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Proceeding Paper

Greywater Treatment Using Agro-Industrial Biochar: A Novel Water Reuse Approach

Pelin Soyertaş Yapıcıoğlu * and Mehmet İrfan Yeşilnacar

Department of Environmental Engineering, Harran University, Sanliurfa 63050, Turkey; mirfan@harran.edu.tr
* Correspondence: pyapicioglu@harran.edu.tr

Abstract: This paper aimed to determine the quality of reclaimed water using biochar. Turbidity, biological oxygen demand (BOD_5), total suspended solid (TSS), and *E. coli* analyses were performed to determine the effluent's quality. At the end of the treatment, the water reclaimed from greywater met the requirements of Class B quality according to European Union (EU) legislation. This study verified that malt dust-derived biochar is an efficient and low-cost adsorbent that can be used to obtain reclaimed water. The reclaimed water was used for the irrigation of the green areas of Osmanbey Campus in Turkey. It was reported that on average %30 of water consumption was prevented by water reuse.

Keywords: biochar; greywater; water reclamation; water reuse

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1. Introduction

The European Union (EU) Blue Deal has enabled the remediation of vulnerable freshwater supplies and coped with the water crisis [1]. Wastewater has sustainable water potential as an alternative freshwater supply [1–4]. Reclaimed water has an important role in the water cycle, as it constitutes an effective method by which to enhance the use of water supplies and can help us to deal with water shortages [1–3]. In particular, wastewater reuse in agriculture includes the utilization of reclaimed water for crop and plant irrigation [1–4]. Effective wastewater treatment methodologies should be carried out to obtain good-quality reclaimed water, according to EU (741/2020) legislation [5]. Recently, biochar applications have been considered an efficient and low-cost wastewater treatment method [6–10]. Most effluents resulting from the biochar adsorption process have complied with regulatory standards for urban and agricultural reuse [6–10].

This paper largely aimed to evaluate the quality and reuse potential of effluents obtained by a malt dust-derived biochar adsorption process for green area irrigation. The evaluation depended on EU (741/2020) wastewater reuse legislation. According to the EU Wastewater Reclamation and Reuse Legislation, Class A-quality reclaimed water can be used for the irrigation of all kinds of agricultural crops [5]. Otherwise, Class B-quality reclaimed water can be used for the irrigation of above-ground and high-above-ground crops such as tomatoes, peppers, or fruit trees [5]. According to the legislation, pH, total suspended solids (TSSs), biological oxygen demand (BOD_5), turbidity, and *Escherichia coli* (*E. coli*) are the parameters in reclaimed water that restrict its ability to meet the minimum water quality criteria [5]. Thus, these parameters were considered for the evaluation of water in this study. The application of biochar during wastewater treatment produces high-quality effluents [11,12]. In this study, malt dust, which is a waste by-product of the brewery industry, was used as the feedstock for the creation of biochar.

Waste recycling and minimization are two of the main polices and adaptation strategies which have favorable impacts on the circular economy, and they are one of several environmental remedies that meet the terms of the European Union's (EU) Green Deal aims [13,14]. In this study, malt dust, which is an agro-industrial waste, was used in great quantities for biochar production, so waste reduction was indirectly achieved. This study is the first to use malt dust-derived biochar as a wastewater adsorbent to achieve reclaimed water. In the literature, there is little research related to the water reuse applications of biochar. In general, membrane processes have been used for water reuse and reclamation [2]. Cosenza et al. (2024) used a membrane bioreactor to generate reclaimed water from municipal campus wastewater [2]. Quispe et al. (2023) investigated the optimization of a biochar filter for the treatment of handwashing wastewater and the potential reuse of this treated water for handwashing [4]. In this study, a biochar adsorption process was performed to generate reclaimed water from greywater composed of kitchen sink and laundry rinse cycle water. Also, a techno-economic performance assessment of water reclamation using this novel adsorbent was performed in terms of water consumption saved.

2. Materials and Method

The overview of this system and conceptual framework of this research are shown in Figure 1. Experimental planning depended on the wastewater analyses conducted in this study. The influent used in the adsorption process was greywater from campus kitchen sinks and domestic laundry rinse wastewater. The characterization of this greywater mixture is given in Table 1. A techno-economic assessment was performed, considering water consumption, based on the consumption of freshwater for green area irrigation at the campus instead of reclaimed water use. The cost reduction was reported in terms of water consumption costs (EUR/month). The wastewater analyses were performed according to standard methods [15].

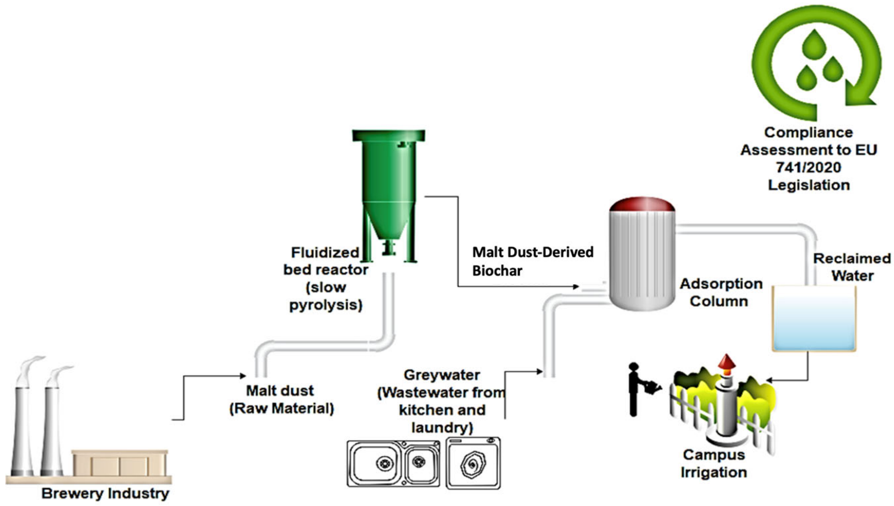

Figure 1. A detailed overview and the main lines of this research.

Table 1. Influent greywater characterization.

Parameter	Value
TSSs (mg/L)	298
Turbidity (NTU)	61
BOD_5 (mg/L)	798
E. coli (Cfu/100 mL)	59

Biochar was derived from malt dust, which was obtained from a brewery in Turkey. A fluidized bed reactor was used for slow pyrolysis at 250, 300, and 500 °C (M1, M2, and M3). Malt dust is a large and solid by-product of the brewery industry. Firstly, the feedstock was ground to generate a homogenous texture. The operating conditions of the slow pyrolysis were a heating rate of 10 °C/min, 30 min of steam, and 2 h of heating. X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared spectrometry (FTIR), and BET (Brunauer, Emmett, and Teller) analyses were performed to determine the biochar's characterization.

An adsorption column with a 1 L volume was operated at lab scale. In this study, a new pollutant adsorption calculation model was developed based on the general adsorption theory by Metcalf and Eddy (2014) (Equation (1)) [16]. A mixture of three types of biochar was added, which amounted to 9 g in total. A general adsorption isotherm was conducted for BOD_5 removal in terms of organic material removal. Seasonal sampling and adsorption were performed.

$$\mathrm{qe} = \frac{(\mathrm{Oi} - \mathrm{Oe})\mathrm{G}}{\mathrm{B}}$$

where

Oi: influent concentration of BOD_5 (mM);
Oe: effluent concentration of BOD_5 (mM) (after biochar adsorption);
G: greywater volume (L);
B: biochar dose (g);
qe: the quantity of organic materials adsorbed onto the biochar (mmol/g).

3. Results and Discussion

The results showed that malt dust-derived biochar was an effective and low-cost technology that could be used to obtain reclaimed water. According to our overall assessment, the effluent from the biochar application met the parameters required to be considered Class B-quality reclaimed water according to the EU (741/2020) wastewater reuse legislation. Table 2 and Figure 2 demonstrates the reclaimed water quality achieved at the end of the biochar adsorption process. The *E. coli* values met both Class A- and Class B-quality criteria for each season. Only the TSSs in winter met the requirements for Class A quality, while the other parameters met the requirements for Class B quality. The results of the overall assessment showed that the effluent met the criteria for Class B-quality reclaimed water when considering the minimum requirements of these criteria. This study verified that malt dust-derived biochar is an efficient and low-cost adsorbent that can be used to obtain high-quality reclaimed water. The reclaimed water was used for the irrigation of green areas of Osmanbey Campus in Turkey.

Table 2. Reclaimed water quality as the result of biochar adsorption.

Parameter	Winter	Spring	Summer	Autumn	Class A	Class B
TSSs (mg/L)	2	11	13	15	≤10	≤35
Turbidity (NTU)	6	7	11	6.5	≤5	_
BOD_5 (mg/L)	11	12	14	11.5	≤10	≤25
E. coli (Cfu/100 mL)	0.5	2	5	1.5	≤10	≤100

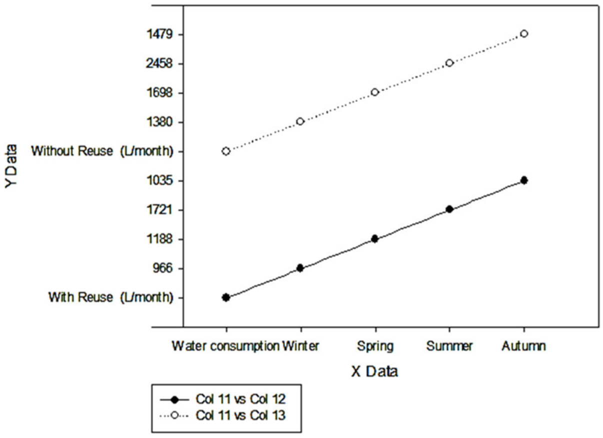

Figure 2. Variation in water consumption with and without reuse.

When comparing the water consumption of two scenarios, which were consumption with and without water reuse, the operational cost was higher without reuse. If water reuse was applied, on average, a 30% reduction in water consumption was recorded. Also, the remediation of the cost was 377 EUR/month. This study verified that biochar is a cost-effective and low-cost wastewater treatment method.

In this study, organic material adsorption onto the malt dust-derived biochar was investigated in terms of BOD_5 removal. Table 3 presents the adsorption results in detail. According to the adsorption results, the most effective biochar was M1, which was produced at the lowest temperature. The biochar characterization results overlapped with the adsorption results. Figures 3 and 4 show the SEM and XRD analysis results, respectively. Figure 5 and Table 4 demonstrate the FTIR and BET analysis results, respectively. According to the results of the SEM analyses, during which the morphology and surface structures of the biochar were examined, porosity reduced as the temperature rose for all biochar. All biochar had a flatter structure at the highest temperature of 500 °C. The biochar produced at 250 °C (M1) contained a higher number of pores and a fibrous structure. All three types of biochar had fibrous, prismatic, and spherical textures. Also, the shapes of their pores were irregular. The M1 produced at the lowest temperature was more effective at taking up the organic materials due to its higher number of pores.

Table 3. Results of organic material adsorption.

	Adsorbents		
Organic material adsorption	M1	M2	M3
qe (mmol/g)	9.95	9.78	9.11

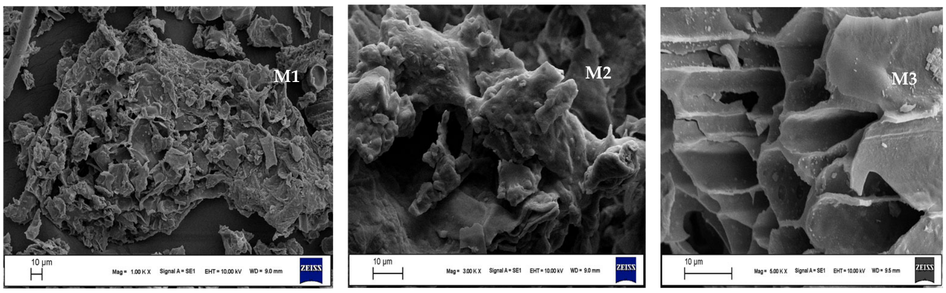

Figure 3. SEM analyses of adsorbents.

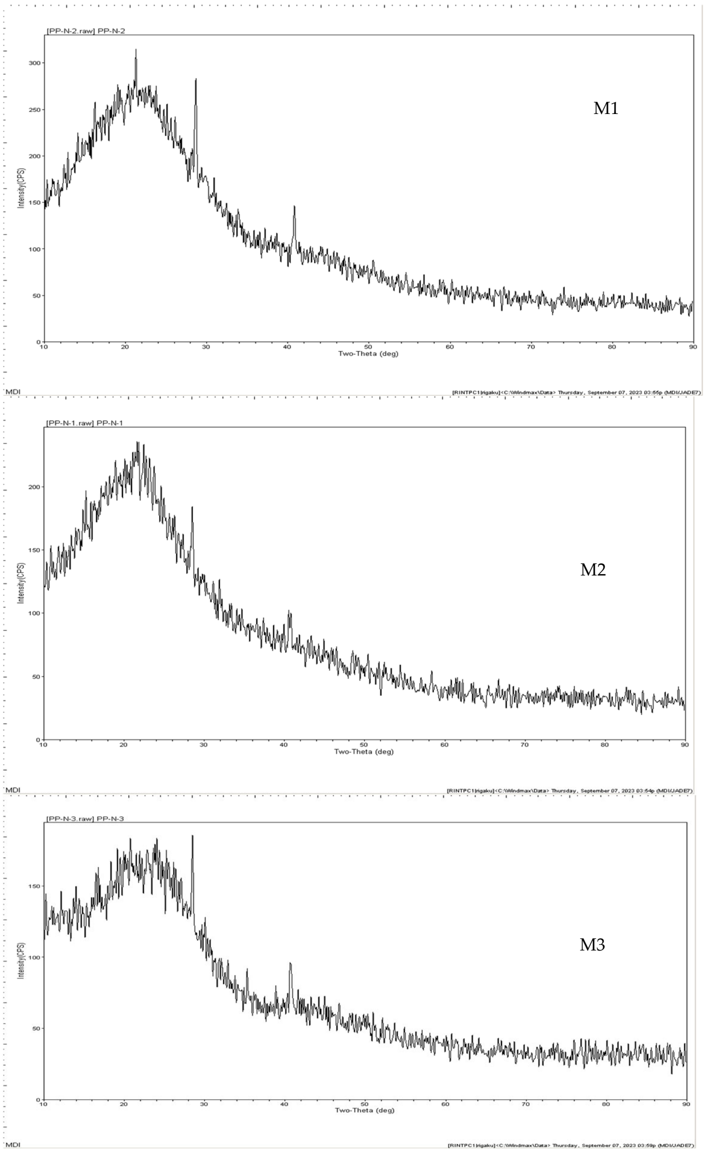

Figure 4. XRD analyses of adsorbents.

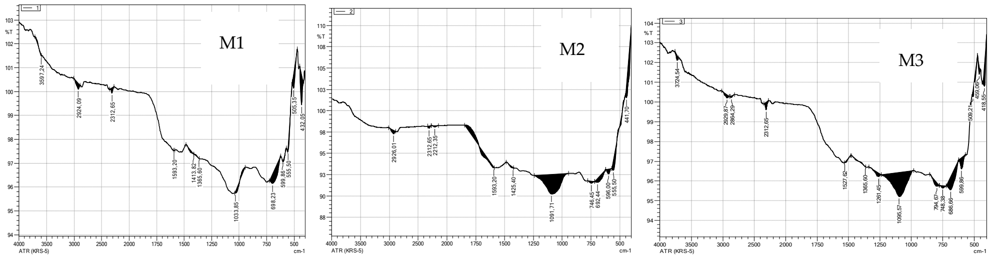

Figure 5. FTIR analyses of adsorbents.

Table 4. BET analysis results of malt dust-derived biochar.

Biochar	BET Surface Area (m^2/g)	Langmuir Surface Area (m^2/g)	Total Pore Volume (cm^3/g)
M1	14.995	26.099	0.359
M2	13.999	24.28	0.29
M3	12.999	22.95	0.219

According to the XRD analyses, an amorphous structure was seen for three biochar. The results of the FTIR analyses showed that all biochar included alkaline functional groups. Organic materials could be easily taken up by malt dust-derived biochar due to its alkaline functional groups.

In the literature, there is limited research related to this topic. In general, membrane processes have been used to try to generate reclaimed water [2]. Cosenza et al. (2024) reported similarly Class B-quality reclaimed water obtained using a membrane bioreactor [2]. Quispe et al. (2023) reported the optimization of a biochar filter for the treatment of handwashing wastewater and the potential of this treated water's reuse for handwashing [4]. There are many advantages related to using biochar as a wastewater reuse and reclamation method [4]. Compared with other treatment methods, such as membrane processes, the application of biochar is a low-cost and efficient reuse and reclamation technique. There are no higher energy requirements for its operation and no freshwater consumption for cleaning. From this perspective, biochar applications are a promising technology that has favorable effects on the circular economy. Biochar application is also regarded as a waste minimization technique due to the use of biowastes as the feedstock. Also, the quality of the effluent at the end of the biochar application is near to the quality obtained after membrane processes. In terms of the circular economy perspective, we discovered that waste biochar (waste adsorbent) could be used as a soil conditioner or manure, for agricultural use, after several analyses. Also, waste biochar could be regenerated by re-pyrolyzing it to produce fresh adsorbents. Waste biochar could be used as feedstock for a new biochar, making this a sustainable approach. This approach offers dual benefits: it reduces industrial waste, contributing to environmental protection, and also provides a sustainable, cost-effective solution for wastewater treatment, particularly in resource-limited areas. This research also demonstrates that greywater treated with biochar meets EU Class B reuse standards, reducing water consumption by 30% and saving money. This sustainable approach aligns well with the principles of a circular economy.

4. Conclusions

This study evidences that malt dust-derived biochar not only adsorbs the contaminants from greywater but also generates high-quality reclaimed water. At the end of the biochar adsorption process, the reclaimed water met the requirements for Class B water according to European Union (EU) (741/2020) legislation. On average, a 30% reduction in water consumption was reported when using biochar adsorption for water reuse. The removal of 98.2% and 91.5% of organic material and pathogens was reported, respectively, when using malt dust-derived biochar. Thus, case studies related to biochar applications in full-scale wastewater treatment systems should be performed in the near future for the purpose of wastewater reclamation and reuse. Biochar could be a low-cost adsorbent for full-scale wastewater treatment plants, providing a circular economy approach that reduces the operational costs of these plants.

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