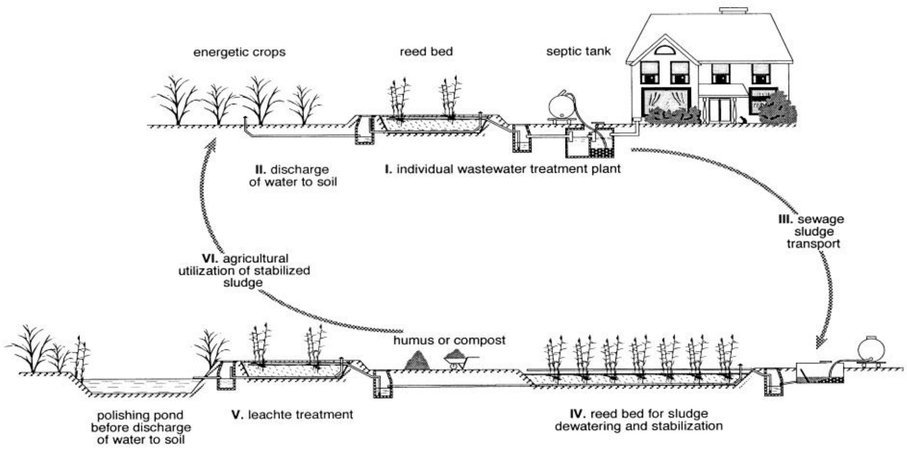


Fig. 3. The concept of sewage and sludge management for an individual household [12]
Rys. 3. Schemat nowoczesnego hydrofitowego systemu sanitarnego dla obszarów niezurbanizowanych [12]

The highest pollutant concentration were discharged to the Bronk TW and there were almost two times higher (except P_{tot}) in comparison to the pollutants discharges to others TWs (Table 3).

Such big difference in concentrations could not be explained by improper septic tank operation is more likely to be a result of Bronk family activities and should be farther investigated by taking a samples before septic tank.

The pollutants concentration in effluent from the rest three houshold did not differ significantly among each other. The average concentration of N_{tot} in the septic tank effluent has been varied from 126.0 to 164.2 mg/l and were two- three times higher in comparison to the value given by Vymazal, 2005; Heistad et al., 2006 (36.3 to 77.5 mg/l). Similar high concentration of nitrogen were found in the septic tank effluent in Podlasie region of Poland [12, 13].

Table 3. The characteristic of wastewater after subsequent stage of treatment in analysed TWs, mg/l
Tabela 3. Średnie stężenia zanieczyszczeń po kolejnych stopniach oczyszczania w analizowanych oczyszczalniach przydomowych, mg/dm^3

Plant	TSS			COD			BOD_5		
	Influent	After VF I	Pond	Influent	After VF I	Pond	Influent	After VF I	Pond
Hewelt Config. II	157.6 ±11.5	112.9 ±9.3	81.5 ±2.0	786.2 ±14.2	412.8 ±23.5	252.0 ±37.9	391.7 ±5.6	177.8 ±10.9	65.9 ±3.6
Blok Config. II	155.6 ±13.1	74.7 ±12.1	47.8 ±6.4	613.8 ±67.4	211.5 ±22.3	88.8 ±10.8	317.2 ±36.7	52.9 ±20.8	24.8 ±5.2
Cybula Config. II	224.2 ±24.00	43.7 ±26.3	38.2 ±1.5	492.9 ±13.3	116.5 ±84.2	150.3 ±27.0	216.0 ±39.8	88.3 ±72.5	39.1 ±21.4
Bronk Config. I	621.1 ±42.6	—	75.4 ±7.2	1591.1 ±157.5	—	507.1 ±36.6	761.1 ±89.2	—	220.5 ±53.0

Plant	N_{tot}			P_{tot}		
	Influent	After VF I	Pond	Influent	After VF I	Pond
Hewelt Config. II	155.5 ±7.7	132.0 ±3.5	94.0 ±1.9	19.4 ±1.0	1.4 ±0.4	0.6 ±0.2
Blok Config. II	126.03 ±30.3	42.6 ±4.8	20.9 ±1.5	18.6 ±1.8	10.4 ±1,9	5.4 ±0.6
Cybula Config. II	147.13 ±22.3	44.9 ±31.3	31.3 ±20.3	20.3 ±1.5	3.4 ±2.3	1,5 ±1.0
Bronk Config. I	164.2 ±7.4	—	85.9 ±9.7	16.8 ±0.9	—	6.7 ±0.9

In recent years the increase of interest in hybrid treatment wetland systems has been observed [1÷3]. These systems are composed of two or more filters with mixed flow direction of sewage. Apparently in the HCW_S the benefits of both types of bed are merged, resulting in better effluent quality (lower organic matter concentration, complete nitrification and partial denitrification).

In Poland the studies were carried out at five local Hybrid Constructed Wetlands (HTW), intended to domestic wastewater treatment, in Darżlubie, Wieszyno, Wiklino, Sarbsk and Schodno in Pomerania Region in Poland. Recipient of treated effluent is Baltic Sea. The sewage after mechanical treatment in primary settling tanks were pumped into beds with subsurface flow of sewage. In all analysed systems, at the beginning of the biological stage of treatment, beds with horizontal flow (SS HF) were used. The analysed systems differ from one another in the order and number of subsequent stages. These differences: the number of beds used and the way of sewage supplied are shown in Table 4.

Table 4. Operating conditions of local Hybrid Constructed Wetlands (HTW)
Tabela 4. Charakterystyka analizowanych HSH

Object	Q [m^3/d]	Configuration
Darżlubie	56.7	SS HF I, cascade filter, SS HF II, SS VF, SS HF III, parallel, continuously
Wiklino	18.6	SS HF I, SS VF, SS HF II, alternately, intermittent
Wieszyno	24.5	SS HF I, SS VF, SS HF II, in series, continuously
Sarbsk	297.0	SS HF, SS VF, parallel, continuously + recirculation into HF
Schodno	2.2÷8.9	SS HF I, SS VF I, SS HF II, SS VF II, willow plantation VF I – 4 compartments alternately, intermittent VF II – 2 compartments alternately, intermittent

The comparison of average pollutants concentration, with standard deviations, in the influent and effluent from monitored Hybrid Treatment Wetlands is presented in Table 5 and 6.

Table 5. Average concentrations for characteristic pollutants in the influent to the HTWs
Tabela 5. Średnie wartości stężeń charakterystycznych wskaźników zanieczyszczeń w ściekach doprowadzanych do analizowanych obiektów

Parameters	Unit	Schodno n=18	Darżlubie n=21	Wiklino n=88	Wieszyno n=18	Sarbsk n=38
TSS	mg/l	156.6 ≥ 51.2	359.5 ≥ 87.9	539.3 ≥127.2	1269.5 ≥ 167.6	819.9 ≥ 208
COD	mg O_2/l	880.0 ≥ 189.2	837.5 ≥ 156.3	466.3 ≥ 92.7	1021.9 ≥ 251.2	687.6 ≥162.9
BOD_5	mg O_2/l	448.5 ≥ 123.2	401.5 ≥ 51.3	265.2 ≥ 51.7	657.3 ≥ 118.5	420.0 ≥ 87.2
N_{tot}	mg/l	96.1 ≥ 36.7	176.3 ≥ 35.6	104.1 ≥ 10.2	114.0 ≥ 22.1	73.8 ≥ 21.9
$N\text{-}NH_4^+$	mg/l	78.0 ≥ 28.5	82.6 ≥ 23.4	87.3 ≥ 9.0	84.8 ≥ 15.3	47.1 ≥ 13.7
$N\text{-}NO_3^-$	mg/l	0.1	1.3 ≥ 0.3	0.8 ≥ 0.2	1.0 ≥ 0.4	0.9 ≥ 0.1
Org-N	mg/l	16.6 ≥ 3.9	90.8 ≥ 26.8	16.2 ≥ 5.3	27.9 ≥ 8.9	25.9 ≥ 7.3
P_{tot}	mg/l	14.6 ≥ 3.9	15.3 ≥ 0.8	15.2 ≥ 0.7	20.1 ≥ 1.2	11.9 ≥ 0.9

n – number of samples

Table 6. Average concentrations of pollutants in the effluent from HTWs
Tabela 6. Średnie wartości stężeń charakterystycznych wskaźników zanieczyszczeń w ściekach odprowadzanych z analizowanych obiektów

Parameters	Unit	Schodno n=18	Darżlubie n=21	Wiklino n=88	Wieszyno n=18	Sarbsk n=38
TSS	mg/l	48.6 ± 20.1	92.0 ± 27.3	36.3 ± 17.2	106.4 ± 31.7	45.6 ± 49.9
COD	mg O_2/l	178.1± 38.1	210.5 ± 67.8	31.5 ± 8.9	175.9 ± 99.3	44.2 ± 15.9
BOD_5	mg O_2/l	96.6 ± 20.1	72.0 ± 21.4	10.9 ± 4.1	85.9 ± 53.6	19.0 ± 1.7
N_{tot}	mg/l	37.2 ± 9.9	56.5 ± 16.9	21.7 ± 5.5	87.3 ± 14.8	27.6 ± 8.5
$N\text{-}NH_4^+$	mg/l	30.6 ± 8.7	30.3 ± 11.5	6.0 ± 4.3	67.1 ± 14.2	16.8 ± 11.2
$N\text{-}NO_3^-$	mg/l	0.3	5.9 ± 2.8	9.6 ± 6.7	0.6 ± 0.3	5.03 ± 9.38
Org-N	mg/l	7.2 ± 1.3	22.5 ± 5.6	4.3 ± 1.7	19.53 ± 12.91	5.8 ± 2.3
P_{tot}	mg/l	3.5 ± 0.9	6.9 ± 2.1	7.2 ± 1.6	14.6 ± 3.9	8.9 ± 3.1

n – number of samples

The objective of carried out monitoring was to determine the quality of sewage after each stage of treatment. Analysed facilities differ among each other both with inflowing pollutants concentration as well as the pollutants efficiency removal. Also the unit area per person equivalent applied in monitored HTWs differ significantly – the lowest was applied in Darżlubie and the bigger in Schodno HTW. As a consequence, among five analysed HTWs, the highest hydraulic load was observed in Darżlubie HTW. In terms of SS VF beds in Darżlubie hydraulic load was 226.8 mm/d and was much higher than recommended to avoid clogging (lass than 120 mm/d during vegetation and even less than 80 mm/d during non-vegetation season) but still did not exceed the maximal hydraulic load for TW beds equal to 300 mm/d [4, 10, 15].

Same of monitored HTWs did not work properly. Most frequently due to improper operation of septic tanks, which were not equipped with oil collector, and to short retention time caused that majority of organic suspended solids skipped away to TWs. Discharging of too high loads of contaminations leads to clogging of the beds and to decrease of contaminations removal efficiency (Wieszyno) in consequence. In many cases the overloading together with exceeding of recommended hydraulic loads lead to the operation conditions change of the systems from subsurface into surface flow which should be dimension and operated with different role [4, 11].

4. Discussion

The comparison of three types of wastewater treatment plant (Bioclere®, one stage treatment wetlands and multistage TWs) applied in scattered development did not bring the definitive answer which technology is the proper one. It could be conclusive that Bioclere® technology was characterized by the highest efficiency of BOD_5 removal as well as in all monitored plants similar effectiveness was observed what could indicated stable run of treatment processes (performance). Although all monitored $WWTP_s$ ensured over 70% efficiency of COD the lowest efficiency was assumed for one stage SS VF beds. The reduction of TSS was over 70% with the exception of Hewelt TW where the reduction was less then 50%. The reduction of nutrient compounds varied significantly. Most of monitored plants shown stable efficiency removal with the rang 60÷90% of TN and about 80% for TP, while in same the reduction is much lower. In spite of low efficiency removal of N and P the plants were characterized by effective removal of organic matter. The efficiency of characteristic pollutants removal is shown in Figure 4.

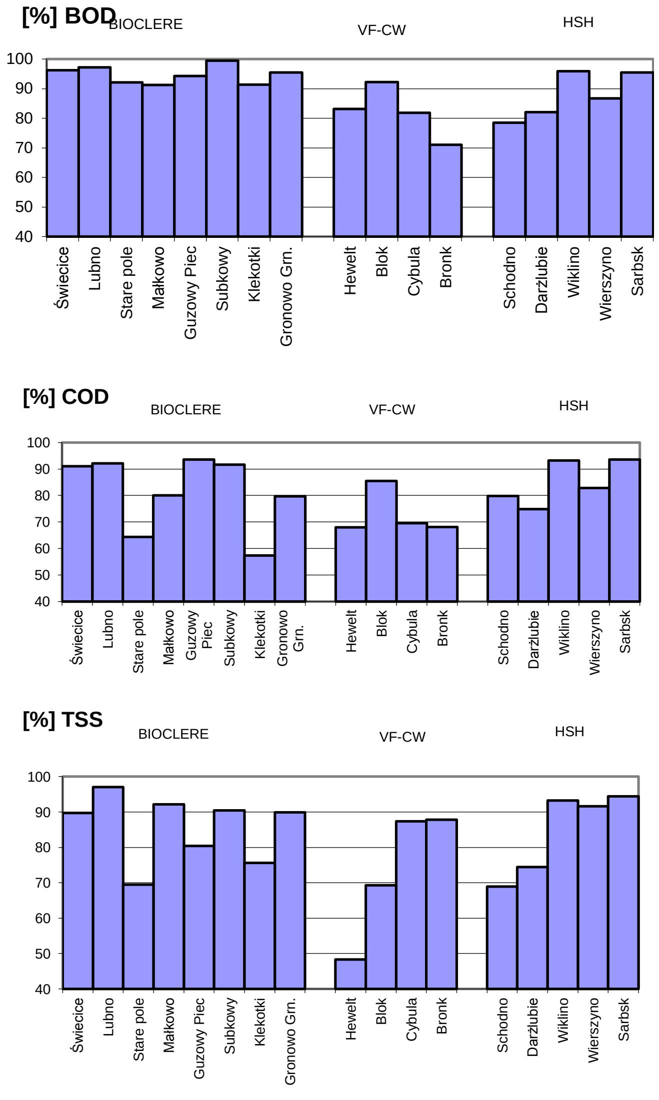
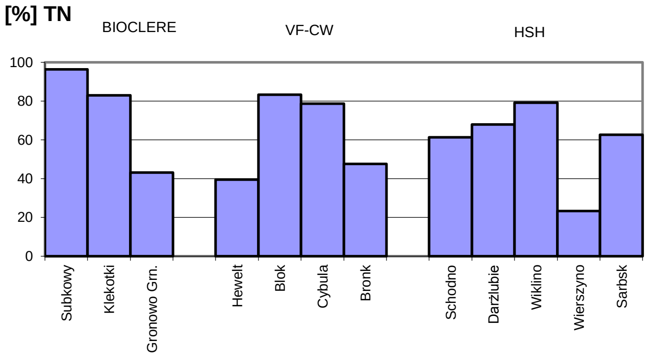
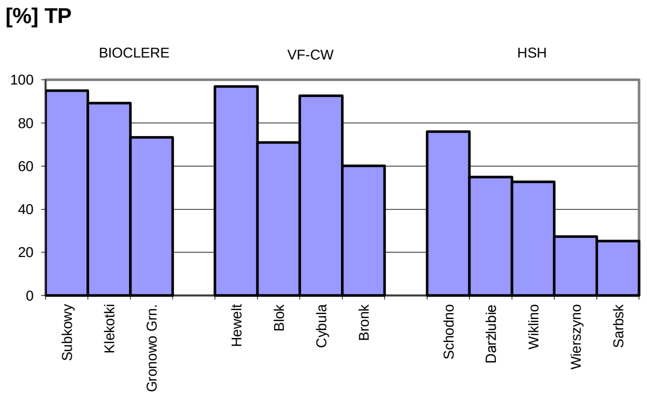


Fig. 4. The comparison of characteristic pollutants efficiency removal in Bioclere®, SS VF I and HCW_s

Rys. 4. Porównanie skuteczności oczyszczalni Bioclere®, VF-CW i HSH w usuwaniu charakterystycznych wskaźników zanieczyszczeń





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6. Conclusions

Based on carried out investigation it could be assumed that all of analyzed wastewater treatment plants ensured good pollutants efficiency removal. Single exceptions are most often coursed by unusual raw wastewater characteristic than application of improper technology. Presented technical solution can be successfully applied for treatment of small wastewater amount from scattered development. In the contrast to activated sludge technology they are not so sensitive for hydraulic load fluctuations and there is no need to employ high educated staff to run such facilities. Although the treatment wetlands, specially multistage ones, do need specific unit area per person equivalent but they provide effective removal of characteristic pollutants. While the alternative solution could be trickling filter technology Bioclere®, which due to compact design needs much less space but the installation and maintenance costs higher. For single houshold very promising solution could be one or two stage treatment wetland with vertical flow. Additional benefits of this solution could be possibilities of individual arrangement the aesthetical appearance of the treatment wetland by investors. Very often individual treatment wetlands could be arrange more like gardens "sewage gardens" than treatment facilities.

Concluding all analysed technologies could be successfully applied for wastewater treatment in rural areas of Poland. The chose of technology is more or less dependent on local condition and economic aspect.

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Doświadczenia z eksploatacji urządzeń do oczyszczania ścieków dla terenów niezurbanizowanych

Streszczenie

Problem oczyszczania ścieków bytowych na obszarach niezurbanizowanych należy uznać za aktualny i wymagający rozwiązania w najbliższych latach. W pracy porównano wyniki uzyskane podczas eksploatacji urządzeń (złóż biologicznych z wypełnieniem z tworzyw sztucznych) z pracą obiektów hydrofitowych. Podejmowane działania potwierdzają, że zarówno konstrukcje konwencjonalnych urządzeń mechanicznych oraz nowe konfiguracje systemów hydrofitowych stanowią interesujące rozwiązania dla małych ilości ścieków wytwarzanych na obszarach niezurbanizowanych.