Chapter

Peat as a Potential Biomass to Remove Azo Dyes in Packed Biofilters

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Abstract

Azo dyes represent a broad group of environmental pollutants that comprise between 60 and 70% of all the dyes and pigments used. The conventional processes are not efficient in treating effluents from the textile industry. Biofiltration emerges as an unconventional, easy-to-use, effective, and low-cost technology for the treatment of textile effluents. Biofiltration uses microbial consortia that form a biofilm on a filter medium. Peat is an organic matter with the ability to retain high moisture content and represents an attractive option to treat these effluents due to its high porosity, sorption capacity, availability, and low cost. The packing materials used were: peat as an organic biomass, perlite as an inorganic material, and a mixture of peat and perlite. Sorption processes in the biofilter peat-packed material and perlite are discussed dealing with its treatment capacity and as potential removers of azo dyes, their advantages and disadvantages compared with other traditional methods, and a review of operating parameters and design criteria that allow its large-scale application as a possible nonconventional treatment technology. The biofilter with the highest removal capacity was the peat-perlite mixture that achieved a 91% for the organic matter (measured as COD), and a 92% for the color removal (Direct blue 2 dye). with a retention time of 1.18 days.

Keywords: azo dyes, biofiltration, peat, perlite, sorption, biomass

1. Introduction

The textile industry is one of the most important worldwide; however, the large number of chemical compounds used in the dyeing and washing process cause its wastewater discharges to have a high content of organic and inorganic compounds that are toxic to the environment [1].

The dyes used by the textile industries contain different structures, which are in greater abundance: the acidic, basic, disperse dyes, azo, basic, anthraquinones, and metal-complex dyes [1]. Currently, the exact number of colorants produced worldwide is not known. Still, there are an estimated 10,000 colorants, with production greater than 7X10^5 tons, and an approximate 5–10% of the colorant remains in the effluents [2].

The main problem derived from the contribution of color to the waters of rivers and lakes is due to the reduction in transparency and the decrease in dissolved oxygen, due to the fact that high color loads hinder the photosynthetic function of plants [1]. Additionally, some problems associated with textile effluents are due to the presence of heavy metals or sulfur, which cause environmental problems due to their toxic nature. Some dyes of azoic nature have been found to have potential carcinogenicity, and at least 3000 commercial azo dyes have been classified as carcinogenic [3].

The production and manufacture of denim are important activities within the textile industry. However, the rise of the blue jeans maquiladora has dramatically deteriorated the environment that surrounds them. Its wastewater discharges are characterized mainly by presenting a blue color, as well as high organic loads [4].

Direct Blue 2, used mainly in denim dyeing, is an azo dye and chromophore since it involves two nitrogen molecules linked by a double bond and contains two aromatic rings in its structure (**Figure 1**). Due to its properties, it is difficult to degrade, and its discharge into the water can interfere with various biological processes that take place in bodies of water [5].

There are different physical, chemical, and biological processes that can be applied to remove colorants from wastewater; however, each process presents technical and economic limitations. Biological treatments are recognized as effective methods for the discoloration and degradation of colorants in highly polluted industrial wastewater [1, 4].

Biofiltration is a technology of easy operation, low investment, and maintenance; the influent is fed in the upper part of the biofilter and infiltrates through the filter medium; the processes that are achieved during the infiltration of the influents are slow filtration and passive, adsorption, absorption, ion exchange, and biodegradation, the latter being a destructive process through the use of microorganisms, predominantly heterotrophic bacteria, which degrade the pollutants present in industrial wastewater [6, 7]. Microorganisms are immobilized by adhering to the surface of a support medium through the formation of a film, which is in contact with wastewater continuously and intermittently [6].

There are various support materials that can be used, among the substrates that have been used for this type of technology is peat, which is partially fossilized plant material, generally dark brown, which is formed with little oxygenation and plenty of water, in places where the rate of accumulation of plant matter is greater than that of decomposition. Being a complex material, whose major constituents are lignin and cellulose, it has a surface area > 200 m^2/g and a porosity of 95% [8, 9]. These properties, together with their ability to adsorb the different compounds, make peat a material that can be used as a support for the formation of biofilms. With respect

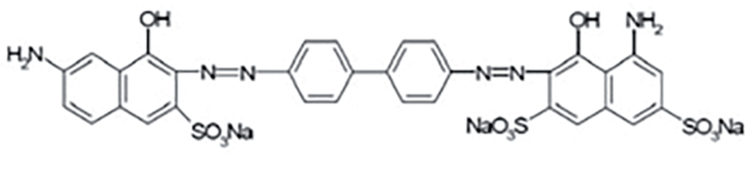

Figure 1.
Chemical structure of direct blue 2 dye.

to expanded perlite, it is a hydrated amorphous volcanic glass material with a water retention capacity of 2–5%, maintaining its original structure, it has a density of 30–150 kg/m^3, it is used to modify soils reducing its firmness and facilitating water drainage and moisture retention [10]. The composition of perlite is 70–75% silicon dioxide: SiO_2 12–15% aluminum oxide, Al_2O_3 3–4% sodium oxide, Na_2O 3–5% potassium oxide, K_2O 0.5–2% oxide iron, Fe_2O_3 0.2–0.7% magnesium oxide, MgO 0.5–1.5% calcium oxide, and CaO 3–5% [11].

The main objective of this work was to design, build, and operate a prototype of a biofiltration system to remove direct blue dye 2 present in wastewater using peat, perlite. and a mixture of peat. Perlite as packing materials.

2. Characteristics of textile wastewater

The textile industry is one of the main sources of pollutants for water worldwide due to the volume and composition of its effluents, which are characterized by being typically alkaline, hot, and colored. These effluents represent a danger to living organisms, as well as to the environment since they carry various types of toxic pollutants [1].

Textile effluents are characterized by a high level of dissimilarities in many parameters such as chemical oxygen demand (COD), pH, total solids (TS), biological oxygen demand (BOD), water use, and color [4]. The industrial manufacturing process rules out unsafe and colored dyes, mostly azo dyes. These colorants cause a great environmental problem, especially to aquatic life, due to their low biodegradability, strong color, high COD, and low BOD/COD ratio [12].

Dyes are classified into synthetic and natural. Synthetic dyes are easy to produce in a wide variety of colors and are very stable molecules; that is why they are widely used compared with natural colorants [1]. Synthetic colorants can be classified according to their mode of application and chemical structure. Based on the mode of application, they can be reactive, acidic, direct, dispersed, etc. While considering their chemical structure, they are categorized as azo, anthraquinone, triaryl methanes, among others [12].

Azo dyes are the most important family among industrial dyes, due to their ease to synthesize and their structural versatility. They are characterized by having an azo functional group (-N = N-) attached to aromatic rings. These colorants provide a practically complete range of shades and high color intensity. In addition, they are very stable to light, heat, water, and other solvents [13]. Azo dyes can be classified by the number of azo bonds they contain (monoazo, diazo, triazo, etc.) or based on the form of application in the fibers (acid, basic, direct, dispersed, mordant, reactive, and sulfurized) [14].

The typical characteristics of textile wastewater are difficult to define, because textile application methods, even the same process, are different for each industry. The concentration of colorants in textile wastewater varies in a wide range from 10 to 250 mg/L [12, 15–17] and in some cases, up to 800 mg/L [18].

Textile industries consume more than 100,000 tons/year dyes, and about 100 tons/year of dye enters the effluent water [19]. There is no exact information on the amount of dye released from various processes to the environment, but the release of the actual amounts of artificial colors into the environment has been identified as an environmental challenge.

3. Textile wastewater treatment

The textile industry uses a large amount of drinking water for the production of fibers. It is estimated that per kilogram of a textile material, 200 L of water is used, which leads to large volumes of wastewater [16]. This, together with the toxic effect of some colorants and their low biodegradability, has driven the search and implementation of technologies for the treatment and recycling of textile effluents. So, before the discharge of textile effluents to bodies of water, they must be treated either by a physical, chemical, biological process or a hybrid system.

3.1 Physical methods

Coagulation-flocculation-based methods are efficient for decolorizing wastewater containing dispersed dyes but show low efficiencies with reactive and vat dyes [20]. Filtration techniques (ultrafiltration, nanofiltration, and reverse osmosis) have been used to recover and reuse water. However, the high costs of the membranes, possible fouling of the same, and the generation of waste containing water-insoluble dyes (for example, indigo dye) limit their large-scale application [21]. On the other hand, adsorption processes (based on activated carbon) have been efficient in removing colorants present in wastewater [22]. However, its price and difficulty to regenerate it make it difficult to apply it in treatment plants.

3.2 Chemical methods

These are the degradation methods most used in the removal of colorants due to their easy application. In this category, we find the advanced oxidation processes (AOPs). These methods have the ability to degrade both the initial colorant and its by-products, either partially or totally under environmental conditions. Furthermore, they can be used in synergy with other methods [23].

Within AOP, the Fenton process (a combination of H2O2 and Fe(II) salts) is the most popular, which has been successfully applied in the degradation of soluble and insoluble dyes [24, 25]. Its main disadvantages are the generation of sludge due to the flocculation of the reagents with the dye and the cost of the reagents. However, the photo-Fenton process offers an improvement to the traditional process, so that in the presence of UV light (even sunlight can be used), it is possible to regenerate Fe(II), making the degradation process more efficient [26].

3.3 Biological methods

Biological processes, due to their cost, are the most used treatments in the removal of colorants present in industrial effluents [27, 28]. Based on oxygen requirements, biological methods are classified as aerobic, anaerobic, and anoxic or facultative, or a combination of these. Few studies have reported on the degradation in aerobic conditions, since in general long periods of acclimatization are required, and the process is sensitive to changes in the concentration of the dye [29]. On the other hand, anaerobic processes are efficient for the bleaching of textile effluents [28]. However, the aromatic amines generated are more toxic than the original compounds and are difficult to break down under anaerobic conditions. In addition, fungal cultures and enzymes have been used for the degradation of dyes [30, 31].

3.4 Hybrid methods

Coupled treatments (anaerobic-aerobic) are a good alternative for treating effluents from the textile industry [28, 32]. In the anaerobic stage, the reduction of the azo bond takes place, and the resulting aromatic amines are mineralized under aerobic conditions. An advantage of this system is the complete mineralization that is often achieved thanks to the synergistic action of different microorganisms [33]. While the main disadvantage is the long hydraulic retention times in the anaerobic stage [27, 28].

4. Nonconventional methods: biofiltration

Biofiltration, synonym for biological filtration, is a secondary treatment process for onsite wastewater. Filtration is one of the more common biological treatment processes. Filters are commonly constructed using sand, gravel, peat, or a synthetic material. These synthetic materials, such as foam, fabric, or plastic and natural materials, such as peat, are grouped together under the generic title "biofilter" [34].

Biofiltration is considered an unconventional process that involves the removal of pollutants (such as drugs, fertilizers, dyes, among others) through a physical (adsorption) and biological process simultaneously of a packed material in a filter. The packed material can be a natural one (organic or inorganic). In addition, low-cost adsorbent media can be used (which can even be an agro-industrial waste), such as bentonite, polymeric resins, or peat, which makes this process more eco-friendly and economically competitive compared with physical or chemical processes [32, 35].

5. Peat as a packing material

Biofiltration using peat as the filter medium is widely used for wastewater treatment processes in small communities and has been used to remove various pollutants and lately also used to remove emerging pollutants, due to its adsorption properties, ability to retain moisture, buffering capacity, and abundance in nature. Peat is an organic material, dark brown in color, and rich in carbon. It is formed as a result of the rotting and partial carbonization of vegetation in the acidic water of swamps, marshes, and wetlands [27]. It is formed in poorly oxygenated wetlands, where the rate of accumulation of plant matter is greater than that of decomposition. It is a very complex material, with lignin and cellulose as major constituents. The polar functional groups of lignin, which include alcohols, aldehydes, ketones, acids, phenolic hydroxides, and ethers, are involved in the formation of chemical bonds during the adsorption processes. As it has a high adsorption capacity for polar organic molecules and is a highly porous material (approx. 95% and a specific area of 200 m2/g), it is usually washed and sieved before being used in wastewater treatment [36].

Four stages in the adsorption process using porous peat are identified: (i) transport of impurities from the bulk of solution to the exterior surface of the peat; (ii) movement of pollutant across the interface and adsorption onto external surface sites; (iii) migration of pollutant molecules within the pores of the peat; and (iv) interaction of pollutant molecules with the available sites on the interior surfaces, bounding the pore and capillary spaces of the peat [36].

6. Design criteria for biofilter scale-up

The textile industry requires a large amount of water, between 100 and 200 L per kg of textile products. The wastewater obtained from the various processes is highly polluted because it contains dyes, surfactants, inorganic salts, and chemical compounds used in the production process [37]. To scale up the processes implemented in the laboratory, the hydraulic retention time (HRT) and the flow rate generated in the production systems must be considered. The following Eq. (1) establishes the volume required for the biofiltration system.

$$V = Q * t \tag{1}$$

Where: V: Usable volume of support medium (m^3), Q: Flow rate (m^3/s), and t: HRT (s).

The total effective volume of the biofilter will be affected by the porosity of the specific packing medium selected; with this information, the flow rate of the wastewater generated, the hydraulic conductivity of the packing medium, the hydraulic gradient have to be determined and applying Darcy's Law, the surface area of the treatment system calculated. This information is necessary before the scale up of these laboratory systems to a full scale.

7. Experimental procedure

7.1 Materials and methods

7.1.1 Packaging materials, inoculum, and biofilter

The reactor was built of acrylic, with the dimensions shown in **Figure 1**. These proportions between the biofilter measurements will need to be considered when scaling is required (geometric similarity). The packaging materials were selected: peat and perlite (**Table 1**). These materials are characterized by having high porosity, adsorption capacity, and availability, which implies that they are low-cost, have ideal characteristics for suitable packaging material. Peat is an organic material, dark brown in color, and rich in carbon. It is formed as a result of the rotting and partial carbonization of vegetation in the acidic water of swamps, marshes, and wetlands [9]. Perlite is a mineral of volcanic origin, whose chemical components are silica and oxides of aluminum, iron, calcium, magnesium, and sodium [11].

The packing materials were washed with plenty of water, to eliminate the color in the case of peat or powders in the case of the rest of the materials. Subsequently, they were dried by exposure to the sun. For the case of all inorganic packing materials, an

Absorbent material	Apparent density (g/cm^3)	Real density (g/cm^3)	Porosity (%)	Water retention (g/100 g)	Reference
Peat	0.1–0.5	1–1.6	94	287	[38, 39]
Perlite	0.05–0.1	0.96–1.2	95	300–400	[11, 40]

Table 1.
Physical characteristics of packing materials.

Parameter	Value
COD (mg/L)	2000
pH	6.74
Total solids (g/L)	20.26
Total suspended solids (g/L)	16.19
Total volatile solids (g/L)	11.90

Table 2.
Characterization of the inoculum.

Compound	Concentration (mg/L)
Saccharose	1000
NH_4Cl	335
KH_2PO_4	70
Yeast extract	5000
Azo dye	50

Table 3.
Synthetic wastewater composition.

average particle size of 8 mm in diameter was selected. As a filter medium, peat and perlite were used alone and, a combination of both, in a 50:50 (v/v) ratio.

The biofilters were inoculated with activated sludge (**Table 2**) from the ECCACIV Wastewater Treatment Plant, located in Jiutepec, Morelos. In total, 20% of the volume of sludge and 80% of the volume of synthetic municipal wastewater were used (**Table 3**), added with a solution containing the azo dye Direct Blue 2. The biofilters were left for up to 7 days, in order for the biofilm formation to take place (**Figure 2**).

7.2 Characterization of packaging materials

7.2.1 Adsorption and desorption isotherms

For each filter medium, adsorption kinetics was performed, based on the methodology proposed by OECD [41]. Known volumes of the test solution are added to the packing material (previously equilibrated with $CaCl_2$ 0.01 M). The mixture is stirred for an appropriate time. Subsequently, the packing material is separated by centrifugation, and the aqueous phase is analyzed by spectrophotometry. The amount of substance adsorbed on the packaging material is calculated as the difference between the amount of test substance initially present in the solution and the amount remaining at the end of the experiment.

In order to investigate whether the adsorption of the dye to the packaging material is reversible or irreversible, a desorption kinetics was carried out. From the adsorption test, once the aqueous phase is separated by centrifugation, the volume of solution removed is replaced by an equal volume of $CaCl_2$ 0.01 M (without containing dye) and stirred again, for an appropriate time. The aqueous phase is recovered (as much as possible), and it is analyzed spectrophotometrically.

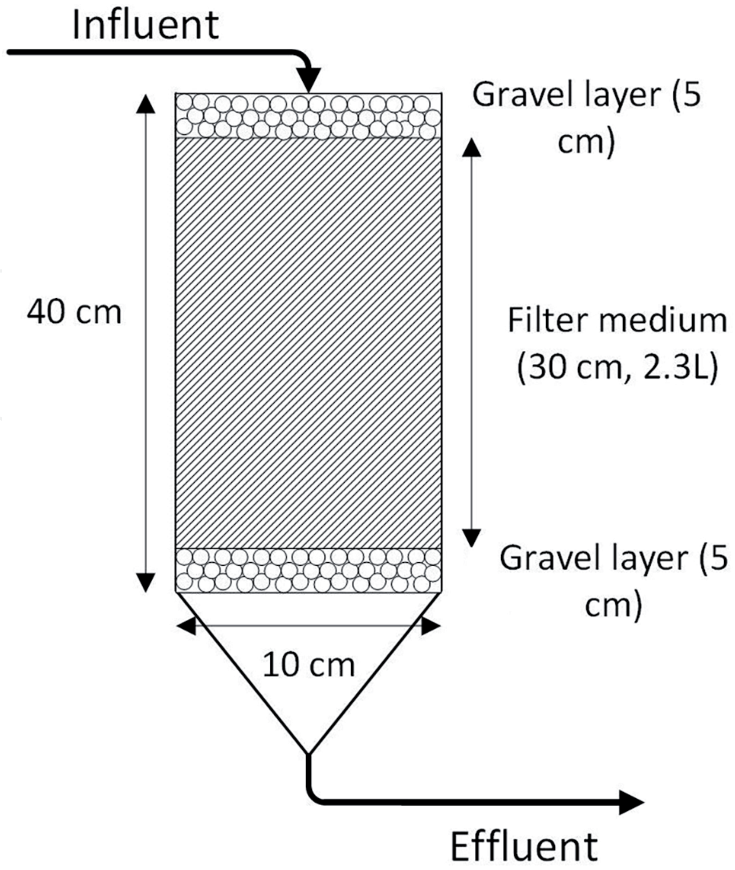

Figure 2.
Design of the biofilter used.

7.3 Determination of the porosity of the filter medium

To determine the hydraulic retention time (HRT) of the biofilters, the methodology described by Garzón-Zúñiga et al. [42] is used, which generally consists of the following steps: 1) determination of the volume of voids in the filter bed layer; 2) determination of the porosity of the filter medium and; 3) determination of HRT, based on the following Eq. (2):

$$\mathrm{HRT} = V_t / Q \tag{2}$$

Where,
Q = flow rate (L/d).
V_t = Porosity Volume of voids in L.
Y = Volume of empty spaces (L).

The flow rate was obtained by doing emptying tests, for which it was previously necessary to fill the biofilters with water (until full coverage of the filter medium). Then, the biofilter was drained, and the volume obtained was measured at different time intervals.

7.4 Evaluation of color removal and degradation of organic matter

The removal of color was followed spectrophotometrically, in the case of the Direct Blue 2 dye, the absorbance in the effluent at 576 nm was measured. On the other hand, the removal of organic matter was determined considering the removal of COD [43].

8. Results and discussion

8.1 Biofilter flow rates and hydraulic retention times

Table 4 shows the flow rates and HRT of each biofilter, calculated using the methodology described by Garzón-Zuñiga et al., [42]. It can be seen that the biofilter with peat shows a higher HRT (1.51 d); this is because the peat can expand and has low porosity, which reduces the empty spaces. In the biofilter with the peat-perlite mixture, the HRT (1.18 d) is lower than that of the peat (HRT = 1.51 d) because the perlite increases the number of empty spaces. For the perlite biofilter, the HRT (1.0 d) is lower than the peat biofilter and the peat/perlite biofilter, because perlite is an inorganic mineral material, and it does not absorb water since it retains it on its surface.

Packing material	Flow (L)	HRT (d)	HRT (h)
Peat	1.10	1.51	36.24
Perlite	1.26	1.00	24.00
Peat/perlite	1.23	1.18	28.32

Table 4.
Hydraulic retention time (HRT) calculated from biofilters.

8.2 Organic matter removal assessment

For 110 days, the biofilters were fed with a synthetic effluent with a color concentration of 50 mg / L and consequently a constant COD. For the biofilter packed with perlite, in **Figure 3**, we observe that, at 15 days, a COD removal of 14% was achieved, and at 30 days decreased to 13%. At 50 days, the removal rate was 61%, and at 110 days, 71% removal was achieved. No studies were found in which perlite is used as packaging for biofiltration of wastewater; however, there are works carried out with inorganic packaging, Villanueva et al., [44] carried out a study with a biofilter packed with gravel, obtaining removals of 27% of the COD at 21 days.

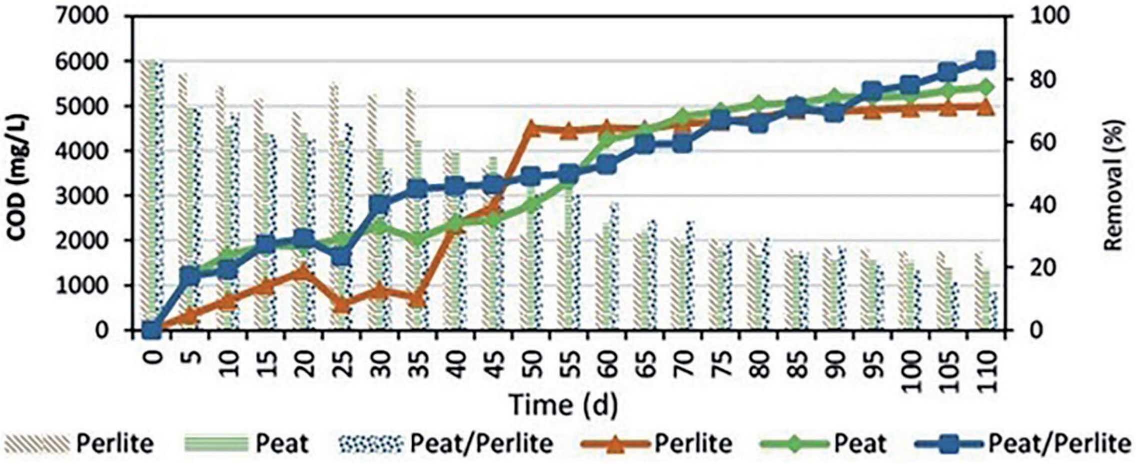

Figure 3.
Organic matter removal was measured as COD in the biofilter with the peat, perlite, and peat-perlite mixture.

For the peat-packed biofilter, **Figure 3** shows that, from day 15, COD removals of 27% were obtained, reaching at 30 days, removals of 33%. Obtaining removals up to 78% after 110 days, compared with the performance of the perlite-packed biofilter (71% COD removal), higher COD removal was achieved with the peat biofilter. In 2011, Velasco [45] reported a study of biofiltration with peat, obtaining an average organic matter removal efficiency of 75.5%, and another study by Mejia [45] reports organic matter removal efficiencies of 53.4%.

For the biofilter packed with peat-perlite, **Figure 3** shows that on day 15, organic matter removal was less than 30%. From this day on, the percentage of removal increased until reaching 70% removal on day 80, achieving a removal rate of 91% at 110 days. Comparing the results with the perlite (71%) and peat (78%) biofilters, the highest removals (86%) were obtained with this biofilter, which may be due to the use of two materials with a very different composition (organic and inorganic); however, the use of perlite helped the biofilter perform better in terms of removal. No works reported in the literature were found, with biofilters packed with peat-perlite for wastewater. In 2011, Velasco [45] carried out a study using nanoparticles of TiO_2 and MgO, in a biofilter packed with peat, reaching 97% in removal of organic matter.

8.3 Color removal assessment

For assessment of the dye concentration (mg/L), the UV–vis spectrophotometry method was used. To evaluate the dye concentration (mg/L), A UV–vis spectrophotometric method was used. First, the calibration curve for direct Blue 2 was performed with solutions of the dye from 10 to 100 mg/L concentration at a wavelength of 576 nm.

For the perlite-packed biofilter, the dye removal efficiencies are shown in **Figure 4**. On day 15, a 46% color removal was achieved, gradually increasing the removal rate. On day 25, the dye removal was 50%, reaching an 82% removal rate at 110 days. In comparison to that reported by Melgoza and De la Cruz [46], inorganic filter media such as tezontle are highly efficient (≈93%) for color removal in real textile effluent with azo dyes.

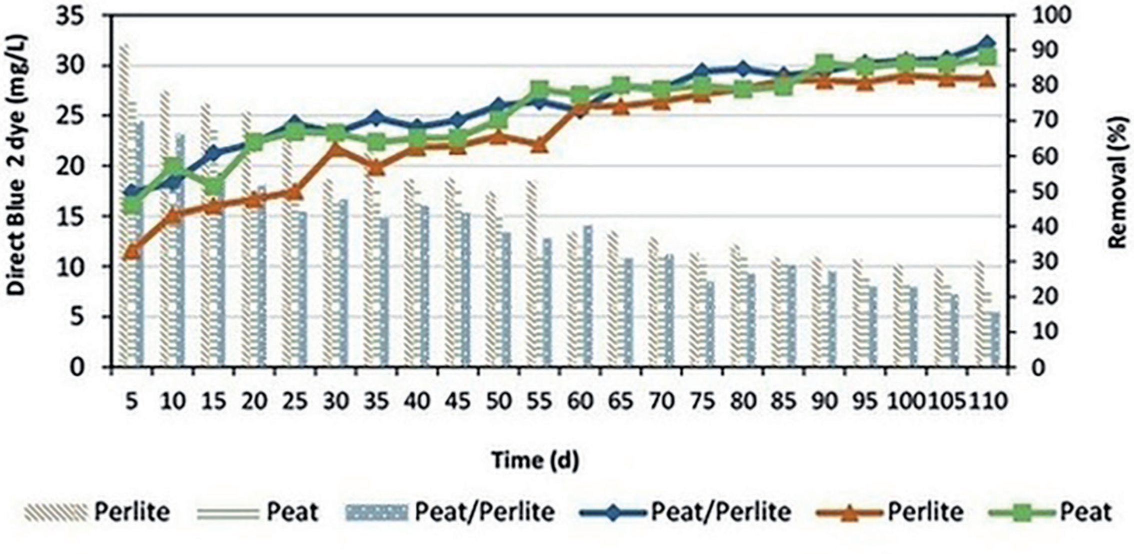

Figure 4.
Dye removal in the biofilters with peat, perlite, and peat-perlite mixture.

In the case of the peat-packed biofilter, **Figure 4** shows that on day 15, the removal of the dye achieved 51%, gradually increasing the removal rate. On day 25, the color eliminated was 67%, reaching an 88% removal rate at 110 days. In general, the performance of the color removal results shows a wide variation, which is probably due to color interferences from the peat or the biofilm formed on the peat. Mejía [47] reports a 50% removal of Terasil SRL black color in biofilters packed with peat and inoculated with Pleurotus ostreatus.

In the case of the biofilter packed with the peat-perlite mixture, **Figure 4** shows a variation in the data obtained on day 15, 61% the removal, and the day 15, the removal increases gradually (>70%), the rate removal was 79% on day 55. In 110 days, the removal reached 92%. Comparing the results with the biofilters with perlite (82%) and peat (88%), with the peat/perlite biofilter, removals of 92% were obtained. It may be due to the constituents of the two materials with different compositions (organic and inorganic) and textures. Therefore, the mixture of the two materials increases the percentage removal efficiency of the dye.

8.4 Sorption process assessment

In the adsorption kinetics, perlite has a sorption capacity of 16.2% in the first 2 hours of contact with the dye, while in the case of peat, the adsorption capacity was 87.5% during the first hour (**Figure 5**).

Adsorption and desorption were described by the linearized form of the Freundlich Eq. (3)

$$\log C_s = \log K_f + 1/n \log C_e \tag{3}$$

where K_f is the adsorption coefficient characterizing the adsorption–desorption capacity, and n is the Freundlich equation exponent related to adsorption intensity that is used as an indicator of the adsorption isotherm nonlinearity.

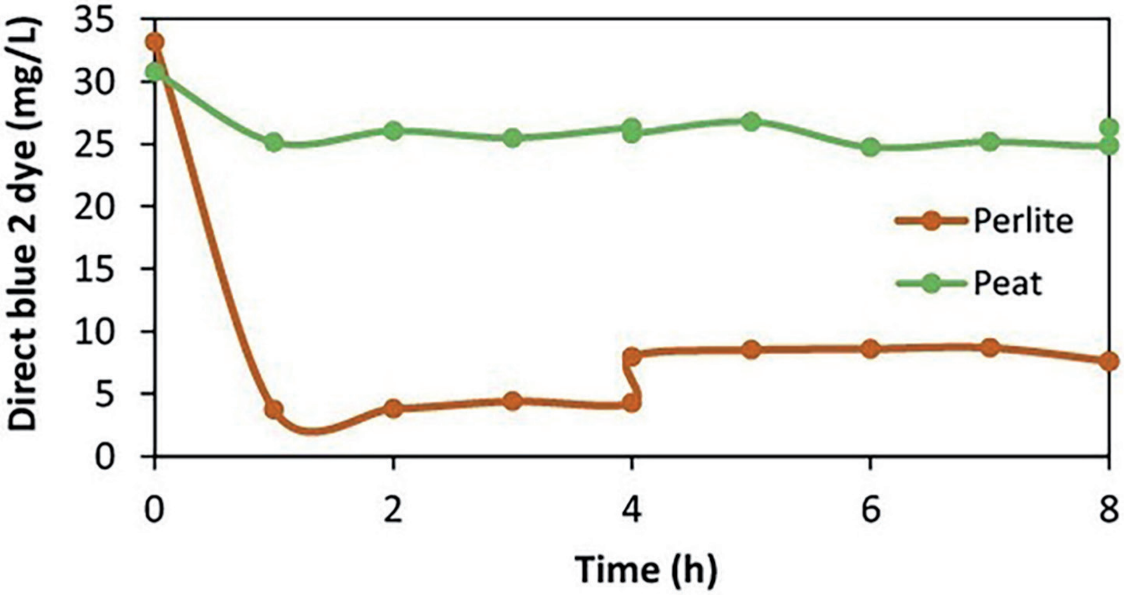

Figure 5.
Kinetics of sorption of direct blue 2 in packing materials.

$K_{f\text{-}ads}$ is the adsorption coefficient, and $K_{f\ des}$ is the desorption coefficient of the Freundlich equation.

The hysteresis coefficient, H, for the adsorption and desorption isotherms was calculated according to Eq. (4):

$$H = (1/n_{des})/(1/n_{ads}) \tag{4}$$

where, $1/n_{ads}$ and $1/n_{des}$ are the Freundlich constants obtained for the adsorption and desorption isotherms, respectively.

The organic matter (OM) normalized adsorption constant (K_{OM}) was calculated by normalizing $K_{f\text{-}ads}$ to the fraction of OM Eq. (5)

$$K_{OM} = K_{f-ads} / OM \times 100 \tag{5}$$

The sorption isotherms for the two packing materials are shown in the **Figure 6**.

Table 5 shows the parameters determined with the adsorption and desorption isotherms.

Based on the parameters determined by Freundlich, peat has a higher adsorption capacity than perlite. This is confirmed by considering the amount of organic matter contained in the materials. Since it has been shown that contaminants are adsorbed on the organic fraction of the substrates. Hysteresis in peat shows that the packing material has a dye-holding capacity since the ratio of the desorption intensity to the adsorption intensity gives a value below 1, indicating that the adsorption rate is higher than the desorption rate, which favors the retention of contaminants in the

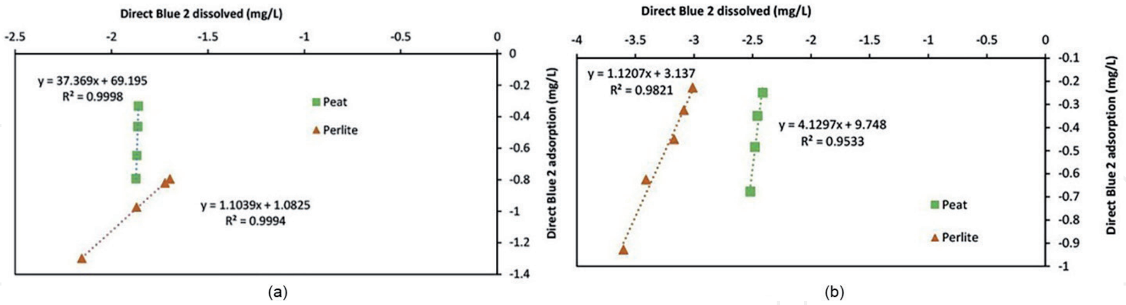

Figure 6.
Isotherms sorption for direct blue 2 dye in perlite and peat (a) Adsorption. (b) Desorption.

Packaging material	Adsorption		Desorption		H	OM* (%)	KOM(%)
	K_{ads}	1/n	K_{des}	1/n			
Peat	1.56×10^{69}	37.37	5.59×10^{69}	4.130	0. 0.11	97.51	1.59×10^{69}
Perlite	12.09	1.10	1370.88	1.121	1.09	0.62	1950

**For the organic matter determination, the methods used were the following ASTM D2974–14.*

Table 5.
Parameters of Freundlich isotherms for peat and perlite.

material. Whereas with an H value such as that of perlite close to 1, it indicates that the adsorption rate is similar to the desorption rate, so the hysteresis process does not occur [48]. Based on the characteristics of the materials used in the biofilters and adsorption data, the perlite serves as a porous and inert material, which provides the packing medium with aeration capacity and support that prevents clogging due to the peat compaction, but does not favor retention. Therefore, the pollutants present in it undergoes adsorption and desorption processes at the same rate, increasing the availability of the pollutants in the perlite-packed area. While peat provides the biofilters with the necessary nutrients for biofilm formation; moreover, adsorption support allows them to retain contaminants, favoring the contact between microorganisms and contaminants, when the pollutants present in the pore water are removed, the pollutants retained in the peat are released, favoring its availability and degradation. Therefore, the biofilter with the highest removal capacity is the peat-perlite mixture.

9. Conclusions

Perlite supplies the biofilter with support, aeration and allows to increase the availability of the pollutant due to its low adsorption capacity. While peat is a packing material that provides nutrients to the microorganisms in charge of the biodegradation process, it retains the direct blue 2 dye increasing the contact capacity between the pollutant and the microorganisms in charge of the degradation process. The perlite does not have a hysteresis process because the adsorption rate is the same as desorption. While the peat showed hysteresis, obtaining a value less than 1, which indicates that the adsorption rate is higher than the desorption rate, which favors the retention of the direct blue 2 dye. Due to the specific adsorption capacity of each material: perlite and peat, the mixture of the materials complements the properties of the packed material and improves the performance of the biofilter itself and consequently the removal capacity of the organic matter and the direct blue dye pollution of the wastewater fed into the biofilter. No reports have been found using this mixture (peat and perlite) as a packing material either in lab or pilot scale, and consequently, there are no full-scale experiences including industrial or municipal wastewater treatment reports using this nonconventional technology and packing material. This is an important opportunity to continue this research line to use this kind of nonconventional packing materials and biomasses to be used for biofilters, due to its ease of operation and economical benefits that allows us to implement them in small communities and/or for industrial wastewater treatment in small installations. Some other scale-up experiences with peat and other waste biomass indicate that it is necessary to pretreat the wastewater to be fed to eliminate solids that could clog the biofilter; therefore, the treatment train is easy to implement (septic tank or a primary settler and the biofilter packed with this mixture, and if needed a disinfection method).

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