

Application of Trickling Filter and Vertical Flow Constructed Wetland Bed to Treat Sewage from Craft Brewery

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ABSTRACT

In Poland, as well as worldwide, an increase in craft beer production can be observed. In the last several years, more than 150 of such breweries have appeared and according to Polish Brewery Association, their number might ultimately reach 500. Many of them emerge in the areas with no access to a central sewerage system so they have to solve the problem of waste management on their own. The article presents the results of research on the possibility of using a hybrid system for biological treatment of sewage from craft breweries. The sewage came from a craft brewery Waszczukowe located in the Podlaskie province. A laboratory scale model consisted of a trickling filter (TF) (research model Gunt CE701e) and vertical flow constructed wetland (SS-VF). Innovative filling (*Certyd* produced by LSA company) of TF and SS VF was applied. The conducted study included determining the changes in the sewage parameters during hybrid treatment, as well as TF and SS VF efficiency separately. The aim of the research was to show the possibility of treating sewage to a point when it was possible to discharge it to a receiver, in compliance with the Polish legal regulations. The research results might be used in designing a treatment system or sewage pretreatment in craft breweries. The average efficiency of TF operating with 100% recirculation was 76% for BOD₅, 80% for COD, 26% for TN and 34% for TP, while the total treatment efficiency of a hybrid system (TF and SS-VF) was 98%, 98%, 72% and 77%, respectively. The load of TF during operation with recirculation was on average 0.38 kg BOD₅ m⁻²d⁻¹, 0.57 kg COD m⁻² d⁻¹. The load of SS-VF was on average 0.09 kg BOD₅ m⁻² d⁻¹ and 0.12 kg COD m⁻²d⁻¹. The obtained results of hybrid treatment permitted to discharge the sewage to the receiver.

Keywords: craft brewery, sewage treatment, trickling filter, vertical flow constructed wetland, *Certyd*

INTRODUCTION

Beer revolution is a term strictly connected with the development of small breweries in Poland since 2011. Small breweries include microbreweries, restaurant and contract breweries. The number of small breweries grew from 29 to 200 between the years 2011 and 2016 [Wojtyra & Grudzień 2017]. Ultimately, around 5000 craft breweries might appear on the Polish market; their share in beer production is currently at around 0.5%. For comparison, there are around 1000 such breweries in Germany and almost 5000 in the United States.

For the craft breweries located in non-urbanized areas, sewage treatment is a significant problem. If there is no possibility of discharging sewage to a central sewerage system or if the WWTP is insufficient, it is necessary to build a system for sewage treatment or pretreatment. The sewage treatment technology for a craft brewery should be adjusted to the changing pollutant loads connected with this specific type of production. The craft brewery sewage is characterized by higher pollutants indicators in comparison with large industrial facilities; also, the irregularity of its discharge is larger [Janczukowicz et al. 2013]. This type of sewage can be treated with physical,

chemical as well as biological methods. The treatment of brewery sewage for reuse requires an application of membrane filtration after the biological stage [Simate et al. 2011].

In the case of manufacture breweries, the most common solution is anaerobic sewage pretreatment before discharge to a municipal WWTP. The anaerobic sewage treatment in beer production has a number of advantages, including the possibility of producing electric energy from the biogas generated in the process of anaerobic sewage treatment. Manufacture breweries typically have access to a sewerage system and municipal WWTPs and can discharge their pretreated sewage there. A full treatment process after which the sewage reaches the parameters that allow its discharge to receivers is also possible [Simate et al. 2011, Driessen & Vereijken 2003, Enitan et al. 2014]. This solution is the most beneficial one from the point of view of WWTPs. Brewery sewage has a similar composition to that of municipal sewage; however, it is characterized by a much higher content of organic substances measured by BOD_5 and COD indicators. It is possible to apply classical sludge aeration chambers, but unlike anaerobic treatment, it is necessary to supply energy for aeration process. Trickling filters (TF) are not popular for brewery sewage treatment. With rotary biological contactors, they are mainly applied for domestic or municipal sewage treatment [Szulżyk-Cieplak et al. 2018]. Their efficiency is lower in comparison with a sludge activated system, especially for the nitrogen and phosphorus removal. An additional treatment may be required to obtain the discharge standards. On the other hand, they have many advantages such as no excess sludge, low power requirements and effectiveness in treating high concentration of organics [Daigger & Boltz 2011, Post & Medlock 2002, Żyłka et al. 2018].

Constructed wetlands have been used for the treatment of municipal and industrial sewage, septage, reject water, rain water or landfill leachate [Dąbrowski et al. 2018, 2019, Kadlec and Wallace 2009, Karolinczak and Dąbrowski 2017, KołECKA et al. 2017, Puchlik 2016]. Such systems are considered as an environmentally friendly and low-cost technology. No chemicals are added and there is no need for artificial aeration. Kadlec (2009) reported the application of CW systems for food processing sewage in the following areas: sugar refining, potato processing, milk products, meat processing as well as dairy, pig and cattle farms. Additionally, winery

effluent can be treated with different types of CWs. On the other hand, only a few applications of CWs can be found for treatment of brewery sewage. The South African Miller brewery plant tested a system of anaerobic treatment with integrated algae pond with final treatment using a horizontal flow CW system [Massi et al. 2018]. Kadlec and Wallace (2009) reported a Free Water Surface (FWS) to be in operation for the Coors Brewery in Colorado, USA.

Due to the low daily amount of sewage discharged from craft breweries there are no grounds to apply the anaerobic system. The biological treatment systems based on active sludge require a constant sewage feed; it is also necessary to solve the problem of sewage sludge treatment. The trickling filter technology ensures high efficiency treatment without typical waste (excess sludge) generated during sludge activated treatment process. There is no need for the artificial aeration and power requirement is low.

The authors suggest applying a hybrid system based on a TF and SS-VF constructed wetland. A similar solution based on a TF system and final treatment in two stages SS VF for domestic wastewater treatment was developed by the French company SCRIPÉ [Gourdon et al. 2017].

The research conducted in laboratory scale with the real sewage from a craft brewery will allow designing an implementation installation which ultimately can be used in Waszczukowe brewery in case of significant production increase.

MATERIAL AND METHODS

Laboratory scale research installation

The hybrid research installation consisted of a TF and SS VF was operating in a laboratory at Department of Environmental Engineering Technology and Systems, BUT. A scheme of the research installation and sampling points are presented in Figure 1.

The TF was designed by GUNT company (Figure 2). The total volume of the TF was 90 liters, while the surface area amounted to 0.09 m². The retention tank had the volume of 200 liters. A rotary distributor allowed supply of the bed, whereas the aeration vents below a fixed bed supplied the biofilm process with oxygen. CE 701 model is equipped with a collecting tank and recirculation pumps. A secondary clarifier and

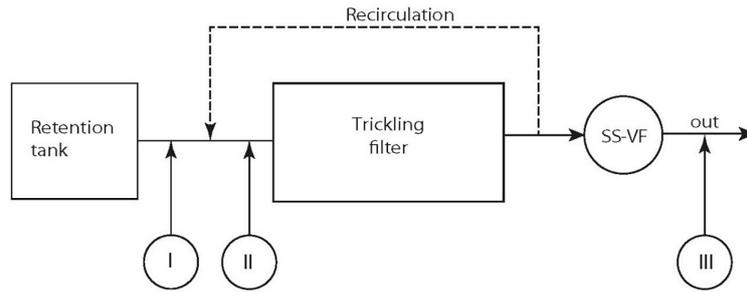


Fig. 1. Scheme of hybrid research installation with sampling points

aeration compressor were used during the startup of the biofilm process with domestic sewage.

In order to avoid clogging, an innovative filling was applied in the TF as additional to plastics (Figure 2). It was lightweight sintered aggregate (LSA) *Certyd*. It is a ceramic and porous material produced in accordance with LSA technology featuring sintering process in a rotary furnace. It is obtained by thermal processing of ash. The product is confirmed with EN-13055:2016-07 Light aggregate standard. It has the certificate of National Institute of Hygiene no. HR/B/86/2015 [LSA LLC]. The main filling of the TF was plastic (80%) and *Certyd* (20%).

The startup was carried out for a few weeks, until stable parameters of domestic sewage were obtained. The examination of the biofilm structure ensured the proper functioning of the bed. After the start up process, the installation started to treat the brewery sewage. The TF was operating with 100% recirculation, the hydraulic load was $0.3 \text{ m}^3 \text{ m}^{-2} \text{ d}^{-1}$.

SS VF was the second part of the hybrid system. Figure 3 presents a cross section of SS VF bed. The surface of SS VF was 0.1 m^2 , its height 0.8 m. The bed was planted with *Phragmites*

australis. It was filled only with *Certyd*, which was tested as a material substituting natural filling e.g. sand and gravel. In the last decade, research was conducted several times applying different materials as filter media in trickling filters and constructed wetlands [Dąbrowski et al. 2018, Ali et al. 2017, Ashan et al. 2017, Łobos-Moysa et al. 2016, Habte Lemji & Eckstädt 2013]. The hydraulic load of the SS VF bed supplied with brewery sewage treated in the TF was $0.1 \text{ m}^3 \text{ m}^{-2} \text{ d}^{-1}$. The SS-VF bed was operating as classical one stage unsaturated system [Nivala et al. 2019, Karolinczak & Dąbrowski 2017].

Sampling and scope of the determination

The efficiency tests of the hybrid system were carried out from February to May 2019 (ten series after the start-up process). The parameters of installation operation were determined on the basis of quality tests of sewage from a craft brewery from 2018. The raw brewery sewage used in laboratory tests was sampled from an averaging tank installed in the brewery and transported to the BUT laboratory. The air temperature during the laboratory scale experiment was stable and varied from



Fig. 2. Trickling filter during operation. View of the filling material: plastic and *Certyd*.

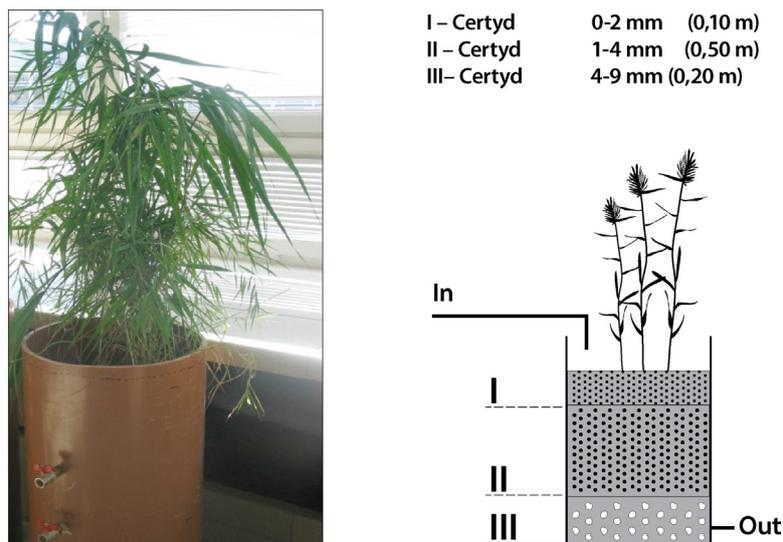


Fig. 3. Laboratory scale constructed wetland SS-VF used during experiment

18°C to 20°C. The basic analyses were performed: biochemical oxygen demand BOD₅, chemical oxygen demand COD, total Kjeldahl nitrogen TKN, ammonia nitrogen N-NH₄⁺, nitrate nitrogen (V) N-NO₃⁻, nitrite nitrogen (III) N-NO₂⁻ and total phosphorus TP. Also, pH, conductivity and dissolved oxygen concentration were monitored to check the technological parameters of the TF and SS VF bed.

The tests were conducted in BUT laboratory in accordance with the procedures set out in the Regulation of the Environmental Protection Minister from 18th November 2014 and in accordance with the American Public Health Association [Regulations 2014, APHA 2005]. The parameters of brewery sewage (with 100% recirculation) as sewage after treatment with the TF supplying a SS VF bed were used to calculate the pollutants load. The removal efficiency was calculated as a concentration reduction in hybrid system and separately for the TF and SS VF bed. Additionally, the parameters of raw brewery sewage without recirculation were determined. All sampling points (I-IV) were presented in Figure 1.

RESULTS AND DISCUSSION

Characteristics of craft brewery sewage

The main parameters of raw sewage from Waszczukowe craft brewery company are presented in Table 1. The samples were taken from an averaging tank located within the company.

The parameters of raw sewage are mainly connected with the washing process [Janczukowicz et al. 2013]. In large brewery companies, cleaning-in-place stations (CIP) are commonly in use. In small breweries, the process of washing is managed without CIP installations. In addition, the water and sewage management in a craft brewery is different in comparison with large companies. It concerns cooling water especially. The parameters presented in Table 1 are mostly similar to those achieved by different authors analyzing brewery sewage characteristics and its treatment [Driessen & Vereijken 2003, Simate et al. 2011, Enitan et al. 2014, Janczukowicz et al. 2013]. The composition of brewery sewage is similar to the parameters of sewage from e.g.

Table 1. Characteristics of raw sewage from craft brewery plant – sampling point I

Parameter	Unit	Mean ± st. dev.	Min-max
BOD ₅	mg O ₂ dm ⁻³	2140 ± 143	1940 – 2360
COD	mg O ₂ dm ⁻³	3910 ± 197	3600 – 4200
TKN	mg N dm ⁻³	42.0 ± 5.0	36.0 – 51.0
NH ₄ ⁺ -N	mg NH ₄ ⁺ -N dm ⁻³	5.6 ± 1.5	3.6 – 8.9
NO ₃ ⁻ -N	mg NO ₃ ⁻ -N dm ⁻³	1.7 ± 0.5	1.0 – 2.6
TN	mg N dm ⁻³	43.8 ± 5.2	37.2 – 52.0
TP	mg P dm ⁻³	23.6 ± 2.5	19.8 – 28.0

dairy or meat industry [Żyłka et al. 2018]. It is characterized by high content of organic substances measured by BOD₅ and COD. While analyzing biogenic compounds, it was concluded that the total nitrogen concentration is lower than in municipal sewage, while the phosphorous concentration is higher [Heidrich & Witkowski 2015, Klimiuk & Łebkowska 2004]. The phosphorous contained in brewery sewage comes from the processes of washing machines. The concentration of biogenic compounds is strictly connected with how machines are washed. In the analyzed brewery an automatic cleaning station Cleaning in Place (CIP) is not used, which might affect the higher concentration of ammonia nitrogen and phosphorus. During the research, it was observed that ammonia in the N-NO₂ form practically does not occur in both raw and treated brewery sewage.

Treatment efficiency

Table 2 presents the results of tests on the sewage which was fed to the trickling filter (sampling point II, Fig. 1), inlet to SS-VF (sampling point III, Fig. 1) and the outflow from hybrid system (sampling point IV, Fig. 1). The applied recirculation level resulted from the necessity of reducing the pollutants load in the sewage which supplied the SS-VF bed so that upon reaching the outflow the sewage had parameters compliant with legal regulations [Regulation 2014].

Applying 100% recirculation during the TF operation decreased the parameters of raw sewage to 1256 mgO₂ dm⁻³ for BOD₅ and 1891 mgO₂ dm⁻³ for COD, respectively. It enabled to increase the process effectiveness through reaching the parameters similar to those of municipal sewage. The concentration of total ammonia after the treatment process with the use of TF varied between from 20.0 to 28.9 mgN dm⁻³ and from 9.5 to 13.1 mg P dm⁻³ for phosphorus, respectively.

Figure 4 presents the efficiency of brewery sewage treatment in research installation: separately for trickling filter TF, constructed wetland SS VF and total efficiency of the hybrid system. The effectiveness was calculated on the basis of average parameter values of sewage supplying particular installation elements.

The obtained results confirm the possibility of highly efficient treatment of all parts of the hybrid system. The trickling filter was operating low-loaded with the average load of 0.376 kg BOD₅ m⁻³d⁻¹.

Low hydraulic load resulted from the fact that the sewage, which supplied the bed was characterized by the high content of organic substance in comparison with typical municipal sewage for which the trickling filter operating parameters were established [Daigger & Boltz 2011, Ali et al. 2017]. The average pollutant load of SS VF was 90.9 gO₂ m⁻²d⁻¹ for BOD₅ and 115.2 gO₂ m⁻²d⁻¹ for COD. Low hydraulic load allowed successful removal of organic substances. The effectiveness of the hybrid system was high and reached 98% for BOD₅ and COD, 72% for TN and 77% for TP. It confirmed the purpose of applying the hybrid system. Gourdon et al. (2017) conducted a similar research on the intensification of removing ammonia and phosphorous in a hybrid system consisting of a trickling filter (for biological pretreatment) followed by two stages of partially saturated vertical flow beds planted with reeds. The removal efficiency of domestic sewage in SS VF beds was on average 97.9% for BOD₅, 94% for COD, 70.9% for TN and 59.6% for TP.

CONCLUSIONS

A growing market of craft breweries in Poland causes the necessity of sewage treatment or pretreatment with the use of a simple, effective

Table 2. Characteristics of inflow to biological filter (sampling point II) and inflow (III) and outflow (IV) from SS VF

Parameter Unit		Inflow to TF		Outflow from TF Inflow to SS VF		Outflow from SS VF	
		Mean ±st.dev.	Min-max	Mean ±st.dev.	Min-max	Mean ±st. dev.	Min-max
BOD ₅	mgO ₂ dm ⁻³	1256±120	980–1440	303±20	270–330	21±2	18–24
COD	mgO ₂ dm ⁻³	1891±106	1730–2060	384±24	350–430	40±3	32–43
TNK	mgN dm ⁻³	31.7±4.1	26.2–41.0	17.4±2.1	14.0–22.0	5.5±0.5	5.0–6.2
NH ₄ ⁺ -N	mgN-NH ₄ ⁺ dm ⁻³	2.8±0.7	2.0–4.0	0.4±0.2	0.2–0.6	0.1±0.1	0.0–0.3
NO ₃ ⁻ -N	mgN-NO ₃ ⁻ dm ⁻³	1.1±0.2	0.8–1.6	6.9±0.9	6.0–9.0	3.7±0.4	3.0–4.2
TN	mgN dm ⁻³	32.8±4.1	27.1–41.8	24.3±2.4	20.0–28.9	9.3±0.5	8.2–10.2
TP	mgP dm ⁻³	17.2 ± 1.2	16.0 – 20.1	11.3 ± 1.1	9.5–13.1	3.9±0.5	2.9–4.7

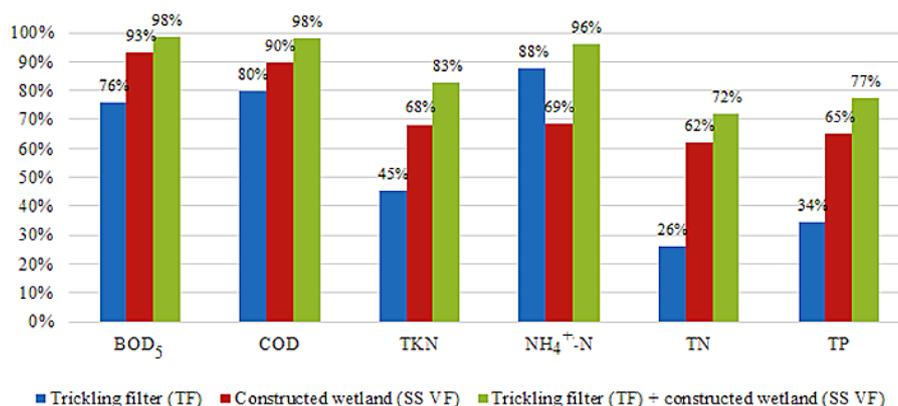


Fig. 4. Efficiency of TF, SS-VF and hybrid system

and tested technology. Diverse demands in terms of sewage treatment degree require hybrid technology which will allow, depending on the needs, full treatment or pretreatment of sewage. In the case of pretreatment of the sewage discharged to municipal WWTPs, it is possible to construct and exploit a chosen element of the hybrid system.

The results from this study confirm the high efficiency of craft brewery sewage treatment in hybrid systems consisting of TF and SS-VF. The total efficiency of organic substances removal measured by BOD₅ was on average 98% for hybrid while 76% for TF and 93% for SS-VF. The TN removal was 72%, 26% and 62% respectively, while TP 77%, 34% and 65%.

Moreover, the research has proven the possibility of applying the *Certyd* filling, obtained from waste, as filter media in the TF and SS VF bed. It was confirmed by the tests on biofilm biocoenosis during the system start-up and exploitation.

The conclusions from the research can be used for a real-scale application project. The possibility of sewage recirculation in SS-VF bed for higher efficiency treatment will also be anticipated in the implementation system. Further studies will explore the possibility of water reuse in the craft brewery industry.

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Table 3. TF and SS-VF load and load removed

Parameter	Load		Load removed	
	TF	SS-VF	TF	SS-VF
	g m ⁻² d ⁻¹			
BOD ₅	376.8±35.9	90.9±5.9	285.9±31.9	88.9±5.7
COD	567.3±31.8	115.2±7.1	452.1±27.0	111.2±7.0
TNK	9.5±1.2	5.2±0.6	4.3±0.6	4.7±0.6
NH ₄ ⁺ -N	0.9±0.2	0.1±0.05	0.7±0.2	0.1±0.04
TN	9.8±1.2	7.3±0.7	2.6±0.7	6.4±0.7
TP	5.2±0.4	3.4±0.3	1.8±0.4	3.0±0.3

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