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Use of Shredded Recycled Plastic as Filter Bed Packing in a Vertical Flow Filter for Onsite Wastewater Treatment Plants: Preliminary Findings

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Abstract: Household wastewater is a problem, especially in areas with a dispersed settlement where there is no wastewater collection system or wastewater treatment plant. In this case, it is necessary to build a local or onsite wastewater treatment plant. This paper is an attempt to analyse the possibility of using recycled shredded ABS plastic (acrylonitrile butadiene styrene) as packing media in an experimental vertical flow filter for use in on-site wastewater treatment plants. Studies have shown that shredded recycled ABS is a promising filtration material that has several features important in the treatment process, like a large surface area, high mechanical strength and chemical inertness. The system was operated with a hydraulic load of 50 dm^3/m^2 (3 months). BOD5 (biochemical oxygen demand), COD (chemical oxygen demand), and total suspended solids (TSS) reduction efficiency in the primary effluent was high; 94.4%, 77.8%, and 92.8%, respectively.

Keywords: flow filter; reuse; shredded recycled plastic; waste management; wastewater treatment plant

1. Introduction

The main sources of clean water are surface and underground water resources. However, due to the rapid growth of the population and the increasing development of industry, many water sources have become polluted [1]. Therefore, wastewater must be properly treated before discharge into the environment [2]. Among the most commonly used wastewater treatment methods are those based on biological processes as they are economically viable, compared to other processes such as advanced oxidation or precipitation. Currently, conventional treatment methods are not always effective and not able to completely remove all water contaminants. The emission of pollutants resulting from ever-growing anthropogenic activities has a visible impact on the natural environment [3]. For example, the use of conventional metal-based coagulants/flocculants to remove suspensions from drinking water and wastewater is now raising new concerns. Drains from municipal landfills are usually heavily polluted and therefore require treatment before being discharged directly into groundwater. Choosing the right drain treatment technology is still a major challenge for municipal landfill operations [4]. In turn, wastewater treatment methods based on aerobic processes are not sustainable due to the constant demand for energy, for aeration, and sludge management (active sludge load) [5]. As water is extremely susceptible to pollution, water pollution control is of great interest as one of the critical environmental challenges [6]. Various sources of contamination, such as heavy metals, dyes, and pathogenic and organic compounds, lead to the deterioration of water quality. Contaminants present in water can be removed by various processes, like filtration, reverse osmosis, degassing, sedimentation, flocculation, precipitation and adsorption [7].

Domestic wastewater is a problem, especially in areas with the dispersed settlement. These areas are often not connected to the wastewater collection system, and the wastewater generated in households is usually discharged to holding tanks or on-site wastewater treatment plants [8]. It often happens that the holding tanks do not meet the integrity and tightness requirements, causing contamination of the ground around the tanks, and the pollutants can penetrate the groundwater. If a wastewater collection system cannot be built in a given area, the construction of an on-site wastewater treatment plant is worth considering [9]. Currently, there are many manufacturers of various types of on-site wastewater treatment plants operating on the market. Biodegradation is effective in treating new wastewater, while long-stored wastewater requires processes such as chemical oxidation, coagulation-flocculation, chemical precipitation, ozonation, activated carbon adsorption and reverse osmosis. Recently, the combination of biological pretreatment with physicochemical processes has been proven to be very effective. Wastewater treatment for plastic material remains a critical issue worldwide to this day, despite significant progress and technological breakthroughs. [10]. During the processes, carbon compounds and biogenic compounds are reduced. An interesting solution is wastewater treatment using the trickling filter technology, since this solution does not require any additional air feed using blowers. This results in lower electricity consumption, the prices of which are currently high, thus increasing the costs of wastewater treatment [11]. Plastic waste recycling is an important problem nowadays [12–15]. Many types of plastics are found in the stream of waste, such as polypropylene (PP), polyethylene (PE), acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), polystyrene (PS) and polyethylene terephthalate (PET) [16,17]. Among these types of plastics, ABS is the biggest concern because it contains many dangerous additives, such as brominated flame retardants (BFRs), which prevent the harmful effects of burning electronic and electrical equipment [18]. ABS or acrylonitrile butadiene styrene is one of the most abundant and widely used plastics. It is so popular due to its high strength and good processing parameters. ABS is most often used for the production of the housings for electronics/household appliances, electronic devices, and automotive components (car parts such as trusses, wheel arches, and some body parts). It is also used for the production of toys, pipes (resistant to various aggressive liquids) and many everyday products. The presence of ABS in plastic waste in very small amounts can, however, significantly reduce the recycling rate and degrade the quality of recycled products by forming compounds with the main plastics. To reduce the serious negative impact on recycling efficiency, human health, and the surrounding environment, ABS needs to be separated from other types of plastic [19]. An important problem is the recycling of ABS from the waste electrical and electronic equipment (WEEE) [20]. Therefore, ABS recycling is problematic, so new methods of processing and handling are constantly sought.

The aim of the research was to determine the possibility of using shredded recycled ABS plastic as a packing for an experimental vertical flow filter for use in on-site wastewater treatment plants.

2. Materials and Methods

2.1. Characteristics of the Treatment System

The test system was a filter bed with a vertical flow. The object of the test was designed and built from scratch as a proprietary solution. The test stand was built in the model shop of the Department of Sanitary Engineering and Water Management at the Faculty of Environmental Engineering and Geodesy of the University of Agriculture in Krakow. The test stand consisted of a supporting structure made of aluminium sections. The base for the trickling filter components was a steel grill, which on the one hand was designed to support the weight of the bed, and on the other, to allow the free flow of treated wastewater from the filter bed. The trickling filter bed was constructed in the form of plastic boxes with the dimensions of W25 × L39 × H11 cm (Figure A1). The boxes were stacked on top of each other, 10 pcs. altogether. The total height of the trickling filter bed was 130 cm. The air supply was through numerous openings and spaces between the boxes. The boxes were covered with a plastic mesh at the bottom, used to protect the bed against the transfer of the shredded recycled plastic into the box below (Figures A2 and A3). The sides of the boxes were covered with a PUR sponge, which also prevented the bed particles from falling out of the filter. The boxes were filled with recycled plastic (ABS), e.g., from used electronic equipment (WEEE). An example photo of the packing of the bed is shown in Figure A1.

ABS with a density of 1.1 g/cm^3 was used in the tests. The filter bed composed of granules with a fraction size of 1.0–3.0 cm or 0.4–0.8 cm, had a porosity of 45%. The hydraulic load was 50 dm^3/m^2. The test stand consists of the following basic components (Figure 1):

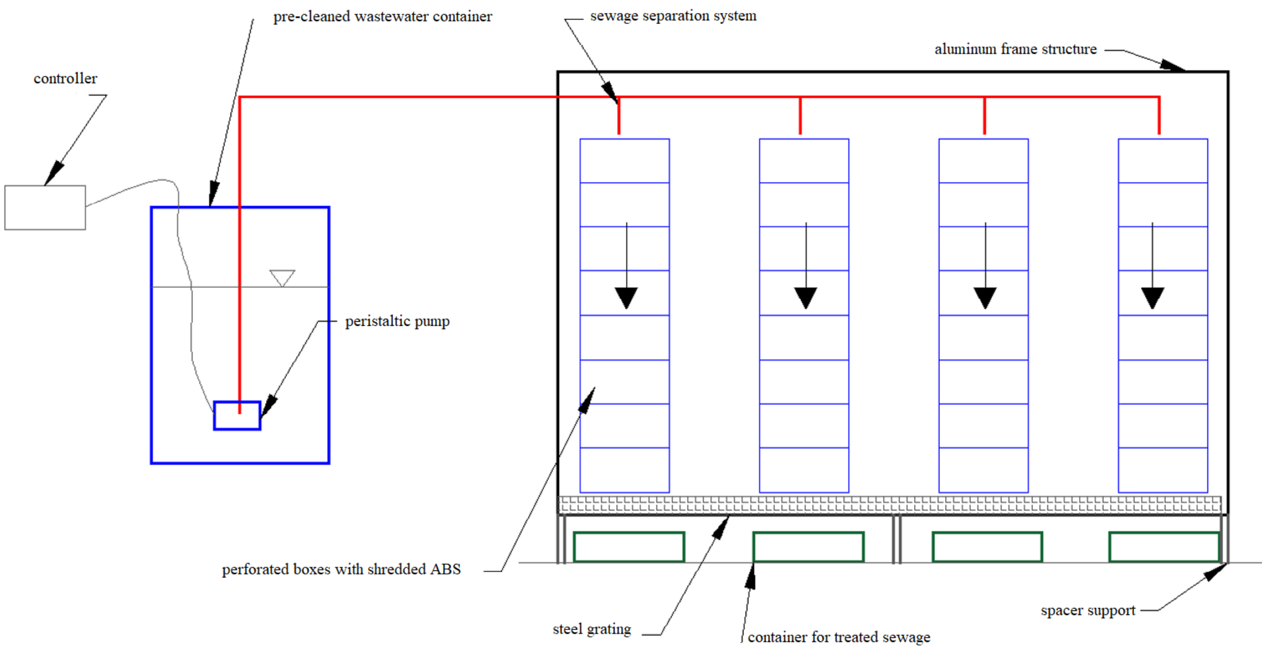

Figure 1. Block diagram of the research model.

2.2. Determination of the Basic Parameters for the Treatment Efficiency

The quality of pre-treated and treated wastewater on a trickling filter was tested. Pre-treated wastewater was drawn from the outflow of the septic tank located in the model shop of the Department of Sanitary Engineering and Water Management. The septic tank was connected to the wastewater system of the University building. Wastewater samples for analysis were taken in accordance with the following standards: PN-74/C-04620-11:1974, and PN-EN ISO 5667-1:2007. The scope of the tests included the following wastewater pollution indicators: BOD_5, COD, suspended solids, dissolved oxygen, the wastewater temperature and pH. Physical and chemical analyses were performed in accordance with applicable standards. The efficiency of reducing selected wastewater pollution indicators was determined and compared with the permissible values set out in the applicable Regulation [21] (the value below 2000 PE of the treatment plant is equal to the load of 40 mg O_2/dm^3 for BOD_5, 150 mg O_2/dm^3 for COD and 50 mg O_2/dm^3 for the total suspended solids). Basic descriptive statistics of the pre-treated and treated wastewater quality were defined (average, minimum, maximum, median, range, standard deviation, and coefficient of variation). Detailed information on the performed physicochemical analyses is given below:

pH measurements were made in accordance with PN-90/C-04540/01:1991, Water and Wastewater—pH, Acidity and Alkalinity Tests. Measurement of the pH of the water and wastewater with electrolytic conductivity of 10 µS/cm and above was made using an electrometric method. The tests were carried out using the CPO-401 multi-parameter measuring instrument by ELMETRON.

Dissolved oxygen concentration measurements were made in accordance with PN-EN 25814:1999. Water Quality—Dissolved Oxygen Determination—Electrochemical Sensor Method. The tests were carried out using the CPO-401 multi-parameter measuring instrument by ELMETRON.

Total suspended solids measurements were taken in accordance with PN-EN 872:2007, Water quality—Determination of Suspended Solids—Glass Fibre Filtration Method.

BOD5 measurements were taken in accordance with PN-EN 1899-1:2002, Water QUALITY—Determination of Biochemical Oxygen Demand After N Days (BODn)—Part 1: Dilution and grafting method with the addition of allyl thiourea. The research was carried out using a mercury-free method, with a set of OXITOP bottles. The measurement of BOD5 with a set of OXITOP bottles involves the determination of the pressure change in a tightly closed measuring vessel (a bottle). The biological reduction of oxygen leads to a decrease in the pressure of the air accumulated above the wastewater sample. The bottles must be kept at 20 °C throughout the incubation period for 5 days in a suitable thermostatic cabinet that is able to maintain a constant (20 °C) temperature. An electronic sensor in the bottle takes measurements of the pressure every day for five days.

COD measurements were taken in accordance with PN-ISO 6060:2006, Water Quality—Determination of Chemical Oxygen Demand. COD concentration values were obtained using an Aquanal Spectro 3 photometer. Samples were taken twice a week. Values were measured for 30 samples per parameter (90 measurements in total).

Using the PAST program, version 4.11, an analysis of Spearman's Rank Correlation Coefficient between the tested physicochemical parameters was performed.

3. Results and Discussion

The source of raw wastewater used in the experiment was a septic tank connected to the building of the University of Agriculture in Krakow. Wastewater from the soil stack was directly led to the septic tank for pretreatment. The quality values of the wastewater pre-treated in the primary septic tank are given in Table 1. Wastewater was directed to the surface of the vertical biological filter and was pre-treated in the septic tank. By analysing the data given in the Table 2, one can notice that the average value of BOD_5 for pre-treated wastewater downstream of the septic tank was 246.7 mgO_2/dm^3, while the median was 240.00 mgO_2/dm^3. The minimum value of BOD5 reached 200 mgO_2/dm^3 and the maximum was 280 mgO_2/dm^3. Hence, the range between these values was not large and amounted to 80 mgO_2/dm^3. In comparison to studies by other authors, it should be stated that the average value of BOD_5 was relatively high—especially when compared to the research conducted by Grygorczuk-Petersons [22], where the authors obtained an average value of BOD_5 at a level of 218 mgO_2/dm^3. Another research [23] showed a high average BOD_5, at the level of 903 mgO_2/dm^3. The author examined 6 single-chamber septic tanks, where BOD_5 values were obtained ranging from 680–1200 mgO_2/dm^3. It can be stated that the values recorded in these tests are relatively high compared to those obtained by other authors. Considering the above, it should be emphasized that wastewater from the septic tanks has generally higher BOD_5 values in relation to raw wastewater flowing through collective wastewater systems.

Table 1. Tabular summary of the results for individual fraction grades of the packing used in the filter bed 2.

Sieve Mesh Size	The Fraction of the Screened Material	The Average Weight of the Screened Material	Residue on the Sieve	Trough (Passed through the Sieve)
mm		g	%	
20	>20.00	0	0	100
10	10.00–20.00	0	0	100
4	4.00–10.00	219.37	73.17	26.83
2	2.00–4.00	65.89	21.98	4.86
1	1.00–2.00	11.39	3.8	1.06
0.50	0.50–1.00	1.79	0.6	0.46
0.100	0.10–0.50	0.59	0.2	0.26
0.063	0.063–0.10	0.45	0.15	0.11
0.000	0.00–0.063	0.33	0.11	0
	Total:	299.83	1	

Table 2. Summary of basic descriptive statistics of the values of contamination indicators of pre-treated wastewater fed to the experimental vertical flow filter.

Descriptive Statistics	BOD_5	COD	COD/BOD_5	Total Suspended Solids	Dissolved Oxygen	Wastewater Temp	pH
	mgO_2/dm^3					°C	-
Mean	246.7	400.9	1.6	426.3	0.1	18.4	7.1
Median	240	418	1.57	398.7	0	18.2	6.96
Minimal	200	328	1.29	303.2	0	17	5.75
Maximal	280	475	2.14	689	0.6	20.2	8.38
Gap	80	147	0.85	385.8	0.6	3.20	2.64
Standard deviation	24.17	51.29	0.25	102.28	0.14	0.86	0.63
Coefficient of variation	0.1	0.13	0.16	0.24	1.44	0.05	0.09
Number of samples	21	21	21	21	21	21	21

The reason for this may be the accumulation of solid particles and their decomposition in the septic tank. The fact that a single-chamber septic tank was used in the research should also be taken into consideration. The values of wastewater pollution indicators downstream in single-chamber septic tanks are higher than those downstream in multi-chamber tanks, which has been proven by other studies.

The average COD/BOD_5 ratio in the pre-treated wastewater fed to the vertical filter was 1.60, which means that the wastewater should be considered readily biodegradable. According to Hanze [23], readily biodegradable wastewater is one with a COD/BOD ratio below 2.0. The median of the COD/BOD_5 ratio amounted to 1.57. The minimum value of the COD/BOD_5 ratio amounted to 1.29, and the maximum value reached 2.14. Based on the presented results, it can be concluded that the pre-treated wastewater was readily biodegradable, which translated into a high organic pollutants reduction efficiency, proved by the reduction of the BOD_5 and COD.

Table 3 shows changes in the BOD_5 value for wastewater treated in the filter bed filled with shredded recycled ABS packing. One can see the period of the filter bed development when after eight days from the start of wastewater dosing, the value of BOD_5 in the treated wastewater was 290 mgO_2/dm^3. After several days, a visible decrease in the BOD_5 in the treated wastewater was observed. Table 4 shows the values of treated wastewater downstream of the vertical flow filter filled with recycled ABS packing, divided into the period of the filter bed development and the period after the filter bed development. On day 34 of the experiment, the BOD_5 value reached the limit value of 40 mgO_2/dm^3 required by the Regulation [21]. According to this study, the effluent from the trickling filter using recycled ABS meets the required discharge. In the following days of the experiment, very low BOD_5 values were recorded in the outlet downstream of the vertical flow filter at the level of 10 mgO_2/dm^3. It can be concluded that, in terms of the BOD5 indicator, the filter bed packing meets the requirements of the Regulation after the period of the bed's development. The development time for the bed/filter was 21 days.

Table 3. Summary of basic descriptive statistics of the values of pollution indicators of the treated wastewater downstream of the vertical flow filter (for the period after the bed's development).

Descriptive Statistics	Unit	BOD_5	COD	Total Suspended Solids
Mean	mg/dm^3	12.30	94.70	25.90
Median	mg/dm^3	10.00	78.00	28.60
Minimal	mg/dm^3	5.00	48.00	5.60
Maximal	mg/dm^3	40.00	216.00	40.00
Gap	mg/dm^3	35.00	168.00	34.40
Standard deviation	mg/dm^3	44843	46.47	9.39
Coefficient of variation	-	0.74	0.49	0.36
Number of samples	Number of units	15	15	15
Acceptable	mg/dm^3	40	150.0	50.00
Number of exceedances	Number of units	0	2	0

Table 4. Summary of basic descriptive statistics of the efficiency of reducing wastewater pollution indicators in a vertical flow filter (for the period after the development of the filter bed).

Descriptive Statistics	BOD_5	COD	Total Suspended Solids
Mean	94.4%	77.8%	92.8%
Median	95.6%	82.2%	92.6%
Minimal	90.0%	52.2%	87.8%
Maximal	98.1%	88.4%	98.0%
Gap	8.1%	36.2%	10.2%
Standard deviation	2.4%	10.1%	2.4%
Coefficient of variation	0.03	0.13	0.03
Number of samples	14	14	14

The average BOD_5 reduction efficiency was 94.4%—the lowest efficiency recorded was 90.0% and the highest was 98.1%. By analysing the efficiency of the BOD5 indicator reduction during the experiment, one can notice a significant increase in efficiency from the level of 65.5% on the eighth day of the experiment.

Taking into account the results of physicochemical analyses, it should be stated that the quality of the wastewater treated using the experimental vertical flow filter was below the limit value imposed by the Regulation [21] for on-site wastewater treatment plants. The average BOD_5 value for the wastewater treated during the period after the filter bed was developed was 12.30 mgO_2/dm^3. The total suspended solids content was about 73%. The efficiency of the ammonia and organic carbon oxidation process did not change significantly, but a very favourable effect was obtained in terms of the backwash phase frequency, which could be reduced by half [24]. Satisfactory results were obtained in comparison to other studies using unconventional types of packing in filters and biological filter beds in on-site wastewater treatment plants [25].

Another study used gravel, sand, and charcoal as filtering materials, arranged from coarse to fine. The results showed that layer filters can effectively reduce the BOD and COD levels [26]. In another research, biochar filters were fed with raw wastewater from a full-scale municipal wastewater treatment plant in Germany at room temperature (22 °C) with a hydraulic load factor of 0.05 $m \cdot h^{-1}$. The COD was found to be reduced by up to 90% [27]. Treatment of dairy wastewater was investigated using laboratory vertical flow wetlands (VF). The degree of pollutant removal in individual filters ranged: from total suspended solids (TSS): 64.2–74.5%; biochemical oxygen demand (BOD): 45.3–63.1% [28]. A pilot denitrification/nitrification plant was designed, built and commissioned, which treats wastewater downstream of the anaerobic reactor. During the operation of the installation, the effect of the COD/N ratio of the remaining organic matter at 18 °C was tested. The maximum removal of organic matter (96%) was achieved with a C/N recycling ratio of 8.25, corrected by the addition of methanol [29]. The corn cob treatment system helped to increase the potential for wastewater reuse by providing a relatively safe replenishment of irrigation water for agricultural purposes [30]. A three-dimensional biofilm-electrode reactor (3D-BER) was constructed to facilitate tertiary denitrification of secondary wastewater from wastewater treatment plants (SEWTP). The pathway of the COD formation and removal was analysed and the relative concentration and composition of organic matter in the inflow and outflow were analysed in order to explain the possible pathways of carbon transformation. Under the influence of electric current in the 3D-BER system, the COD removal rates were strongly and positively correlated (R^2 = 0.9353) [31]. To provide an alternative, research has been conducted on the efficiency of an L-shaped semi-permeable filter filled with steel slag as the filtration medium. The wastewater turbidity value in the vertical section of the filter was higher than in the horizontal section, which may affect the COD removal efficiency of the filter. In addition, the system has shown adequate COD removal rates, ranging from 10% to 76% [32]. In the study, the filtration media (i.e., Fe_3O_4@Carbon [FCM] filtration media) were synthesized and then used in a biological aerated filter (BAF) to simultaneously reclaim phosphate and remove nitrogen (SPN) from municipal wastewater. The interconnectivity and uniformity of the pores were also suitable for biofilm microdistribution, where different FCM aerobic and anaerobic zones were formed. This process facilitates micro-interactions between key microorganisms and the filtration media [33].

It is worth noting that the technique of combining locally available absorbent materials such as sand, biochar and teff straw in the medium has proved to be successful. The biochar was prepared from eucalyptus wood, the teff straw was obtained from teff stalks and the sand was made from native crushed stones. The chemical oxygen demand, biological oxygen demand and total alkalinity removal ranged from 79% to ≥83%. In contrast, more than 90% of the total suspended solids was removed. Statistical analysis of the correlation of laundry wastewater parameters revealed the following relations: COD ($r = -0.84$), TS ($r = -0.83$) i BOD ($r = -0.81$) [34]. A layered combination of bioceramics, zeolite and anthracite was used as a substrate in a vertical flow constructed wetland (VFCW). The treatment space moved downward due to the wear of the adsorption capacity of the top substrate layer over time. VFCWs filled with a layered combination of bioceramics, zeolite and anthracite have been found to have great potential in municipal wastewater treatment [35].

Plant-based filtration techniques have proven to be suitable solutions for wastewater treatment. The influent from the black water pilot-scale filtration basins (RALBI) was treated during a six-month research. The study shows the elimination of different pollutants from black water effluents with an efficiency of 46.9–63.26% COD with an average flow load of 0.317 g/d. In addition, the wastewater can be reused in water-scarce areas, in urban settings as well as in rural agricultural areas. The study analysed the efficiency of pollutant removal from wastewater by the mechanically shredded waste in the form of PET flakes, polyurethane foam strips, shredded rubber tires and filling wool in vertical flow filters with a septic tank. It has been shown that the selection of waste material for packing the vertical filters should be preceded by a decision-making system [36].

Another study investigated the treatment of wastewater from palm oil production through a filtration process using crude and calcined limestone (CL). The column tests were carried out using limestone particles of different sizes. The highest predicted COD removal efficiency was approximately 51% for calcined limestone under optimal flow conditions of 20 mL/min and a limestone particle size of 4 mm, respectively, compared to raw limestone (R^2 = 0.916) [37]. A sequential vertical flow trickling filter and a horizontal multilayer bioreactor were investigated for the treatment of decentralised municipal wastewater. The results showed that the COD removal rate at different concentrations of sodium dodecylbenzenesulfonate (SDBS) can reach a level of 92.1% at an initial COD concentration of 960 mg/L [38]. Recycled crushed glass filters removed 92% and 45% of total suspended solids (TSS) and chemical oxygen demand (COD), respectively. Total suspended solids were removed equally well by sand filters and recycled crushed glass filters (α = 0.05), while the COD reduction was 21% greater in the filters filled with sand [39]. Evaluation of the performance of the activated sludge bioreactor system (ASBS) in the treatment of pulp and paper industry wastewater (PPIW) showed a higher efficiency of treatment in terms of COD removal. The study has also proven that a biosorbent made from biomass waste can potentially help protect non-renewable resources and promote the achievement of a zero-waste state and the principle of a circular bioeconomy [40]. Field-Scale Combined Environmental Treatment Systems (FCETS) have been designed to remove nutrients from aquaculture wastewater in ponds, depending on the characteristics of the nutrients present. The results showed that the average removal rate for TSS was 83.3% and for COD 52% [41]. The use of a filter medium to remove organic matter and reclaim nutrients in black water treatment is a novel concept and has not been sufficiently researched so far. Anaerobic filtration of wastewater with carbon adsorbents removed 80% of organic residues and more than 90% of suspended solids and turbidity. Treated, nutrient-rich water can be used as a source of added value for a variety of end-use options.

The experimental system, consisting of a Lamella primary septic tank, combined with a filtration reactor made of a geotextile pocket filled with activated carbon and medium or fine sand, was assessed as effective. The laboratory-scale installation removed over 70% of COD and BOD5 from raw grey water. Studies have demonstrated the potential of vertical flow constructed wetlands (VFCW) for decentralised wastewater treatment, with an average removal efficiency of 78% for chemical oxygen demand (COD) and 84% for total suspended solids [42]. The biofilm process was tested using Integrated Fixed Film Activated Sludge (IFAS) and Moving Bed Biofilm Reactor (MBBR). The COD and BOD removal efficiency was high—96% and 98%, respectively. The results of this work suggest that a high COD to N ratio and low concentration of dissolved oxygen in anoxic tanks and carriers with a large surface area may be recommended for efficient COD, BOD and TN removal in these systems [43].

Upflow Anaerobic Sludge Blanket (UASB) reactors are commonly used to treat domestic wastewater and often require secondary treatment. As a control measure, an identical UASB reactor was used for raw wastewater treatment only. The results showed the removal of 65% of the COD by the system [44]. The Moving Bed Biofilm Reactor (MBBR) is a well-developed technology for Simultaneous Nitrification and Denitrification (SND). In MBBR reactors, biofilm development and pollutant removal efficiency are closely linked to the physical and chemical properties of these media. The test results showed that in MBBR reactors filled with surface-modified media, an accelerated start of the SND process was observed with a larger amount of biomass placed on the media. At low levels of soluble oxygen (0.6–0.8 mg L^{-1}) and a low C/N ratio ($\leq$5), the COD removal efficiency may reach the level of 79.3–85.7% [45].

The efficiency of post-slaughter wastewater treatment was tested in a Hybrid Upflow Anaerobic Sludge Blanket Reactor (HUASBR), consisting of polypropylene as a growth surface. During the acclimatisation stage, the amount of real wastewater sludge was gradually increased, while the amount of synthetic wastewater sludge was proportionally reduced in the mixed reactor feeding. The observed total suspended solids removal efficiency was in a range of 72–98% throughout the test [46]. The mechanism of the influence of the new pollutant (diclofenac, DCF) in wastewater on the efficiency of the Enhanced Biological Phosphorus Removal (EBPR) process showed that when the concentration of

DCF was 2.0 mg/L, the COD removal efficiency decreased significantly to the level of 71.2 ± 4.2% [47]. The in-situ treated textile wastewater was electrocoagulated for reuse in agricultural irrigation. 18.6% of the COD, 83.5% of turbidity and 64.7% of total suspended solids were obtained [48]. New devices based on the New Integrated Self-Reflux Rotating Biological Contactor (NISRRBC) have been developed for the treatment of rural wastewater. The COD concentrations in wastewater were respectively 15.34 ± 7.29 mg/L. The system created a favourable gradient for microenvironmental conditions and functional flora, thus facilitating the removal of contaminants from the wastewater [49]. Direct anaerobic treatment of domestic wastewater is becoming attractive as it can transform a wastewater treatment plant from energy-consuming to energy-producing. A pilot Anaerobic Sludge Blanket Reactor (UASB) sludge digestion chamber was tested for household wastewater. The results show a stable COD removal efficiency at the level of 60 ± 4.6%, depending on the temperature [50]. An H-type microbial fuel cell (H-MFC) was used to treat used distillery wastewater (DSW), diluted with standard wastewater (SWW) in various mixing ratios. A significant reduction in COD, ranging from 66% to 78.66%, was observed. At a mixing ratio of 50% DSW to 50% SWW, 39.66% of total dissolved solids (TDS) and 97% of total suspended solids (TSS) were removed. The tests have shown that the appropriate dilution of the used distillery flush wastewater with standard wastewater can lead to effective remediation of wastewater and the production of energy [51]. AnMBR (anaerobic membrane bioreactor) was used to treat controlled household wastewater. The system reduced the BOD5 and COD by 86–90% in the temperature range 13–32 °C and with comparable COD load factors of 1.3–1.4 kg-COD m^{-3} d^{-1} and membrane streams 7.6–7.9 L m^{-2} h^{-1} (LMH) [52]. It was found that the EGSB reactor (expanded granular sludge bed) can be used on a pilot scale for bioremediation of LAS (Linear alkylbenzene sulfonate) in sanitary wastewater within 314 days. A 99–99.5% removal of COD and 99–99.8% removal of $N\text{-}NH_4^+$ was observed after using reverse osmosis and activated sludge in a membrane bioreactor [53]. Our research showed that the highest correlation was between dissolved oxygen and COD (Figure 2) The use of reclaimed ABS, appropriately shredded and preliminary rinsed, can be an interesting alternative to other standard materials. During the research period, a significant qualitative variability of flows in the dry season was observed. Average COD and BOD5 levels of 1528 mg/L and 439 mg/L, respectively, were observed, which corresponds to high-capacity effluents. Differences in porosity resulted in different hydraulic retention times (HRT), i.e., 1.21 days and 1.52 days for the gravel and terracotta bed set. The research showed that, ultimately, the average mass load indicator BOD5 and COD (MLR) at the level of 28 g/m^2/day and 138 g/m^2/day, respectively, should be considered the baseline indicator [54].

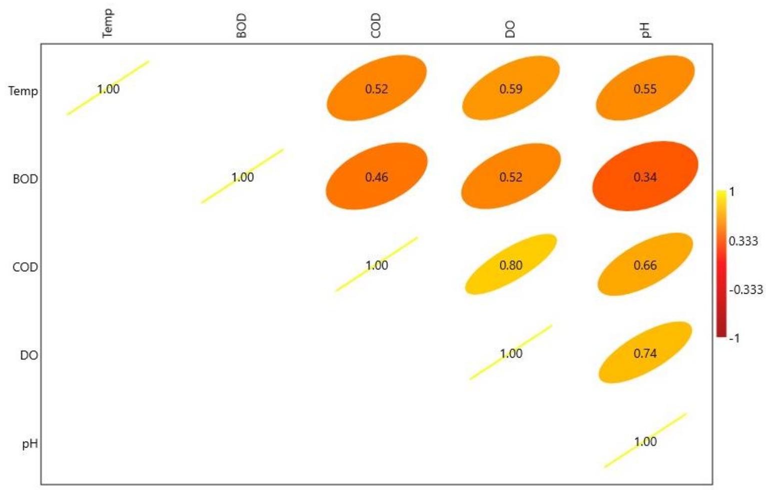

Figure 2. The Spearman's Rank Correlation Coefficient for the analysed quality parameters of the household wastewater.

4. Conclusions

Shredded ABS plastic, sourced from recycled electronic and electrical waste, can be used as filter bed packing in vertical flow filters. The average efficiency of the reduction of the basic indicators of wastewater pollution was high and amounted to 94.4% for BOD_5, 77.8% for COD and 92.8% for total suspended solids, respectively. The results indicated the need to rinse the shredded ABS beforehand with water to separate the finest particles and other contaminants. We recommend stacking shredded ABS in layers in boxes, as it creates very good conditions for the oxygenation of the treated wastewater. The test results showed that such a system allows for the reduction of carbon compounds in the treated wastewater. In further research, attention should be paid to other applications of shredded ABS as a filter bed packing in the process of household wastewater treatment.

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Appendix A

Figure A1. Test stand, primary septic tank—inflow of raw wastewater from the main building wastewater system and general view of the vertical flow filter.

Figure A2. Box filled with the packing material—filter bed (variant with a uniform sponge base).

Figure A3. Shredded plastic (recycled ABS) used as the packing of the filter bed (shredded ABS from recycled WEEE recycling used as a filtering material).

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