

Trickling Filter for High Efficiency Treatment of Dairy Sewage

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ABSTRACT

The article presents the results of the research on the possibility of using a trickling filter for high efficiency treatment of dairy sewage. Nowadays, to the best of the authors' knowledge, it is possible to change the activated sludge system to the trickling filter technology, especially in small dairy plants with lower raw sewage parameters in comparison to larger plants. In the research, dairy wastewater after dissolved air flotation (DAF) process was treated with a laboratory scale Gunt CE701e research model which allows to control the basic parameters of the treatment with a trickling filter (TF). The conducted study included determining the changing sewage parameters during the DAF process, as well as the trickling filter (TF) efficiency. Such parameters as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total Organic Carbon (TOC), total Kjeldahl nitrogen (TKN) and total phosphorous (TP) were checked. The research results confirmed the possibility of high efficiency treatment of dairy sewage with DAF and trickling filter technologies. The average efficiency of DAF treatment was 59.3% for BOD, 49.0% for COD and 80.0% for TP, while the average treatment efficiency of TF was 87.3%, 78.3% and 27.9% without recirculation and 95.2%, 85.5% and 42.0% with 100% recirculation applied, respectively. The load of TF during the operation without recirculation was on average 0.22 kgBOD₅·m⁻³·d⁻¹ and 0.25 with 100% recirculation. Applying recirculation allowed to reach the BOD, COD and total phosphorus standards for the sewage discharged to a receiver from Bielmlek dairy WWTP. On the other hand, the concentration of total nitrogen exceeded the permitted standards in this facility.

Keywords: dairy sewage, trickling filter, dissolved air flotation, efficiency

INTRODUCTION

TFs have been used to provide biological sewage treatment for more than 100 years. A TF is a non-submerged fixed-film biological reactor using rock or plastic media over which sewage is distributed continuously [Tchobanoglous, 1997; Godoy-Olmos et al., 2016]. They were commonly used in Poland in the 1970s and 1980s for treating both municipal and food industry sewage. Classic TFs (sprinkling system) generally operated with Imhoff tanks. Additionally, rotary biological contactors (RBC) were widely applied in small towns and such facilities as hotels, holiday resorts etc. Discontinuing their usage in Poland resulted from introducing the demands concerning intensive removal of biogenic compounds in 1991 [Regulations, 1991; Regulations, 2014].

It practically caused the disappearance of this technology for the sake of the activated sludge. In Russia, for example, a limited use of trickling filter stemmed from very high standards for removing the organic substance for specific sewage receivers. [Gogina & Yantsen, 2015]. Unlike in Poland, wastewater treatment plants using TF or RBCs still function successfully, for instance in Great Britain, where RBCs operate with vertical or horizontal flow constructed wetlands [Obarska-Pempkowiak et al., 2010]. The experiments involving RBCs for landfill leachate treatment confirm that an effective usage of constructed wetlands technology is possible not only for the treatment of municipal sewage [Passeggi et al., 2012, Habte & Eckstadt, 2013]. This technology, contrary to the activated sludge, is much simpler and bears lower exploitation cost. Operating TFs

or RBCs do not generate the waste typical for the activated sludge method; they are also characterized by lower power requirements [EPA, 2000; Daigger & Boltz, 2011; Post & Medlock, 2002, Henrich & Marggraff, 2013]. TFs can be classified as roughing, carbon oxidation, carbon oxidation and nitrification and tertiary nitrification [Tchobanoglous, 1997, Daigger & Boltz 2011, Henrich, 2014]. The classification of TFs into low, medium and highly loaded ones is based on the value of $\text{kgBOD}_5 \cdot \text{m}^{-3} \cdot \text{d}^{-1}$ indicator. Highly loaded ones operate with $0.65\text{--}3.2 \text{ kg BOD}_5 \cdot \text{m}^{-3} \cdot \text{d}^{-1}$ and low loaded ones with 0.07 to $0.22 \text{ kg BOD}_5 \cdot \text{m}^{-3} \cdot \text{d}^{-1}$ [Tchobanoglous, 1997]. In the TFs classification, surface hydraulic load parameter, expressed as $\text{m}^3 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$, is also used [Dymacze-wski et al., 1997]

MATERIAL AND METHODS

Dairy WWTP characteristic

The research was carried out in a wastewater treatment plant of dairy cooperative Bielmlek in Bielsk Podlaski, Poland. The dairy plant specializes in the production of cheese, butter, powdered milk and powdered whey. The designed hydraulic capacity of their dairy WWTP is $750 \text{ m}^3 \cdot \text{d}^{-1}$, while the maximum is $1200 \text{ m}^3 \cdot \text{d}^{-1}$. Mechanical and biological blocs are capable of treating daily up to $1106 \text{ kgO}_2 \cdot \text{d}^{-1}$, $2531 \text{ kgO}_2 \cdot \text{d}^{-1}$, $348 \text{ kg} \cdot \text{d}^{-1}$, $90 \text{ kgN} \cdot \text{d}^{-1}$ and $13,5 \text{ kgP} \cdot \text{d}^{-1}$ of BOD_5 , COD, TSS, TN and TP respectively. The production profile of the site determines a high concentration of or-

ganic pollutants in sewage, as well as high fluctuations in the quality and quantity of wastewater [Dąbrowski & Żyłka, 2015; Danalewich et al., 1998]. According to the data obtained in 2016, the average flow capacity was $550 \text{ m}^3 \cdot \text{d}^{-1}$ (range $220\text{--}2020$), the personal equivalent was on average 13500 and daily dewatered sludge production was 0.22 tons of dry mass. The average concentration of pollutants in the inflow in 2016 was 1521 ($350\text{--}2650$) $\text{mgO}_2 \cdot \text{dm}^{-3}$, 2055 ($456\text{--}4410$) $\text{mgO}_2 \cdot \text{dm}^{-3}$, 90.1 ($7.2\text{--}265.0$) $\text{mgN} \cdot \text{dm}^{-3}$ and 19.5 ($4.7\text{--}36.0$) $\text{mgP} \cdot \text{dm}^{-3}$ for BOD_5 , COD, TN and TP respectively. The primary sewage treatment is based on screening, sand removal and dissolved air flotation DAF (Fig. 1). The biological treatment is carried out in two Sequencing Batch Reactors (SBRs). Excessive sludge is mechanically dewatered and used as fertilizer. The treated wastewater is discharged to the Biała river. Figure 2 presents a scheme of Bielmlek dairy WWTP (sewage and sludge treatment). The required treatment efficiency for dairy WWTPs is determined by Water Permission [IPPC, 2015]. It specifies the maximum concentration of pollutants in the outflow as 25, 125, 30 and 1 $\text{mg} \cdot \text{dm}^{-3}$ for BOD_5 , COD, TN and TP, respectively.

Laboratory scale installation

In laboratory tests, the pretreated sewage from Bielmlek dairy WWTP after DAF flotation was used. A testing system designed by the GUNT company (figure 3) was applied mainly for carbon removal and nitrification. It consisted of a TF filled with fittings made of HDPE ma-



Figure 1. DAF flotation in Bielmlek WWTP

terial. The total volume of the TF is 90 liters, while its diameter measures 340 mm. The supplying tank has the volume of 200 liters. The carrier material (HDPE) has the specific surface of $180 \text{ m}^2 \cdot \text{m}^{-3}$. The rotary distributor allows an even supply of the bed (sprinkling), while the aeration vents located below a fixed bed supply the biofilm process with oxygen. The CE 701 model is also equipped with a collecting tank and recirculation pumps. A secondary clarifier and aeration compressor are used only during the startup of the biofilm process.

Sampling, measuring methods and startup of biofilm process

The efficiency tests of DAF flotation in Bielmlek dairy WWTP were carried out in October and November 2017 (ten series). The laboratory scale part of the research with the TF was conducted in November 2017 (12 series with $0.44 \text{ m}^3 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ hydraulic load, with and without recirculation). During the operation, 100% recirculation was applied to achieve the results allowing for reaching the parameters required for the quality of treated sewage in Bielmlek WWTP [IPPC, 2015]. The air temperature during the laboratory scale experiment was stable and varied from 16°C to 18°C . The basic physical and chemical analyses were performed, including: biochemical oxygen demand BOD_5 , chemical oxygen demand COD, total organic carbon TOC, total Kjeldahl nitrogen TKN, ammonia nitrogen N-NH_4^+ , nitrate nitrogen N-NO_3^- , nitrite nitrogen N-NO_2^- and total phosphorus TP. The parameters of dairy sewage supplying the installation were used to calculate the load of the TF. Deter-

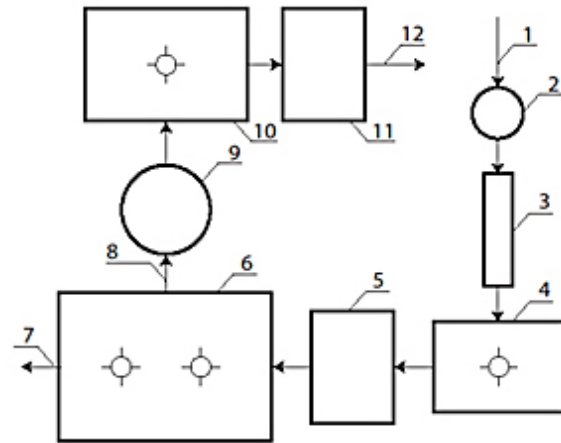


Figure 2. Flow diagram of Bielmlek dairy WWTP: 1. Raw dairy sewage, 2. Screen, 3. Grit chamber, 4. Buffer tank, 5. DAF flotator, 6. SBRs, 7. Treated sewage discharged to receiver (Biała river), 8. Excess sludge, 9. Thickener, 10. Aerobic sewage sludge stabilization chamber, 11. Dewatering press, 12. Sludge for disposal

minations were conducted in a certified laboratory, in accordance with the procedures set out in the Regulation of the Environmental Protection Minister from 18th November 2014 and in line with the American Public Health Association [APHA, 2005].

In accordance the instruction, the start-up of the TF model lasted eleven weeks. At the beginning, the TF was supplied with activated sludge using aeration to obtain biofilm. Then, supplying the research installation with dairy sewage began. The examination of the biofilm structure (its content) in a BUT laboratory confirmed the proper functioning of the bed. Figure 4 presents microorganisms in the biofilm obtained during the startup.



Figure 3. Research installation with main elements during operation (Nov 2017)

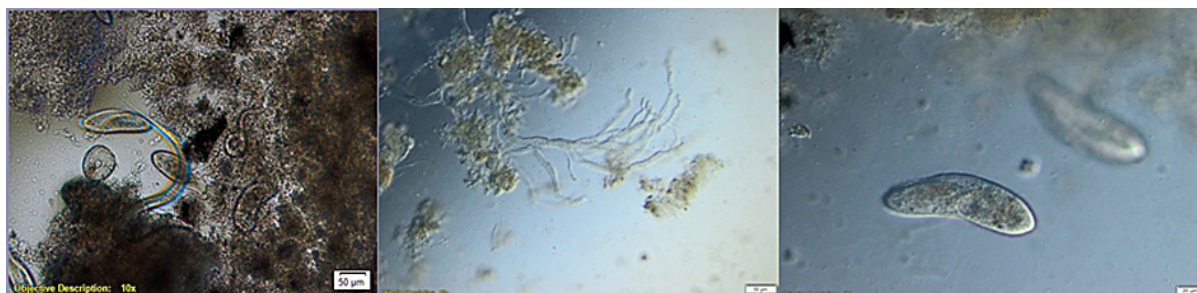


Figure 4. Biocenosis of biofilm, research installation after the startup [Butarewicz]

RESULTS AND DISCUSSION

Efficiency of DAF treatment

The DAF device proved to be very effective in removing the pollution load from the dairy wastewater. During the research period, the mean value of percentage removal was 59.3%, 49.0%, 39.8%, and 80% for BOD_5 , COD, TN and TP, respectively (Fig. 5). It corresponds to the literature data. Passeggi *et al.* (2012) obtained 20% efficiency in terms of COD removal, while Rusten *et al.* (1993) examined the influence of different coagulants concentration and obtained 60% efficiency. Organic pollutants expressed as BOD and COD in the influent ranged from $850 \text{ mgO}_2 \cdot \text{dm}^{-3}$ to $1650 \text{ mgO}_2 \cdot \text{dm}^{-3}$ and from $1215 \text{ mgO}_2 \cdot \text{dm}^{-3}$ to $2465 \text{ mgO}_2 \cdot \text{dm}^{-3}$ respectively, while in the effluent, they ranged from $410 \text{ mgO}_2 \cdot \text{dm}^{-3}$ to $660 \text{ mgO}_2 \cdot \text{dm}^{-3}$, and from $780 \text{ mgO}_2 \cdot \text{dm}^{-3}$ to $930 \text{ mgO}_2 \cdot \text{dm}^{-3}$, respectively. Nutrients, expressed as total nitrogen and total phosphorus in the influent ranged from $52 \text{ mgN} \cdot \text{dm}^{-3}$ to $152 \text{ mgN} \cdot \text{dm}^{-3}$ and from $13,6 \text{ mgP} \cdot \text{dm}^{-3}$ to $25.4 \text{ mgP} \cdot \text{dm}^{-3}$ respectively, while in the effluent they ranged from $24 \text{ mgN} \cdot \text{dm}^{-3}$ to $59 \text{ mgN} \cdot \text{dm}^{-3}$ and from $1.0 \text{ mgP} \cdot \text{dm}^{-3}$

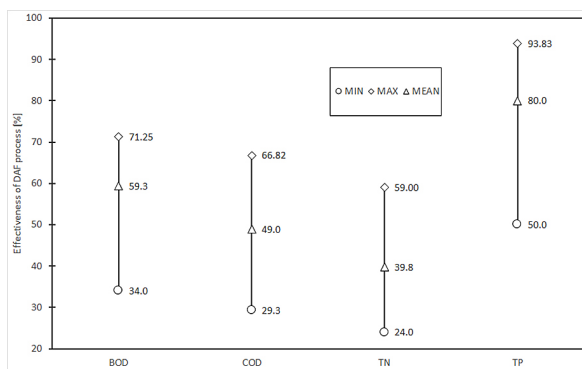


Figure 5. Pollutants removing effectiveness of the DAF process in Bielmlek dairy WWTP during the research period

to $6,8 \text{ mgP} \cdot \text{dm}^{-3}$ respectively (table 1). Babatola *et al.* (2011) studied the efficiency of DAF device for dairy sewage and received the removal rates equal to 66.09%, 65.89% and 94.49% for BOD, COD and TN respectively. The DAF system is also very effective in removing fats and oils from wastewater. The research carried by Al-Shamrani *et al.* (2002) showed that properly adjusted mixing and flocculation times can lead to significant oil separation, achieving more than 99% removal.

Efficiency of TF treatment

Table 2 presents the dairy wastewater characteristic after the DAF process (average and SD) which supplied the TF during the research period. It also presents the results of treatment during the operation with and without recirculation. The average chemical composition of the dairy wastewater feeding the TF varied from 460 to $540 \text{ mgO}_2 \cdot \text{dm}^{-3}$ for BOD_5 , 740 – $810 \text{ mgO}_2 \cdot \text{dm}^{-3}$ for COD, 190 – $240 \text{ mg} \cdot \text{dm}^{-3}$ for TOC, 5 – $9.4 \text{ mgN} \cdot \text{dm}^{-3}$ for ammonia nitrogen and 1.4 – $3 \text{ mgP} \cdot \text{dm}^{-3}$ for total phosphorus. The content of sewage before the flotation process (table 1) did not differ from the typical sewage content in broad production range (milk, cheese, powder milk). The sewage content after the DAF process is very individual and depends mainly on the amount of chemicals used in this process [Dąbrowski, 2011, Dąbrowski *et al.* 2016.] It was observed that during the experiment without treated sewage recirculation, sewage parameters significantly exceeded the permitted emission standards for Bielmlek WWTP [IPPC, 2015]. Only the phosphorous concentration was below the permitted value.

The load indicator during treatment without recirculation was calculated using the average values of BOD_5 , hydraulic flow and TF volume. It reached $0.22 \text{ kgBOD}_5 \cdot \text{m}^{-3} \cdot \text{d}^{-1}$ and 0.25 with 100% recirculation. The treatment efficiency of the TF with recirculation was 95.2% for BOD and 85.5%

Table 1. Concentration of pollutants before and after the DAF process. Mean values ± standard deviation.

BOD ₅		COD		N-tot.		P-tot.	
mgO ₂ ·dm ⁻³		mgO ₂ ·dm ⁻³		mgN·dm ⁻³		mgP·dm ⁻³	
IN	OUT	IN	OUT	INL	OUT	IN	OUT
1336±281.1	518±70.7	1735±374.3	843±57.8	84±29.9	40±12.4	20.3±4.5	3.8±1.5

Table 2. Wastewater parameters during trickling filter treating. Mean value ± standard deviation

Item	Unit	Inlet	Outlet – no recirculation	Outlet – 100% recirculation
BOD ₅	mgO ₂ ·dm ⁻³	505.5±26.71	63.7±7.73	24.2±2.10
COD	mgO ₂ ·dm ⁻³	782±22.39	169.3±12.53	113.6±5.83
TOC	mg·dm ⁻³	212.5±18.06	32.6±4.53	11.3±1.64
TKN	mgN·dm ⁻³	48±4.83	35.8±2.15	25.2±2.86
N-NH ₄ ⁺	mgN-NH ₄ ⁺ ·dm ⁻³	6.89±1.53	1.48±0.51	0.76±0.21
N-NO ₃ ⁻	mgN-NO ₃ ⁻ ·dm ⁻³	1.54±0.61	13.03±1.89	14.04±2.44
TP	mgP·dm ⁻³	2.32±0.60	1.66±0.43	1.33±0.40

for COD. In the sewage treated with recirculation, the average BOD was 24.2 mgO₂·dm⁻³ and COD 113.6 mgO₂·dm⁻³. Such parameters met the demands set for Bielmlek WWTP (BOD₅, COD, P Total). Recirculation of the treated sewage caused a decrease in the BOD₅ value in the influent from 505.5 to 283.7 mgO₂·dm⁻³. In the case of COD, recirculation caused its decrease in the TF influent from 782.0 to 475.6 mgO₂·dm⁻³. Reaching a high level of removing organic substance during the TF treatment was possible due to a very low bed load, as well as high temperature during the tests. In the research conducted by Rodziewicz et al. (2014) on an anaerobic disc batch reactor, the value of COD decreased from 530.5 to 74.0 mgO₂·dm⁻³ during the synthetic sewage primary treatment with the use of four stage RBC. The TFs operating at low load are dedicated to conduct the nitrification process [Daigger & Boltz, 2011]. Increased effectiveness in removing the

organic substance measured by BOD₅ and COD values can be achieved by, for example, using modified media for biofilm growing [Łobos-Mojša et al., 2016]. In the authors' own research, a very low concentration of ammonia nitrogen in the dairy sewage after the DAF process was observed. The concentration of ammonia nitrogen was on average 6.89 mgN-NH₄⁺·dm⁻³ (table 2), while the concentration of TKN was on average 48.0 mgN·dm⁻³. Finally, 88.8% decrease of ammonia nitrogen and nearly 47.0% of TKN (with recirculation) were achieved. The concentration of nitrates raised from 1.54 mgN-NO₃⁻·dm⁻³ to 13.03mgN-NO₃⁻·dm⁻³ and 14.04mgN-NO₃⁻·dm⁻³ in the experiments with and without recirculation, respectively. The calculated value of total nitrogen in the treated sewage, on the basis of the average concentration of Kjeldahl nitrogen, nitrates and nitrites, equaled 48.8 mgN·dm⁻³ for the treatment without recirculation and 39.0 mgN·dm⁻³ for

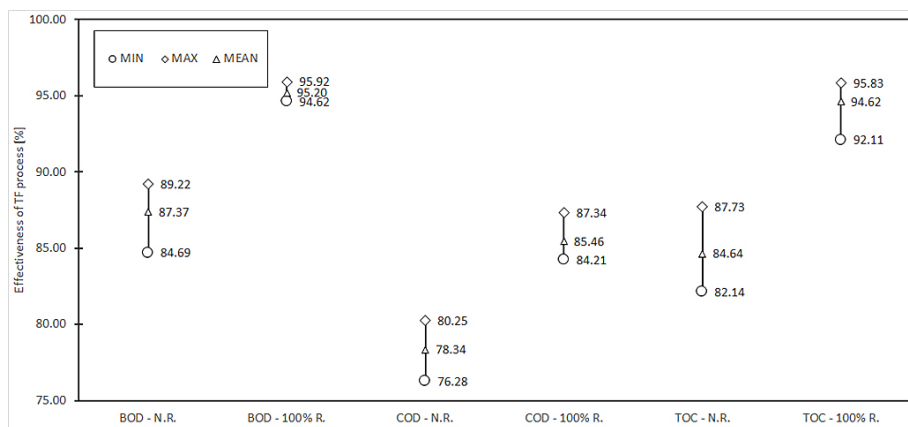


Figure 6. Effectiveness of the TF process. Parameters BOD, COD and TOC; N.R. – no recirculation applied (N.R.), 100% R. – 100% recirculation applied

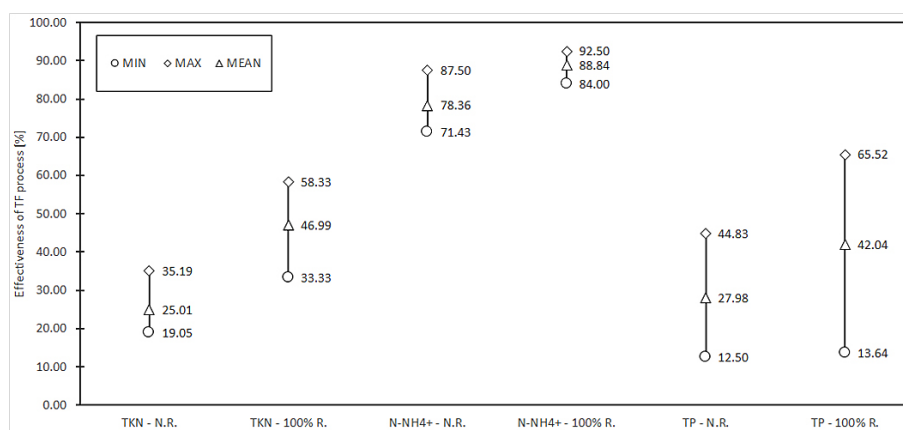


Figure 7. Effectiveness of the TF process. Parameters TKN, N-NH₄⁺ and TP; N.R. – no recirculation applied, 100% R. – 100% recirculation applied

the treatment with recirculation. The concentration of nitrites was below 0.2 mg N-NO₂·dm⁻³ in raw sewage and after treatment with and without recirculation. The conditions of conducting the process ensured high level of nitrification typical for TFs [Post & Medlock, 2002]. Intensification of the nitrogen removal through the process of biological denitrification requires applying multi-layered beds with modified filling or increasing recirculation level [Kanda et al., 2016; Łobos-Moysa et al., 2016].

CONCLUSIONS

Currently, the DAF process is commonly used in the food industry WWTPs, especially with meat and dairy production wastewater. Its application can decrease the load of organic matter, phosphorus and nitrogen in raw wastewater. It substantially decreases the load of the biological treatment part of WWTPs. During the research concerning treating dairy wastewater after DAF process with TF technology, it was proven that it is possible to achieve high efficiency of treatment. The parameters after treatment with low load TF allowed to discharge sewage to the receiver (BOD, COD and TP). The average efficiency of treatment was up to 95.9% for BOD and up to 87.3% for COD. The issue of high efficiency phosphorus removal was solved during the DAF treatment. During the authors' own research, the concentration of TP decreased from 20.3 to 3.8 mgP·dm⁻³ with DAF and reached 1.33 mgP·dm⁻³ after TF treatment, on average. The efficiency of the chemical phosphorus removal depends mainly on the amount of chemicals used during its precipitation. It confirms the

possibility of changing the activated sludge into TF technology, especially in small dairy plants. The primary advantage of this solution is a lack of excess sludge and lower consumption of energy. Further research will be conducted to determine the influence of temperature on the possibility of high efficiency treatment and the possibility of intensifying the removal of total nitrogen.

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