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Use of Plants in the Treatment of Tannery Wastewater

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ABSTRACT

Plants are used for wastewater treatment, which is a natural and ecological method. It is an alternative to conventional methods for wastewater from various sources. Because they take advantage of the capabilities of nature and naturally occurring adapted plants, they are characterized by their ability to carry out many processes and transformations that they carry out themselves and those occurring within them, such as in the aerobic and anaerobic zones of the root zone. Microorganisms present in the soil provide additional support for the vegetation, supporting the treatment processes. Due to the rising cost of wastewater treatment in typical wastewater treatment plants, the hydrophytic method is becoming competitive due to the low expenses associated with its operation and control. This method also works well for industrial wastewater, including tannery wastewater. Wastewater from the tanning industry is troublesome to manage and can also be a source of chromium, while studies have confirmed the possibility of treating such wastewater on plant beds.

Keywords: constructed wetland beds, hydrophytic vegetation, effluent tannery.

INTRODUCTION

The constructed wetland is one of the wastewater treatment methods that is applied. It is a natural and ecological alternative to conventional methods of treating wastewater from various sources [Tang *et al.,* 2021]. Their operation simulates hydraulic and habitat conditions and utilizes the same physical, chemical, and biological processes that occur in natural marsh ecosystems, with the participation of different sets of microorganisms and appropriately selected plants [Obarska-Pempkowiak *et al.,* 2010, Jóźwiakowski, 2012]. This system's correct and most efficient functioning is achieved by selecting hydraulic parameters for the bed, pollutant loads, temperature, and plant species. Plants play an essential role, and their main functions include extracting substances, transferring oxygen to the substrate, supporting the growth of the bacterial biofilm, or improving the permeability of the substrate [De Souza *et al.,* 2017]. Proposal to change the sentence sequence to: Hydrophytic treatment plants can be used to treat, among others, domestic, municipal, industrial and agricultural wastewater, as well as wastewater from gas stations, oily wastewater, rainwater, leachate from landfills, area runoff from agricultural fields or airports [Boruszko et al., 2014, Piecuch et al., 2015]

The hydrophytic method of wastewater treatment involves the simultaneous use of the processes of sorption, chemical reactions, ion exchange, sedimentation, and evapotranspiration, as well as the biological activity of macrophytic plants and microorganisms, and their action is bioaccumulation and biodegradation of organic and nutrient compounds. Of the biogenic compounds, nitrogen compounds are removed through the processes of ammonification, nitrification, denitrification, and bioaccumulation (phytoaccumulation), while phosphorus is mainly subject to accumulation, sorption, and precipitation [Warężak *et al.,* 2014]. The conditions in the soil-plant filter are favorable for developing hydrophytes, intensifying the oxidation and reduction of pollutants, supported by the processes of sorption, sedimentation, and assimilation [Warężak *et al.,* 2014]. The schematic mechanism of pollutant removal in a plant treatment plant is presented in Figure 1. Rooting vegetation forms the so-called rhizospheric effect [Śliwka, 2007]. The plants can transport oxygen to the root-soil zone, where wastewater flows and anaerobic conditions prevail. It enables the formation of an aerobic zone near the roots and is referred to as the rhizospheric effect. Figure 2 shows schematically the conditions around the rhizosphere of aquatic macrophytes. Aerobic bacteria oxidize carbon compounds and carry out the process of nitrification in the aerobic zone, while dephosphatation and denitrification occur in the anaerobic zone [Maj *et al.,* s.a.]. These processes can be compared to the phenomena occurring in a two-stage biological bed [Śliwka, 2007]. The formation of an aerobic zone near the roots influences the loosening of the soil structure around the root, improving the filtration coefficient [Maj *et al.,* s.a.].

Oxygen is involved not only in the functioning of the plant but also in the wastewater treatment processes carried out by it and with its participation. The level of oxygen availability in the soil depends on its degree of water saturation. In the case of saturated soil, oxygen availability is limited, and the free spaces between soil particles are filled with water and air. The low solubility of oxygen in water affects the need for oxygen uptake and transport from the above-ground parts to the underground parts of the plant, roots, and rhizomes. The air crumb - aerenchyma - air tissue system is responsible for oxygen transport, and the transport itself is carried out by concentration diffusion from a place of higher concentration to a place of lower concentration of this gas. It includes molecular diffusion, concentration diffusion, and convective flow [Obarska-Pempkowiak *et al.,* 2010].

The advantages of hydrophytic treatment plants include maintenance-free operation, low operating costs, resistance to uneven wastewater inflow, and high efficiency while removing nutrients or specific pollutants like heavy metals. Despite the advantages, these methods are not free of disadvantages, and the plant treatment plant requires a large area and considerable investment costs at the beginning of its construction. During its existence, the metals removed are accumulated in the biomass of the plants, and during the winter period, malfunctioning vegetation can cause problems. In addition, the plant induction and adaptation period at the very beginning can take up to 3 years [Śliwka, 2007, Warężak *et al.,* 2014, Giero, 2012].

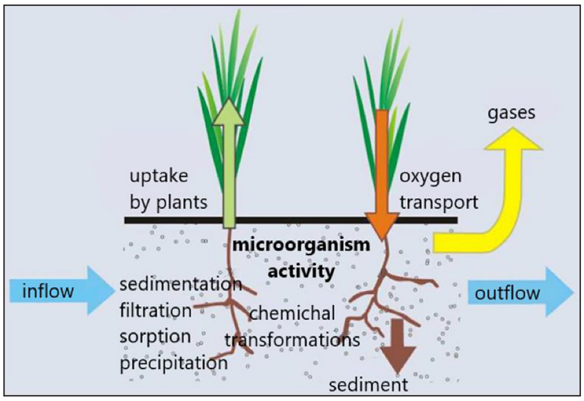

Figure 1. Schematic of the pollutant removal mechanism in a plant treatment plant [Bergier *et al.,* 2004, Śliwka, 2007]

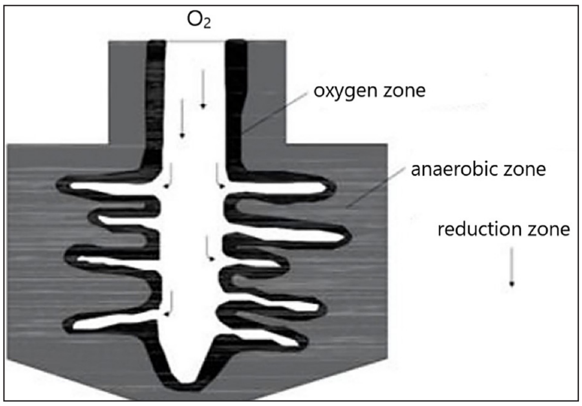

Figure 2. Schematic of oxidation-reduction conditions around the rhizosphere of aquatic macrophytes [Obarska-Pempkowiak *et al.,* 2010]

PLANT SPECIES USED IN HYDROPHYTIC METHOD

Hydrophytic treatment facilities use the functionality of plants to treat wastewater, but not every plant is used for this purpose. The most commonly used plants include common reed (*Phragmites australis*), due to its extensive rhizome and root system, and wicker-willow (*Salix viminalis*), which is prone to rapid biomass growth [Obarska-Pempkowiak *et al.,* 2010]. The method also makes use of such plant species as sword mignonette (*Glyceria aquatica*), broad-leaved scabious (*Typha latifolia*), yellow scythe (*Iris pseudoacorus*), small eyelash (*Lemna minor*), and common *calamus* (*Acorus calamus L.*). Macrophytes used in hydrophytic treatment plants can be divided into four groups according to their mode of existence in the treatment system [Gajewska, 2019]:

- emergent macrophytes – e.g., common reed, broad-leaved scabious – occur in soils saturated with water or entirely submerged. They develop up to about 0.5 m above the ground's surface, transporting oxygen from the aboveground, green parts of the plant to its root zone.

- macrophytes with floating leaves – e.g., white water mushroom, yellow water lily – are plants rooted in the substrate, floating leaves, or floating above the water surface.
- submerged macrophytes – e.g., stiff hornwort, red seaweed - are submerged plants that float in water depths, developing in oxygenated water.
- free-floating macrophytes – e.g., small eyelash - are plants that float on the water surface and can remove nutrients - nitrogen and phosphorus by uptake and incorporation into biomass and denitrification. They are capable of removing suspended solids.

TECHNICAL AND TECHNOLOGICAL PARAMETERS OF THE INSTALLATION

Different hydrophytic treatment bed systems can be divided mainly due to how the wastewater flows and the vegetation used in it [Olejnik *et al.,* 2016]. Hydrophytic wastewater treatment systems are divided into:

1. Due to the type of vegetation used [Klodowska, 2021]:

a) systems with marsh vegetation,
b) systems with rooted vegetation,
c) systems with floating aquatic vegetation.

2. Due to the direction of wastewater flow [Obarska-Pempkowiak *et al.,* 2010, Warężak *et al.,* 2014]:

a) systems with surface flow of wastewater (FWS, or SF, free water surface, surface flow),
b) vegetated submerged beds, subsurface flow systems (VSB, or SSF).

FWS are systems with surface flow, and their level is maintained above the ground surface, while plants are elevated above the water surface. These systems are mainly used in temperate climates to treat wastewater during the growing season after it has been treated mechanically, mechanically-chemically, or mechanically-biologically [Obarska-Pempkowiak *et al.,* 2010]. Different baffles, serpentine ditches, or transverse dikes increase the time wastewater flows through the FWS system [Obarska-Pempkowiak *et al.,* 2010, Szymura *et al.,* 2010]. These systems are characterized by simple operation and low construction costs, but their wastewater treatment efficiency decreases during periods of low temperature [Karczmarczyk *et al.,* 2007].

VSBs (subsurface flow systems) are characterized by wastewater flow through the ground, a bed in which plants are ingrained and may additionally consist of multiple layers. These systems are typically used as a second stage of wastewater treatment after mechanical treatment [Obarska-Pempkowiak *et al.,* 2010].

VSB system can also be divided according to the direction of wastewater flow into [Tilley *et al.,* 2014]:

- HF-CW – horizontal flow constructed wetland system (Figure 3).
- VF-CW – vertical flow constructed wetland system (Figure 4).

The systems differ in cross-section flow method but are similar in the processes involved. Table 1 summarizes the processes for removing specific pollutants, divided into subsurface and subsurface flow treatment plants.

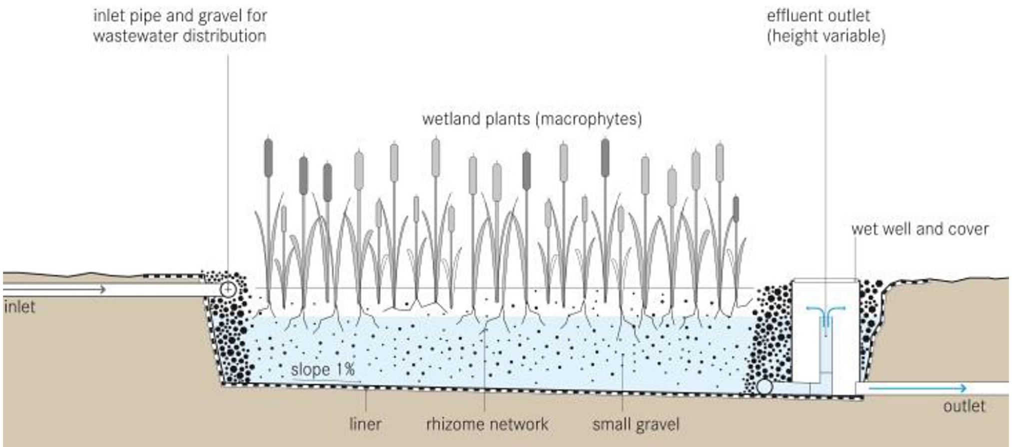

Figure 3. Schematic of the horizontal flow constructed wetland [Tilley *et al.,* 2014]

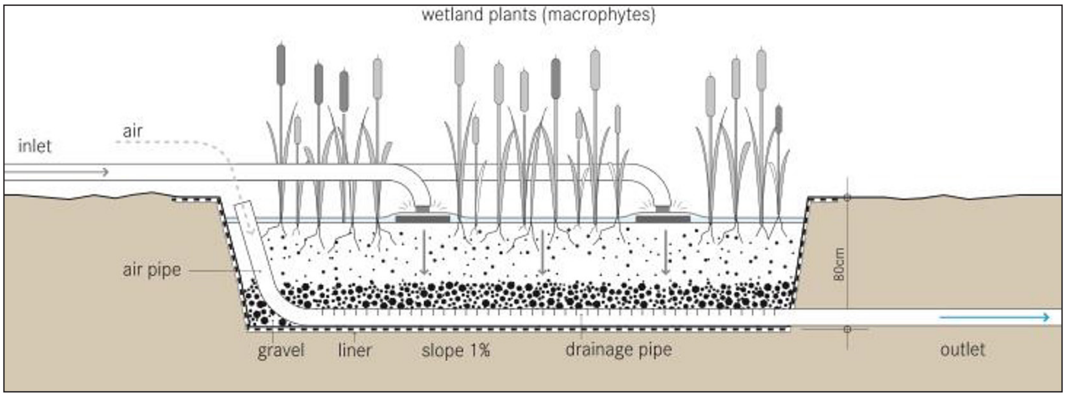

Figure 4. Schematic of the vertical flow constructed wetland [Tilley *et al.,* 2014]

Table 1. Processes occurring in surface and subsurface flow treatment plants [Obarska-Pempkowiak *et al.,* 2010]

Pollution	Type of flow	
	Surface	Subsurface
Suspension	Filtration and sedimentation	Sedimentation and filtration
Organic matter	Aerobic and anaerobic decomposition, sedimentation, and accumulation throughout the bed volume	Aerobic and anaerobic decomposition, sedimentation, and accumulation primarily in the root zone
Total nitrogen	Nitrification/denitrification, accumulation by plants, ammonia oxidation	Nitrification/denitrification, accumulation by plants, ammonia oxidation
Total phosphorus	Sedimentation, accumulation by plants and in the ground	Filtration, adsorption on fill material, sedimentation, accumulation by plants
Trace metals	Adsorption on plant parts, organic and mineral particles of bottom sediment	Adsorption on bedding material, organic material, and in the root zone
Pathogens (viruses, bacteria, parasites)	Natural degradation, filtration, sedimentation, and antibiotic secretion by plant roots	Natural degradation, filtration, antibiotic secretion by plant roots, sedimentation

PRODUCTION IN TANNING PLANTS

Tasks performed in tanning leather manufacturing facilities make it possible to obtain goods of a quality that is exceptionally different from raw animal skin subjected to these processes. Leather tanning involves some processes in water baths, such as a wet workshop, dry through mechanical processes, and finishing processes, giving a color texture. In general, the processes can be put together in order: soaking – restoring the skin to its proper water content; dehairing – mechanical removal of subcutaneous tissue, reducing the thickness and weight of the skin, which reduces the amount of chemical dosage; liming - alkaline swelling of the skin, facilitating the opening of hair follicles, and further the process of dehairing - removal of hair. The following process is the reversal of the effects of the previous one - decalcification - neutralization and desquamation of the hides, reducing their thickness, etching - through the use of enzymes the leather is softened, pickling - acidification and preparation for tanning, tanning proper - protection of the leather from biological degradation processes [Dziadel *et al.,* 2022, Famielec, 2014]. This is where the sequence of first wet operations ends. In between, numerous rinses are carried out, and most processes are performed in new baths. The tanned leather is already resistant to biological agents and can be stored in this form, and the further form of its processing is related to the requirements for the final product. The tanned leather can be split, separating the underside split from it - the mizzen, and then planed, equalizing its thickness over the entire surface. Further, the skins are returned to the wet workshop for dyeing, oiling, and obtaining additional properties. At a later stage, tasks are associated with drying, softening, pressing, painting, pouring, and sanding, depending on the capabilities of the plant. The most important of the wet processes is tanning. This process, when done well, immunizes leather against the factors of biological degradation [Wieczorek-Ciurowa *et al.,* 2011], to which it is immediately exposed in its raw form when inadequately stored. Unfortunately, despite the benefits of leather, the tanning industry primarily relies on water-intensive processes that generate large amounts of wastewater, mainly from wet processes, including those concentrated in chromium. Thus, these plants are responsible for significant chromium pollution [Lofrano *et al.,* 2013, Celary *et al.,* 2014, Ascón-Aguilar *et al.,* 2019]. This is due to the functionality of chromium tannins, which produce the fastest and most reliable tanning of leather relative to, for example, vegetable tanning. The volume of wastewater generated can range from 30 to 60 m^3 per ton of raw hides [Dziadel *et al.,* 2022, Mendrycka *et al.,* 2012, Szalińska, 2002]. Wastewater is characterized by variability in the pollutants contained between each process due to different reactions carried out and reactants dosed. Among the many pollutants, the most considerable amount of salt enters the wastewater after soaking, decalcification, and tanning, which are sulfate and sulfide lime BOD_5 and COD sources. High pollution means that wastewater must be managed and treated before entering the environment [Malovanyy *et al.,* 2020], but ultimately, about 15% of the chemistry used remains in the finished leather, with the remainder going into the wastewater [Rydin *et al.,* 2013].

PRACTICAL EXAMPLES OF USING PLANTS TO TREAT TANNERY WASTEWATER

Hydrophytic treatment plants treat many types of wastewater, including industrial wastewater. Industrial wastewater includes tannery wastewater, resulting from the processes carried out in tanning leather. Tanneries are known to be significant users of water. The wastewater contains concentrated organic pollutants, dissolved and undissolved suspended solids, ammonia, organic nitrogen, chromium, and high salt content [Vymazal, 2014]. Often, wastewater in tanning plants is separated into two types: those containing chromium compounds and those that do not contain chromium or contain minimal amounts, not resulting from processes but from per-process situations such as washing floors, machinery, and the possible outflow of chromium into general reservoirs. The water intensity of the processes affects the concentration of pollutants in the wastewater; the more significant the amounts of water used in the processes, the lower the concentrations [Rydin *et al.,* 2013]. A study by Dziadel *et al.* (2022) based on wastewater from one of the tanning plants in Poland identified pre-tanning wastewater as biodegradable, confirming that the hydrophytic method, in their case, would be effective. Experiments in Poland and abroad have been treated with tannery wastewater using hydrophytes.

Zapan *et al.* (2020) described an experiment during which tannery wastewater previously treated by physicochemical methods, collected in Arequipa, Peru, was treated. A hybrid two-stage hydrophytic system was used there (Figure 5), in which the wastewater was first introduced to a subsurface horizontal flow bed with overhanging watercress (*Isolepsi cernua*) and then subjected to free surface flow with watercress (*Nasturtium aquaticum*). The wastewater was treated in two stages, and the beds were fed with a load of 50%, 75%, and 100% of

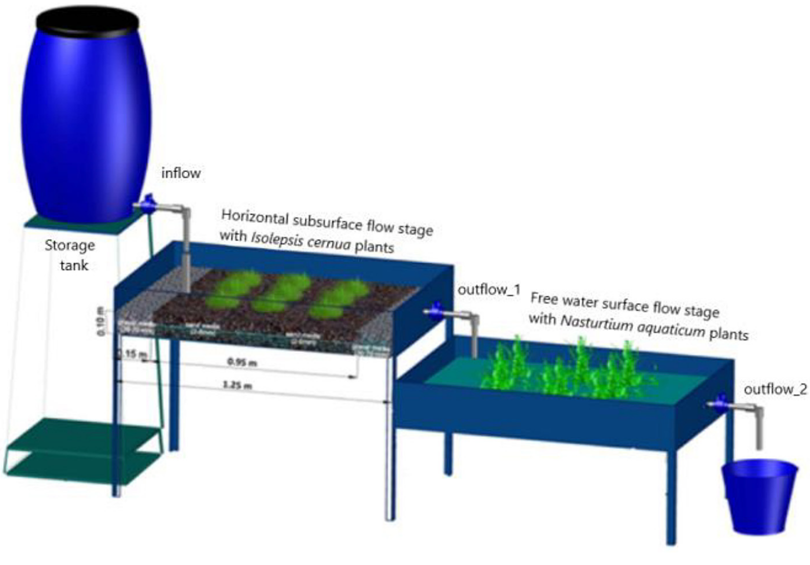

Figure 5. Experimental layout of the hybrid, two-stage model [Zapana *et al.,* 2020]

the pollutants. As the concentration of pollutants in the wastewater increased after the first stage, efficiency decreased. In each case, in turn, after the second stage, the values were similar [Zapana *et al.* 2020]. The treatment efficiency of the studied wastewater parameters and their values before and after treatment are shown in Table 2. As a consequence of the experiment, it was concluded that such a wastewater treatment method is effective and meets the acceptable minimum of national and international wastewater discharge parameters.

Ekhlasur *et al.* (2020) presented the results of a study in which highly saline tannery wastewater (2.2–6.6 g Cl/dm^3) was treated on a hydrophytic bed in an HF-CW system - with subsurface, horizontal flow. This study compared two plants: reed canary grass (*Arundo donax*) and bush solitaries (*Sarcocornia fruticosa*). Both plants functioned in the same configurations in terms of surface area, depth, and hydraulic loading, and the same pollutant treatment efficiency results were obtained in both: COD (65%), BOD$_5$ (73%), TSS – total suspended solids (65%), N$_{NH4}$ (73%), and TKN – total Kjeldahl nitrogen with a slight advantage for the laseolite (83%) to the saltwater (79%). The presented system and treatment met the standards for the elimination of pollutants. Another study conducted by Calheiros *et al.* (2007) boiled down to a comparison of 5 types of plants: Indian streambank (*Canna indica*), broad-leaved *club-moss* (*Typha latifolia*), common reed (*Phragmites australis*), St. Augustine grass (*Stenotaphrum secundatum*), and yellow scythe (*Iris pseudacorus*). The wastewater was treated in a subsurface, horizontal flow hydrophytic system on five independent beds. Of the plants listed, *Typha latifolia* and *Phragmites australis* were the species better adapted to the tannery wastewater for survival and reproduction. Ultimately, it was determined that the subsurface horizontal flow system used was a viable alternative for reducing organic matter in tannery wastewater while tolerating fluctuations in supply and interruptions in supply. Nutrient removal efficiency was low relative to the BOD$_5$ and COD removal efficiency. However, it should be borne in mind that difficulties can be encountered in designing various hydrophytic treatment plant systems. Despite a carefully crafted plant and good vegetation, its adaptation can be compromised due to nutrient deficiencies and wastewater toxicity [Calheiros *et al.,* 2014].

An in-house study was also conducted, during which tannery wastewater was treated. Wastewater treatment was carried out on a model bed in a VF-CW system – a vertical subsurface flow bed with three layers of fill of different granularity, and the plant used was a common reed (*Phragmites australis*). The bed was placed in a cylindrical

Table 2. Average values of raw, treated wastewater parameters and their treatment efficiency at the given stages [Zapana *et al.,* 2020]

Degree of wastewater load supply	Type of wastewater sample	pH	EC [µS/cm]	BOD [mgO$_2$/dm^3]	COD [mgO$_2$/dm^3]	TSS [mg/dm^3]	TDS [mg/dm^3]	Cr [mg/dm^3]
50 %	raw	8.7 ± 0.2	2443 ± 8	321.6 ± 22.7	1281.2 ± 747.9	134.3 ± 56.8	1165 ± 30	4.30 ± 2.71
	After Grade I	7.6 ± 0.1	1905 ± 295	9.5 ± 4.6	32.7 ± 10.5	4.3 ± 0.6	955 ± 145	0.01 ± 0.00
	Efficiency [%]	[-]	[-]	**97.04**	**97.45**	**96.78**	**18.05**	**99.74**
	After Grade II	8.2 ± 0.2	1570 ± 300	6.2 ± 2.1	38.7 ± 4.5	4.6 ± 0.2	780 ± 150	0.09 ± 0.00
	efficiency [%]	[-]	[-]	**98.06**	**96.98**	**96.60**	**33.06**	**98.01**
75 %	raw	8.7 ± 0.2	3483 ± 169	480.1 ± 22.6	1776.8 ± 966.2	204.4 ± 88.1	1756 ± 99	5.97 ± 3.50
	After Grade I	7.7 ± 0.1	3386 ± 163	38.4 ± 8.8	89.9 ± 19.6	13.5 ± 5.3	1694 ± 84	0.02 ± 0.01
	efficiency [%]	[-]	[-]	**92.01**	**94.94**	**93.38**	**3.52**	**99.61**
	After Grade II	8.4 ± 0.0	2798 ± 462	6.6 ± 1.1	51.0 ± 6.5	5.0 ± 1.1	1532 ± 282	0.06 ± 0.01
	efficiency [%]	[-]	[-]	**98.63**	**97.13**	**97.55**	**12.74**	**98.93**
100 %	raw	8.7 ± 0.2	4705 ± 165	649.3 ± 39.3	2412.1 ± 1345.5	272.5 ± 117.5	2355 ± 85	8.11 ± 4.86
	After Grade I	7.6 ± 0.1	4382 ± 373	174.5 ± 46.4	258.5 ± 55.8	26.6 ± 10.4	2186 ± 187	0.03 ± 0.01
	efficiency [%]	[-]	[-]	**73.12**	**89.28**	**90.22**	**7.18**	**99.57**
	After Grade II	8.3 ± 0.2	3368 ± 376	11.7 ± 3.5	67.5 ± 6.6	6.2 ± 1.7	1700 ± 184	0.05 ± 0.01
	efficiency [%]	[-]	[-]	**98.20**	**97.20**	**97.72**	**27.81**	**99.36**

polyethylene (PE) tank with a capacity of 120 l; the diameter of the bed was about 0.50 m, and the height was about 0.70 m. The drainage layer of the bed was vented. A diagram of the deposit is presented in Figure 6. The target load of the deposit was 0.1 m^3/m^2/day. In the early stages, the bed was fed with treated wastewater and only later with raw wastewater to acclimate and appropriately adapt the plants to wastewater treatment. The treated wastewater did not contain chromium, was the mixed, averaged effluent from operations carried out before the tanning process, and was collected in a typical tank. Passing the wastewater through the bed resulted in its treatment at a satisfactory level, obtaining a removal efficiency of more than 90% for most parameters. The removal efficiency of individual pollutant parameters was for: BOD_5 – 91.81%; COD – 96.10%; total suspended solids – 89.79%; total nitrogen – 94.19%; ammonia nitrogen – 96.08% and nitrate nitrogen 63.27%. The reed developed adequately during the study, and the results show that it is adapted to treat this type of wastewater [Dziadel, 2022].

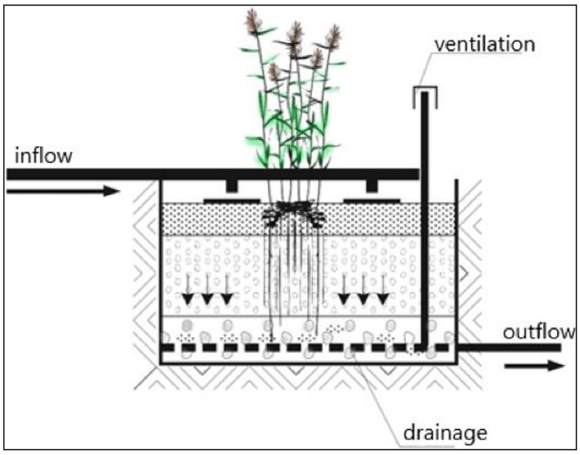

Figure 6. Cross-section of a vertical flow hydrophytic bed model [Dziadel, 2022]

Pollution parameters of treated raw and treated wastewater are summarized in Table 3. Determination of parameters of specific pollutants was carried out following applicable standards and test procedures [Ignatowicz and Puchlik, 2011; Ignatowicz et al., 2020]:

- BOD_5 – manometric method using the Oxi Top Standard system from WTW GmbH, according to PN-EN 1899-2:2002 standard
- COD – bichromate method, determination of COD_{Cr} was performed with UV/VIS Pharo 300 spectrophotometer from Merck, after prior oxidation of the test sample in a thermoreactor at 148 °C, according to PN-ISO 15705:2005 standard
- total suspended solids – weight method, range: (2.0–10000) mg/dm^3, according to PN-EN 872:2007+Ap1:2007 standard
- total nitrogen – concentration of total nitrogen, according to standard PB-23, 2 of 20.08.2011
- ammonium nitrogen ($N\text{-}NH_4^+$) – photometric method, the concentration of $N\text{-}NH_4^+$ was determined with a UV/VIS Pharo 300 spectrophotometer from Merck according to PN-ISO 7150-1:2002 standard
- nitrate nitrogen ($N\text{-}NO_3^-$) – concentration of nitrate nitrogen, a spectrophotometric method, range: (0.100–50.0) mg/dm^3, according to PN-82/C-04576/08 standard

The study by Alemu *et al.* (2021) used five parallel, independent deposits, one of which was a control. The deposits were operated in a subsurface horizontal flow system. *Pennisetum purpureum, Typha dominigensis, Cyprus latifolius* and *Echinochloa pyramidalis* were used during

Table 3. Average values of raw wastewater parameters fed to and discharged from the hydrophytic bed [Dziadel, 2022]

Parameter	Unit	Raw sewage	Treated wastewater
BOD_5	mg O_2/dm^3	2335.65 1570.00– 5300.00	191.29 115.00–690.00
COD	mg O_2/dm^3	8512.09 5790.00–11000.00	332.12 147.00–1070.00
Total suspended solids	mg/dm^3	3115.37 2018.00–3850.00	318.11 100.00–770.00
Total nitrogen	mg N/dm^3	335.30 214.00–369.00	19.48 10.00–51.00
Ammonium nitrogen	mg $N\text{-}NH_4^+/dm^3$	263.78 206.80–353.00	10.35 3.34–39.60
Nitrate nitrogen	mg $N\text{-}NO_3^-/dm^3$	4.52 0.56–11.00	1.66 0.70–9.10
Reaction	-	8.12–8.80	7.60–8.30

Note: *in the numerator: arithmetic mean, in the denominator: min–max.

the study. The beds were pre-filled with tap water and then partially dosed with tannery wastewater to minimize the plant shock caused by introducing toxic tannery wastewater and adapting them to this type of wastewater. As a result, the plants showed visible changes as the concentration of dosed wastewater increased. Yellowing and dropping of leaves, shriveling, drooping, and death of plant parts were observed. Despite these phenomena, plant growth and demarcation were good. The most severe effects were observed at a concentration of wastewater introduced into the system at a ratio of 1:1 mixed with tap water. Based on visual observation, biomass production and propagation were most evident in the order: *P. purpureum, T. domingensis, C. latifolius,* and *E. pyramidalis.* After the test, the beds were effective in removing chromium, COD, and BOD$_5$, while the removal of total phosphorus, nitrate, or total suspended solids was relatively low. Figure 7 shows the removal efficiencies of COD, BOD$_5$, and total suspended solids for each deposit as an average of 6 trials.

In their study, Younas *et al.* (2022) created a model with a system of floating aquatic vegetation on the water's surface. For this purpose, they used three tanks that contained water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia Crassipes*), and broadleaf baton (*Typha latifolia*). In the case of the clubroot, a polystyrene plate was used to float and hold the seedlings on top so the roots could spread underneath it in the polluted water – the wastewater under study. The volume of incoming wastewater was 0.5 dm^3 /min, and the retention time was six days. The treated wastewater represented the outflow from the tannery after all the leather tanning processes, from raw leather to its finished form. The values of pollutant parameters were compared on a scale of 2 months, and the average efficiency of their removal is included in Table 4. Using models with floating vegetation on the water surface is an innovative solution, but with satisfactory results, and can be used for tasks such as treating domestic or industrial wastewater. In terms of investment and control, its operation has low costs and is almost maintenance-free; such a solution becomes an alternative to standard hydrophytic systems using rooted vegetation. An experiment by Younas *et al.* (2022) showed that *Eichhornia crassipes* perform best in an aquatic environment, obtaining more than 90% removal efficiency of COD, BOD$_5$, and chromium. *Typha latifolia* showed the poorest performance in such an environment, indicating that it is not well adapted to an aquatic-only environment.

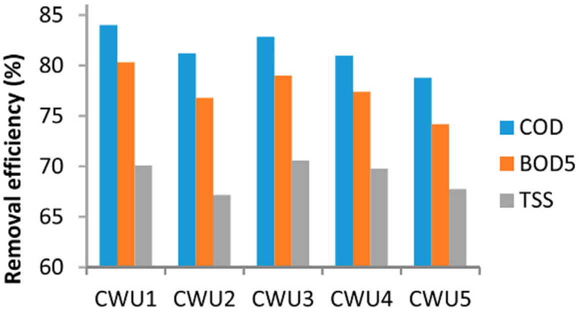

Figure 7. Average removal efficiency of COD, BOD$_5$ and total suspended solids on model beds: CWU1 – *P. purpureum,* CWU2: *T. domingensis*, CWU3 – *C. latifolius*, CWU4: *E. pyramidalis,* CWU5 – control (unvegetated) [Alemu *et al.,* 2021]

CONCLUSIONS

The hydrophytic method finds its application in a wide range of the type of wastewater it can treat. Its functioning is based on the capabilities of plants such as the common reed (*Phragmites australis*), which is the most common of plants. Their adaptation to perform the function of wastewater treatment is related to processes in the soil, the participation of microorganisms, and the provision of adequate aerobic and anaerobic areas in the soil, thus enabling other processes to take place, the more decomposing and transforming substances contained in wastewater. Confirmation of the biodegradability of tannery wastewater makes it possible to treat it using plant-based methods, and the studies and experimental trials carried out on various plants and models different in terms of bed or flow give

Table 4. Removal efficiency of specific pollutants, comparison against plants used [Younas *et al.,* 2022]

Name	COD [%]	BOD$_5$ [%]	TSS [%]	Cr [%]
Water Hyacinth	95	96	84	94
Water lettuce	27	41	85	94
Typha latifolia	48	31	72	33

results showing that this is a method that works even with stressful tannery wastewater.

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REFERENCES

1. Alemu A., Gabbiye N., Lemma B. 2021. Evaluation of tannery wastewater by integrating vesicular basalt with local plant species in a constructed wetland system. Frontiers in Environmental Science. 9, 721014.
2. Ascón-Aguilar E., Marrufo-Saldaña L., Neyra-Ascón W. 2019. Reduction of total chromium levels from raw tannery wastewater via electrocoagulation using response surface methodology, Journal of Ecological Engineering, 20(11), 217–224.
3. Bergier T., Czech A., Czupryński P., Łopata A., Wachniew P., Wojtał J. 2004. Plant-based wastewater treatment plants. A guide for municipalities. Natural Systems Publishing House, Cracow
4. Boruszko D., Dąbrowski W., Grygorczuk-Petersons E., Magrel L., Wiater J. 2014. Low-cost methods of wastewater treatment and sludge treatment. Construction and Environmental Engineering, 5, 135–142.
5. Calheiros C.S.C., Rangel A.O.S.S., Castro P.M.L. 2007. Constructed wetland systems vegetated with different plants applied to the treatment of tannery wastewater, Water Research 41(8), 1790–1798.
6. Calheiros C.S.C., Rangel A.O.S.S., Castro P.M.L. 2014. Constructed wetlands for tannery wastewater treatment in portugal: Ten years of experience, International Journal of Phytoremediation, 16(9), 859–870.
7. Celary P., Sobik-Szołtysek J. 2014. Vitrification of sludge from the tanning industry with cullet, Environmental Engineering and Protection, 17(3), 449–457.
8. de Souza T.D., Borges A.C., de Matos A.T., Mounteer A.H., de Queiroz M.E.L.R. 2017. Removal of chlorpyrifos insecticide in constructed wetlands with different plant species. Revista Brasileira de Engenharia Agrícola e Ambiental. 21(12), 878–883.
9. Dziadel M. 2022. Treatment of wastewater from the tanning industry by hydrophytic methods, Master's thesis, Bialystok University of Technology, Bialystok.
10. Dziadel M., Ignatowicz K. 2022. Assessment of the quality of wastewater generated during production at a tannery plant, Journal of Ecological Engineering, 23(5), 109–115.
11. Famielec S. 2014. The process of burning tannery waste in a tunnel kiln as a method of its disposal. Rozporawa doktorska, Kraków.
12. Gajewska M. 2019. Hydrophytic beds with vertical wastewater flow. Characteristics of processes and applications. Published by the Polish Academy of Sciences, Monographs of the Committee on Environmental Engineering, Warsaw.
13. Giero M. 2012. Technological concept of a domestic sewage treatment plant, in Environmental Engineering - Young Eye, ed. Skoczko I., Bialystok, 1, 54–58.
14. Ignatowicz K., Puchlik M. 2011. Rotary Biological Contactor as Alternative for Small Amount of Wastewater Treatment. Rocznik Ochrona Środowiska, 13, 1385-1404.
15. Ignatowicz K., Puchlik M., Lozowicki J. 2020. Removal of Pesticides from Wastewater by the Use of Constructed Wetlands. Journal of Ecological Engineering, 21(1), 219-223.
16. Klodowska I.M. 2021. Environmentally friendly hydrophytic systems. Warmińsko-Mazurski Ośrodek Doradztwa Rolniczego based in Olsztyn. Olsztyn
17. Jóźwiakowski K. 2012. Studies on the effectiveness of wastewater treatment in selected soil-plant systems. Habilitation dissertation. Commission for Technical Infrastructure of Villages of the Polish Academy of Sciences, Krakow, Association Infrastruktura i Ekologia Terenów Wiejskich, Krakow.
18. Karczmarczyk A., Mosiej J. 2007. Efficiency of wastewater treatment in hydrophytic systems on the example of horizontal flow reed beds. ACTA Scientiarum Polonorum, Architectura, 6(4), 79–88.
19. Lofrano G., Meriç S., Zengin G.E., Orhon D. 2013. Chemical and biological treatment for leather tannery chemicals and wastewaters: A review, Science of the Total Environment, 461–462, 265–281.
20. May K., Koszelnik P. Hydrophytic treatment plants as a solution to wastewater problems in scattered housing developments. [n.r.], [n.m.], 91–101.
21. Malovanyy M., Palamarchuk O., Trach I., Petruk H., Sakalova H., Soloviy K., Vasylinych T., Tymchuk I., Vronksa N. 2020. Adsorption Extraciotn of Chromium Ions (III) with the Help of Bentonite Clays. Journal of Ecological Engineering, 21(7), 178–185.
22. Rahman M.E., Halmi M.I.E.B., Samad M.Y.B.A., Uddin M.K., Mahmud K., Shukor M.Y.A., Abdullah S.R.S., Shamsuzzaman S.M. 2020. Design, operation and optimization of constructed wetland for removal pollutant, International Journal of Environmental Research and Public Health, 17, 8339.
23. Mendrycka M., Stawarz M. 2012. Application of a biopreparation supporting the treatment of tannery wastewater with activated sludge, Ecological Engineering, 28, 43–56.
24. Obarska-Pempkowiak H., Gajewska M.,

Wojciechowska E. 2010. Hydrophytic treatment of water and wastewater. Wydawnictwo Naukowe PWN SA, Warsaw.

25. Olejnik D., Wolska M., Wojciechowski K. 2016. Evaluation of the efficiency of operation of selected hydrophytic systems. Technology and Product Quality, 61, 5–16.
26. Piecuch T., Andriyevska L., Dąbrowski J., Dąbrowski T., Jurasza B., Kowalczyk A. 2015. Treatment of wastewater from car repair stations. Yearbook of Environmental Protection, 17, 814–832.
27. Rydin S., Black M., Scalet B.M., Canova M. 2013. Best available techniques (BAT) reference document for: Leather tanning. Directive 2010/75/EU on industrial emissions (Integrated Pollution Prevention and Control).
28. Szalińska E. 2002. Chromium transformations in an aquatic environment polluted with tannery wastewater, Cracow University of Technology, Cracow.
29. Szymura M., Szymura T., Dunajski A., Bergier T. 2010. Plant-based treatment plants as a solution to wastewater problems in scattered housing facilities. Center for System Solutions, Provincial Fund for Environmental Protection and Water Management in Wroclaw, Sendzimir Foundation, Wroclaw.
30. Śliwka M. 2007. Application of laser stimulation of selected hydrophytes species to enhance their bioremediation capacity. Doctoral dissertation. Cracow.
31. Tang Z., Wood J., Smith D., Thapa A., Aryal N. 2021. A Review on Constructed Treatment Wetlands for Removal of Pollutants in the Agricultural Runoff. Sustainability, 13, 13578.
32. Tilley E., Ulrich L., Lüthi C., Reymond P., Zurbrügg C. 2014. Compedium of sanitation systems and technologies – 2nd revised edition. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland.
33. Vymazal J. 2014. Constructed wetlands for treatment of industrial wastewaters: A review. Ecological Engineering, 73, 724–751.
34. Warężak T., Myszograj S., Dera M. 2014. Efficiency of removal of organic and nutrient compounds in a hydrophytic bioreactor using a biopreparation. Journal of Civil, Environmental and Architectural Engineering, 31, 61(3/I/14), 387–399.
35. Wieczorek- Ciurowa K., Famielec S., Fela K., Woźny Z. 2010. The process of combustion of waste from the tanning industry, CHEMIK 2011, 65, 10, 917–922.
36. Younas A., Kumar L., Deitech M.J., Qureshi S.S., Shafiq J., Ali Naqvi S., Kumar A., Amjad A.Q., Nizamuddin S. 2022. Treatment of industrial wastewater in floating treatment wetland: A case study of sialkot tannery. Sustainability, 14, 12854
37. Zapana J.S.P., Arán D.S., Bocardo E.F., Harguinteguy C.A. 2020. Treatment of tannery wastewater in pilot scale hybrid constructed wetland system in Arequipa, Peru. International Journal of Environmental Science and Technology.