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River Water Treatment in a Filter Filled with Peat and Modeling Particle Capture

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Abstract: Peat has the potential to be an effective filter medium for river water, addressing not only total suspended solids (TSS) but also other contaminants. However, the breakthrough of TSS will determine the filter's operability. In this study, two identical filter columns filled with peat were continuously supplied with river water for approximately 45 hours. Influent and effluent turbidity, conductivity, pH, and TSS concentrations were measured at 2-hour intervals. The TSS removal efficiency was approximately 100% during the initial 16-hour period, after which it gradually decreased. Irrespective of the breakthrough, the conductivity in the effluent consistently decreased. The pH variation also did not show any interruption. The developed particle capture model yielded determination coefficients (R^2) of 0.88 and 0.82 for calibration and verification, respectively. However, the model overestimated until 30 hours, after which it fitted well. The model can be used to estimate the peat-filled filter bed thickness for any required influent flow rate. It is concluded that peat is an effective filter medium for TSS and other contaminants in river water. The conventional governing equation for gravity filters must be modified for peat to develop an optimal particle capture model.

Keywords: Conductivity, Filtration, Modeling, Particle Capture, Peat, Suspended Solids, Turbidity

1. Introduction

Various surface water bodies utilized as sources for water treatment may harbor diverse types of suspended and dissolved solids in varying concentrations, directly impacting water turbidity and conductivity. Filtration plays a dominant role in physical methods for water treatment. The most common filtration process is granular filtration, also known as depth filtration. In depth filtration, the separation of suspended or colloidal contaminants from water is achieved by passing water through a porous medium or multiple porous media. The increasing scarcity of clean water and rising costs of conventional filtration methods have spurred the development of affordable filtration alternatives that are both accessible and effective. Among the most commonly utilized low-cost filter media are sand, gravel, and biochar. It is important to recognize that the efficacy of these materials as filter media hinges on various factors, including the specific contaminants present in the water, filter design, and operating conditions.

Due to its diverse chemical and physical properties that are favorable for executing treatment mechanisms, peat could be a potential filter medium in water filters. Peat soil, a type of organic soil, is primarily composed of decomposed plant materials accumulated in waterlogged conditions. The organic materials in peat are primarily derived from partially decayed vegetation [1]. Due to its high organic content and fibrous nature, peat soil has a low bulk density. Peat can hold significant amounts of water. Peat soils are generally acidic, with pH values ranging from 3.5 to 5.5, depending on the degree of decomposition and the type of vegetation from which they are derived [2]. Peat soils have a high cation exchange capacity due to the abundance of organic matter [3]. The high organic matter content of peat provides a suitable environment for microbial activity. Peats decompose slowly due to the anaerobic and acidic conditions, which inhibit the activity of decomposer organisms [4]. Past research provides evidence of its treatment potential through ion exchange and adsorption [5], [6], [7] and [8]. Hence, the peat as a filter medium in water filters would ensure the treatment of not only suspended solids but also some dissolved solids.

Mathematical modeling of particle capture in water treatment filters serves as a vital tool for

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comprehending, optimizing, and enhancing water treatment processes. Such modeling aids in the production of safe and clean water, concurrently reducing costs and minimizing environmental impacts. To ensure reliable predictability of filter performance, a comprehensive understanding of the mechanisms driving the rapid gravity filtration process is essential [9]. Research has utilized equations like the continuity equation and kinetic equation for filtration modeling. For instance, Herzig [10] developed numerical models for suspension flow through porous media, simplifying mass balance equations to derive a first-order equation.

Particle capture in a filter during water treatment is influenced by various factors. The type and properties of the filter media play a crucial role. Different materials have varying pore sizes and surface characteristics that affect their ability to capture particles. Selecting a filter with appropriate pore sizes for the size of particles being removed is crucial. Filters are typically designed to capture specific ranges of particle sizes, so the size distribution of the contaminants affects how well they are removed. To select a porous medium for a single-medium filter, effective size, uniformity coefficient, porosity, specific gravity, depth of medium, and filtration rate are the key parameters [11]. The rate at which water flows through the filter affects particle capture. Higher flow rates can reduce contact time between particles and the filter media, potentially reducing capture efficiency. The depth of the filter bed influences the contact time between particles and the filter media. Deeper beds generally provide more opportunities for particles to be captured but may also lead to increased pressure drop and higher operating costs. The cleanliness of the filter media affects its ability to capture particles. Accumulated debris or biofilm on the filter surface can reduce filtration efficiency. The composition of the water being treated, including its pH, turbidity, and chemical constituents, can affect particle capture. Certain water characteristics may interact with the filter media or particles, influencing filtration performance. Factors such as temperature, pressure, and hydraulic conditions within the filter system can impact particle capture efficiency. Understanding and optimizing these factors are essential for designing effective filtration systems in water treatment processes.

Hence, the mechanism of particle capture in a filter filled with peat is unique and may not be exactly like other media. Therefore, modeling particle capture is essential to establish design criteria for peat as a filtration medium. The aim of the present study was to investigate the applicability of peat as a filter medium in water filters for treating river water. The objectives were to determine the removal efficiencies and to develop a mathematical model to predict the transport of suspended solids, which will aid in designing and operating the filter.

2. Material and Methods

2.1 Material Collection and Preparation

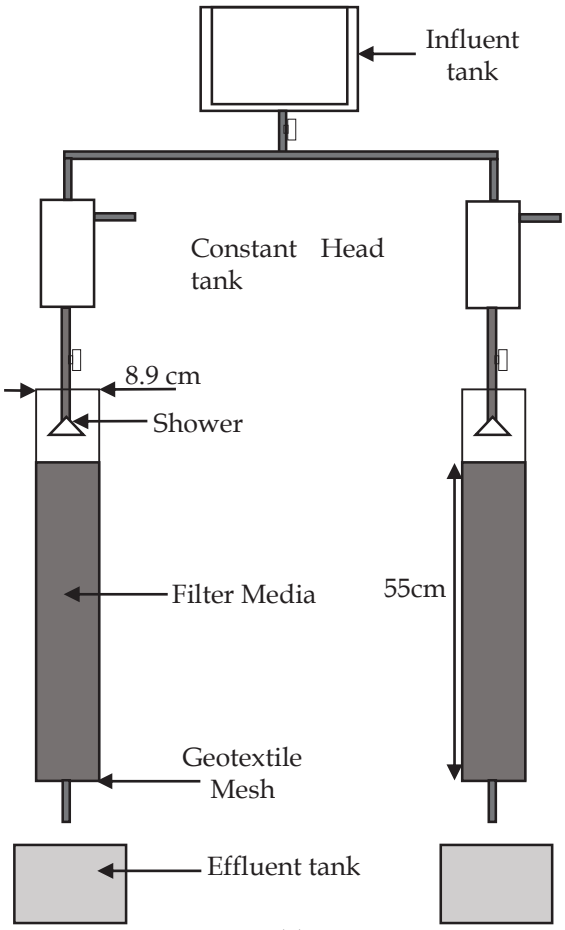
Peat was collected from a residential area. The collected peat displayed a visually dark brown hue and was found to be moist. Impurities such as cloth pieces and glass fragments were manually removed. The entire soil sample was thoroughly washed and then dried in an oven for 24 hours. Then the specific gravity (2.45) of the selected sample was measured. The organic content was measured to be 11.7%. According to the measurements conducted by Chenthan [12] the specific gravity and organic content of different types of Sri Lankan peat varied from 1.73 to 2.59, and 4.3% to 32.9%, respectively. Based on the literature on peat soils, the specific gravity varies from 0.95 to 2.66, and the organic content varies from 0% to 100% [12]. Furthermore, the organic content in sand is less than 1%[13]. Hence, it can be considered that the index property values of peat obtained through the measurements are consistent with those in the literature.

Sieve analysis was conducted, and a sample with an effective size and uniformity coefficient falling within the relevant typical ranges for mono-medium sand bed filters was selected. Typically, for mono-medium sand bed filters, the effective size falls within the range of 0.4 to 0.8 mm and the uniformity coefficient within the range of 1.2 to 1.6 [14].

2.2 Experimental Set-Up

The setup consisted of two filter columns for calibration and verification, as shown in Figure 1. These filter columns were constructed using two PVC pipes. The internal diameter was 8.5 cm and the filter bed height was 55 cm. A mesh was positioned at the base of each filter bed before packing the filter medium. The setup included an overhead influent storage tank and two constant head tanks, ensuring a consistent flow rate to both the columns. Additionally, containers were provided to receive effluent.

The columns were maintained under aerobic conditions.



(a)

(b)

Figure 1 – Experimental Set-Up (a) Schematic Diagram (b) An Image

2.3 Loading of the Columns

Before filling in the columns, the bulk density and moisture content of the peat were measured. The porosity range for sand in filters is 0.4 to 0.47[15]. Therefore, 0.45 was chosen as the porosity to exist within the medium of these two columns after being packed with peat. Subsequently, the required packing density was calculated using the measured specific gravity, bulk density, moisture content, and selected porosity. The calculated packing density was 1747.18 kg/m^3. Both the columns had a height of 75 cm, with a selected medium bed height of 55 cm. To ensure proper compaction and optimal performance, a layer-by-layer filling approach was adopted, with each layer having a thickness of 5 cm. For each layer, 125 ml of water was added. After loading, the porosity was again calculated. This porosity was considered as the initial porosity (0.45).

2.4 Experimental Run

Both the columns underwent a continuous leaching process using tap water to flush out readily soluble impurities attached to the peat. The calibration column was leached for 42 days, while the verification column underwent leaching for 49 days, until the turbidity reached negligible levels.

Once the loading of the two filter columns and the leaching process were completed, several key parameters were calculated. These parameters included the average flow rate, Hydraulic Retention Time (HRT), and the Hydraulic Loading Rate (HLR).

The influent was collected from Gin river (Wackwella, Galle, Sri Lanka).Initial measurements of Total Suspended Solids (TSS), Turbidity, pH, and Conductivity were taken in the influent. The columns were continuously applied with this influent until the effluent TSS concentration almost matched the influent concentration, indicating that the filter bed was fully clogged and the filtration process had reached the breakthrough point. It took 45 hours of operation before the effluent TSS reached a level close to that of the influent. Throughout the experimental run, effluent samples were collected from the bottom of both the columns at 2-hour intervals. Darcy's Law was used to calculate the filtration velocity. After the experimental run, the bulk density and the moisture content were measured in order to calculate the final porosity.

2.5 Particle Capture Model Development

2.5.1 Derivation of the Governing Equation

The governing equation for the transport of the suspended solids was derived by applying the materials balance equation [16].

Eq.1 and Eq.2 give the materials balance equation.

Accumulation = inflow-outflow …(1)

$\frac{\partial q}{\partial t} + \alpha(t)\frac{\partial C}{\partial t})\Delta V = QC - Q(C + \frac{\Delta C}{\Delta z}\Delta z)$ …(2)

Where,

$\frac{\partial q}{\partial t}$ = Change in the quantity of solids deposited within the filter time {g/(m^3.min)}

$\alpha(t)$ = Average porosity as a function of time

$\frac{\partial C}{\partial t}$ = Change in the average concentration of solids in pore space with time {g/(m^3.min)}

ΔV = Differential volume

Q =Volumetric flow rate (L/min)

C = Concentration of TSS (g/m^3)

$\frac{\Delta C}{\Delta z}$ = Change in the concentration of suspended solids in the fluid stream with the distance {g/(m^3.m)}

v= Filtration velocity(cm/s)

2.5.2 Solutions for the Governing Equation

As the quantity of fluid contained within the bed is usually small compared with the volume of liquid passing through the bed, the term $\alpha(t)\frac{\partial C}{\partial t}$ in the Eq. (2) was neglected. Then the equation can be written,

$$-v\frac{\partial C}{\partial z} = \frac{\partial q}{\partial t} \quad \dots (3)$$

where,

q = Specific deposit

Two equations for volume of particle retained and the volume of particle in motion entrained by liquid can be written as follows [17].

AqΔL = Volume of particles retained … (4)

AαΔL = Volume of particles in motion entrained by liquid … (5)

where,

A = cross sectional area

ΔL = filter depth

C = concentration of particulate matter at a given time and depth

If the influent concentration of suspended solids = C_0, by considering Eq. 5, the volume of particle retained in the filter column can be rewritten as,

$A\alpha(C_0 - C)\Delta L$ …(6)

By using Eq.4 and Eq.6, a general equation for 'q' can be written as follows.

$q = a\ (C_0 - C)$ …(7)

By substituting Eq. 7 to Eq. 3, Eq. 8 can be written.By simplifying the Eq. 8, Eq. 9 can be written.

$$-v\frac{\partial C}{\partial z} = \frac{\partial[\alpha(C_0 - C)]}{\partial t} \quad \dots (8)$$

$$-v\frac{\partial C}{\partial z} = \frac{\alpha\partial C_0}{\partial t} - \alpha\frac{\partial C}{\partial t} \quad \dots (9)$$

C_0 = Initial TSS concentration is a constant.

Therefore, it can be solved as below.

$$\frac{\partial C}{\partial z} - \frac{\alpha}{v}\frac{\partial C}{\partial t} = 0 \quad \dots (10)$$

The following boundary conditions were considered.

$C_i = C_0$	z=0	0<t<T
$C_i = 0$	z≥0	t=0
$C_i = C_0$	z=0	t>T
$C_i = 0$	z→∞	t>0

t>0 was considered,

Taking the Laplace transform,

$$L\left\{\frac{\partial C}{\partial V}\right\} - \frac{\alpha}{v}L\left\{\frac{\partial C}{\partial t}\right\} = L\{0\} \quad \dots (11)$$

Laplace transform of C_i(x,t) is equal to $\bar{C}i\ (x,s)$

$$\frac{\partial \bar{C}}{\partial z} - \frac{\alpha}{v}\{s\bar{C}(z,s) - C_i(x,0)\} = 0$$

After applying the boundary conditions,

C_i(x,0) =0

This is a first order, linear ordinary differential equation. Therefore,

$$\bar{C}(z,s) = A(s)e^{\int\frac{\alpha S}{v}dz}$$

$$\bar{C}(z,s) = A(s)e^{\frac{\alpha Sz}{v}} \quad \dots (12)$$

Eq. 12 is the general equation.

A(s) is a function of 's'; as the $\bar{C_i}$ is a function of two variables.

Obtaining A(s) via;

$$\bar{C}(0,s) = L\{C(0,t)\} = L\{C_0\} = \frac{C_0}{s} \quad \dots (13)$$

Hence,

$$\frac{C_0}{s} = A(s)e^{\frac{\alpha}{v}s\times 0} \quad \dots (14)$$

$$A(s) = \frac{C_0}{s}$$

Thus, $\bar{C}(z,s) = \frac{C_0}{s}e^{\frac{\alpha Sz}{v}}$ …(15)

Taking the inverse transform and applying the second shifting theorem, a unit step function (Eq. 15) [18] was obtained as the solution for the governing equation.

$$C(z,t) = u\left(t + \frac{\alpha}{v}z\right)g(t - \frac{\alpha}{v}z)$$

$$C(z,t) = u(t - \frac{\alpha}{v}z) \quad \dots (16)$$

For a smooth approximation to a unit step function h(x), the logistic function could be used as Eq. 17[19].

$$H(x) \approx \frac{1}{2} + \frac{1}{2}\tanh kx = \frac{1}{1+e^{-2kx}} \quad \dots (17)$$

Therefore, by giving the analytical approximation to Eq. 16, Eq. 18 can be represented as the solution for the governing equation Eq. 2 considering the format of Eq. 17.

$$\left(\mathrm{t}+\frac{\alpha}{V}z\right) \approx \frac{1}{2}+\frac{1}{2}\tanh k\left(\mathrm{t}-\frac{\alpha}{v}z\right) = \frac{1}{1+e^{-2k\left(\mathrm{t}-\frac{\alpha}{v}z\right)}}$$

$$C(z,t)=\frac{C_0}{1+e^{-2k\left(\mathrm{t}-\frac{\alpha}{v}z\right)}} \quad ...(18)$$

where 'k' is a constant that depends on the filter medium characteristics.

A computer program was developed using MATLAB to execute Eq. 18. The 'k' value, which was the only unknown in the modelled equation, was varied within a range (0 – 0.0001) using the influent/effluent data obtained for the column intended for calibration. The respective 'k' value that yielded the highest determination coefficient (R^2) and the lowest sum of squares of error was taken as the optimum 'k' value.

2.5.3 Input Parameters of the Model

The input parameters of the model were C_0, filtration velocity, the depth of the filter bed and the porosity. The porosity and the filtration velocity were the average of the respective initial and final values.

2.5.4 Sensitivity Analysis

A sensitivity analysis was carried out in order to investigate the degree of contribution of each parameter in the model. The analysis was carried out for the parameters k, porosity (α), velocity (v) and initial concentration (C_0). The range for each parameter was varied, considering not to have indefinite answers. The other parameters were kept constant while the parameter which was concerned for the sensitivity analysis was varying.

2.6 Estimation of the Correlation Between the Volume of Water Treated and the Filter Bed Depth

Eq. 16 could be used to obtain an expression (Eq. 20) for the volume of water that can be treated as a function of the influent flow rate, the desired effluent TSS concentration, the porosity, the filtration velocity, the 'k' value, and the depth of the filter bed, as follows:

$$\ln e\left[^{-2k\left(\mathrm{t}-\frac{\alpha}{v}z\right)}\right]=\ln\frac{C_0}{C(z,t)}-1 \quad ... (19)$$

$$-2k\left(\mathrm{t}-\frac{\alpha}{v}z\right)=\ln\frac{C_0}{C(z,t)}-1 \quad ... (20)$$

$$t=\frac{\alpha}{v}z-\frac{1}{2k}\times\ln\frac{C_0}{C(z,t)}-1 \quad ... (21)$$

If the flow rate is assumed as 'q' m^3/s, the amount of water that can be treated (V) will be 'qt' m^3

$$\frac{V}{q}=\frac{\alpha}{v}z-\frac{1}{2k}\times\ln\frac{C_0}{C(z,t)}-1 \quad ... (22)$$

Then,

$$V=\left(\frac{\alpha}{v}z-\frac{1}{2k}\times\ln\frac{C_0}{C(z,t)}-1\right)\times q \quad ... (23)$$

3. Results and Discussion

3.1 Variation of the Filter Bed Characteristics

Table 1 depicts the filter bed characteristics of each column before and after the experimental run. Both calibration and verification columns showed approximately the same changes in the physical and hydraulic properties of the media. The specific gravity decreased, indicating a reduction in the density of the solid particles in the peat. This could be due to the adsorption of contaminants or changes in the mineral composition of the peat [20]. The porosity decreased, suggesting that some of the pore spaces in the peat have been filled with particulates or biofilm from the river water, reducing the void spaces. The bulk density slightly decreased, aligning with the decrease in specific gravity and porosity, indicating slight compaction of the peat structure. The hydraulic retention time (HRT) increased significantly, meaning that the water took longer to pass through the filter. This can be due to clogging or decreased permeability of the peat medium. The hydraulic loading rate (HLR) decreased substantially, indicating that the filter was processing water at a much slower rate, likely due to reduced permeability or clogging of the filter medium. The filtration velocity decreased significantly, reinforcing the observation that the flow of water through the peat filter had been greatly reduced. The filtration process using peat as the filter medium shows that the peat's ability to filter water diminished over time, evidenced by decreased specific gravity, porosity, and bulk density, alongside significantly increased hydraulic retention time and decreased hydraulic loading rate and filtration velocity. Based on the findings of Rehman et al. [21], an increase in HRT from 24 h to 72 h resulted in improved reduction of Total Dissolved Solids (TDS) and Chemical Oxygen Demand (COD). Additionally, research conducted by Wilson et al. [22] indicated that variations in hydraulic loading rates had minimal impact on the treatment of TSS across different filter types.

3.2 Variation of the Effluent Characteristics

Figure 2 depicts the variation of the TSS in the effluent during the experimental run for both the columns. Figure 3 indicates the respective removal efficiencies. Figure 4 shows the turbidity variation in the effluent for both the columns. The turbidity variation graphs align well with those of TSS, as turbidity is caused by suspended solids. An entire filtration run is usually divided into three stages: ripening, working, and breakthrough. Breakthrough refers to the point at which the filter medium can no longer effectively capture suspended solids, leading to an increase in TSS in the effluent. At the start of the filtration run, the improvement in particle removal efficiency is known as ripening. The characteristics of bed ripening are a major concern in the design and operation of rapid gravity filters [9]. The effluent TSS data do not provide evidence of a ripening stage because the removal efficiency commenced at 100%. This could be because the operation started after flushing the readily flushable contaminants and a new filter bed was used. Hence, the experimental run only includes the working and breakthrough stages.

Table 1 – Characteristics of the Filter Bed

Parameter	Calibration column		Verification column	
	Initial	Final	Initial	Final
Specific gravity	2.45	2.12	2.45	2.08
Bulk density (kg/m^3)	1747.2	1734.7	1747.2	1749.1
Moisture content	29.86	29.71	29.86	29.64
Porosity	0.45	0.37	0.45	0.35
HRT(hr)	1.02	3.27	1.39	4.5
HLR(m^3/m^2. d)	0.24	0.06	0.17	0.04
Filtration velocity x 10^{-4} (m/s)	5.4	3.77	5.4	3.26

The breakthrough of both columns commenced at about 16 hours, implying that backwashing should be done after 16 h of operation under these conditions. Based on the findings of Kone et al. [23], it was observed that the breakthrough time decreases during the rainy season and increases with the height of the filter media. During the rainy season, TSS concentration in river water is high. River water samples for this study was collected during the rainy season. Hence, the TSS concentration of the river water used for this study could be a higher value. Thus the peat filter medium would give longer breakthrough time if the river water was collected during the drought. Rapid sand filters typically experience breakthrough after 24–72 h of operation, depending on the influent water quality and filtration rate [24]. Cleasby and Logsdon[25] mentioned the need to backwash rapid sand filters within a range of 8 to 48 h in most municipal water treatment applications. This frequency is influenced by turbidity and organic matter content in the influent, as these factors contribute to particle load, causing filters to clog and reduce efficiency.

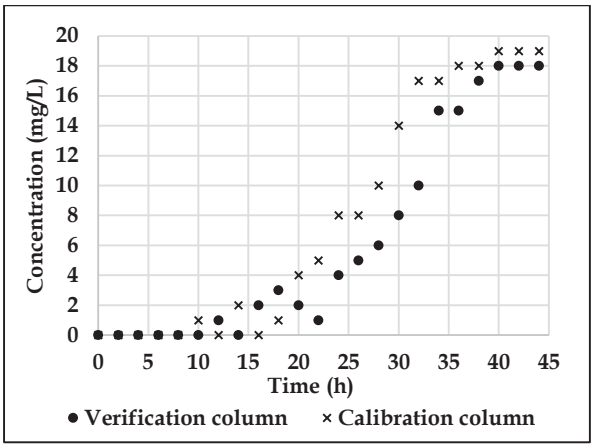


Figure 2 – Variation of TSS in the Calibration and Verification Columns

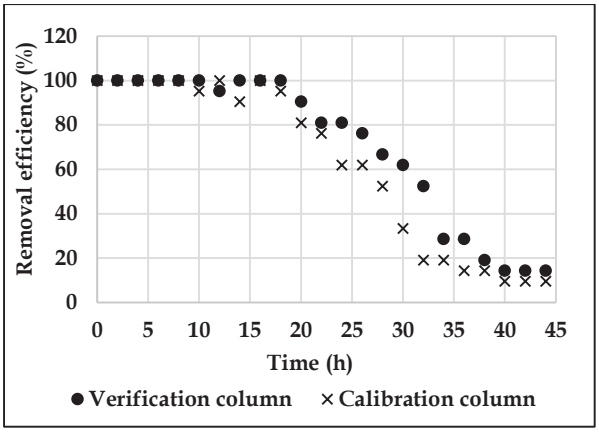


Figure 3 – Removal Efficiency of TSS in the Calibration and Verification Columns

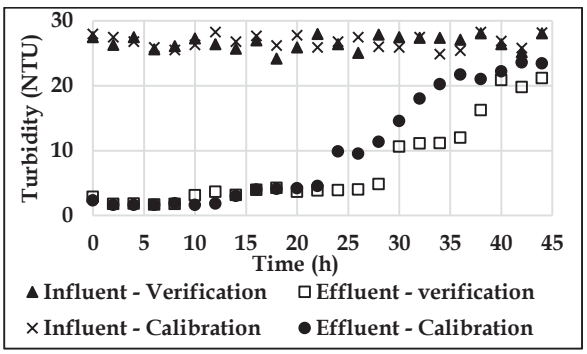


Figure 4 – Turbidity Variation in the Effluent of the Calibration and Verification Columns

Further research is needed to optimize the affecting parameters to increase the breakthrough time. The variation of the TSS concentration, its removal efficiencies, and turbidity in both the columns were approximately aligned with each other until breakthrough. Afterward, the calibration column showed a rapid deterioration in the treatment ability of the filter medium. The verification column maintained more than 50% removal efficiency for about 32 hours, while the calibration column maintained more than 50% removal efficiency for only the first 22 hours. Hence, it is to be noted that the removal efficiencies of TSS was slightly better in the verification column than that of the calibration column. Table 1 indicates that the HRT of the verification column was somewhat higher than that of the calibration column. This can explain the observed differences.

The observations from the particle capture investigation in peat soil columns can be discussed considering several factors that influence the performance of such systems in removing TSS from river water. These factors include the characteristics of the peat soil, the dynamics of suspended solids [26], and the operational conditions of the columns. The performance of filtration columns is largely affected by operational conditions such as flow rate, hydraulic loading, and maintenance practices [27]. At the beginning of the experiment, the peat soil likely exhibited high removal efficiency due to its high porosity, adsorptive capacity, and fresh medium. Peat soils are known for their high porosity and organic content [28], which provide ample surface area for particle adsorption and physical straining of suspended solids. Initially, the medium was not clogged or coated with particles, allowing optimal performance. The drop in removal efficiency after 16 hours can be attributed to several key mechanisms: clogging and saturation, biofilm formation, and breakthrough of smaller particles. Over time, the pores of the peat soil can become clogged with captured particles, reducing the effective porosity and permeability of the soil, and hindering further particle capture. Microbial activity can lead to the formation of biofilms on the peat surfaces, which can alter the physical and chemical properties of the soil matrix, sometimes reducing its capacity to capture additional particles. As the larger pores become clogged, only smaller particles can pass through, leading to a shift in the size distribution of particles being captured. Eventually, the soil matrix may not be able to retain the finer particles as efficiently. By the end of 45 hours, several compounded factors likely led to the observed low efficiency: exhaustion of adsorptive sites, reduction of hydraulic conductivity, and changes in water chemistry. The active sites on peat particles for adsorbing suspended solids may become saturated, leaving fewer sites available for new particles. The continuous deposition of particles within the peat matrix can significantly reduce its hydraulic conductivity, leading to preferential flow paths or channelling where water bypasses the soil matrix, reducing contact time and filtration efficiency. The prolonged interaction of river water with peat soil might alter the water chemistry (e.g., pH, ionic strength) [29], affecting the charge and stability of suspended particles and their interactions with the peat matrix.

Figures 5 and 6 show the variation of pH and conductivity in the calibration and verification columns, respectively. In both the columns, the pH ranged between 7 and 7.5 in the influent, while that of the effluent was 6.5 and 7. Hence, there is an overall reduction in pH. This reduction is relatively minor. If the effluent is intended for specific uses, such as supporting aquatic life where pH stability is crucial, pH adjustment might be required as part of the treatment. pH adjustment may also be needed if the treatment mechanism of the target parameter depends on the pH value. The conductivity decreased in a similar pattern in both the columns. Though the breakthrough occurred after 16 hours, the reduction of conductivity in the effluent did not decrease accordingly thereafter. This implies that the medium continued treating dissolved solids even though the breakthrough for TSS had occurred. TDS measurements could confirm this observation. Peat is naturally acidic, with pH values typically ranging from 3.5 to 4.5. When river water passes through the peat filter, organic acids present in the peat, such as humic and fulvic acids, can leach into the water, lowering the pH of the effluent [30], [31]. Peat has ion exchange capacities due to the presence of functional groups like carboxyl and phenolic groups. These can exchange H+ ions with other cations in the water, contributing to the decrease in pH [5] [8]. Peat is known for its high adsorption capacity due to its porous structure and large surface area. It can adsorb various ions and molecules from the water, reducing the overall ionic concentration and thereby decreasing conductivity [6]. The acidic nature and high organic content of peat allow it to bind

heavy metals and other ions effectively. This binding reduces the concentration of these ions in the effluent, leading to lower conductivity [7]. This process continues beyond the physical saturation of the filter medium. Even after TSS breakthrough, the peat can continue to remove ions from the water, hence the continued reduction in conductivity. The ion-exchange and adsorption processes are different from the physical filtration of suspended solids and can continue effectively until the ion-exchange capacity of the peat is exhausted.

However, the operability of the filter depends on the head loss development, based on which the TSS breakthrough occurs. Therefore, optimizing criteria for particle capture would enhance the overall performance of a peat-filled water filter irrespective of the target parameter, i.e., either TSS or TDS.

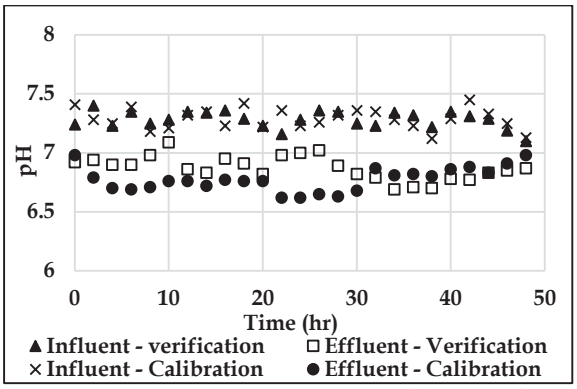


Figure 5 – pH Variation in the Effluent of the Calibration and Verification Columns

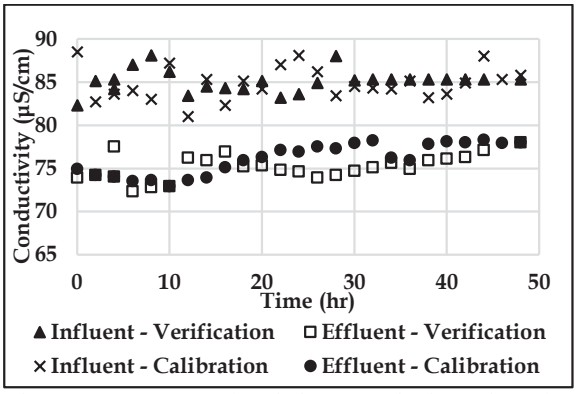


Figure 6 – Conductivity Variation in the Effluent of the Calibration and Verification Columns

3.3 Particle Capture Model

3.3.1 Evaluation of the Model

Figure 7 depicts the modeled and measured TSS variations. The 'k' value, dependent on the filter medium, was determined to be 1.3703×10^{-5}. The determination coefficients (R^2) between the modeled and measured data were 0.88 and 0.82, respectively. Initially, the model significantly overestimated the measured values for the first 30 hours. Subsequently, it closely aligned with the measured values.

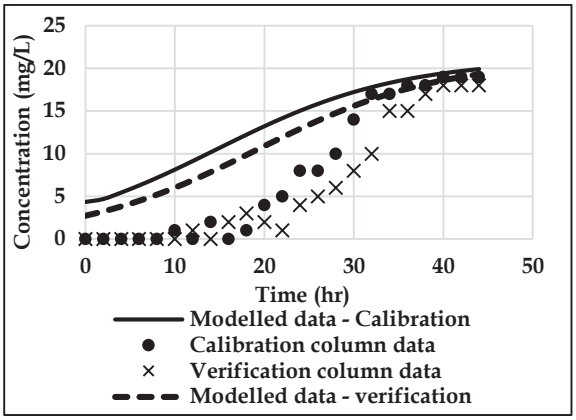


Figure 7 - Modelled and Measured Values of TSS for the Calibration and Verification Columns

The discrepancy observed between the modelled and measured data, where the model initially overestimates the measured data up to approximately 30 h before aligning with it, can be attributed to several factors related to particle capture dynamics in porous media. These factors include filter clogging, particle size distribution, and changes in flow patterns over time. The initial overestimation by the model can be attributed to simplifications or assumptions made during its development. Early stages of filtration involve dynamic processes such as particle rearrangement and the formation of a filter cake [32], phenomena that simple model equations may not fully capture. Initially, the peat medium exhibits higher porosity and permeability, resulting in a higher initial capture efficiency than predicted by the model. However, real-world conditions can vary due to media heterogeneities and fluctuations in the river water particle load. As filtration progresses, particles accumulate on the filter medium, forming a filter cake that enhances filtration efficiency by increasing surface area and acting as a physical barrier for particle removal [33]. This accumulation can lead to deviations between modelled and actual data, as the model may not fully account for changes in the filter's characteristics over time, such as compaction and consolidation of the peat medium. The compliance of the verification column's measured data with the modeled data was better than that of the calibration column, indicating that the filtration rate can significantly impact the model. This is because the filtration rate of the verification column was lower than that of the calibration column.

After approximately 30 hours, the system typically reaches a quasi-steady-state condition where the rate of particle deposition and filter media resistance reach equilibrium [32]. At this stage, the model predictions align more closely with measured data as the system stabilizes.

3.4 Sensitivity Analysis

Figure 8 to Figure 11 depict the results of the sensitivity analyses. The least sensitive parameter is porosity (α). The value of 'α' for a mono medium sand filter typically ranges from 0.4 to 0.47, and this range was selected for the sensitivity analysis of 'α'. The parameter 'k' was varied from 0.00001 to 0.00002, revealing that its effect is not significant within this range. Velocity was varied from 0.04 cm/s to 0.0001 cm/s. The most sensitive parameters were velocity and C_0.

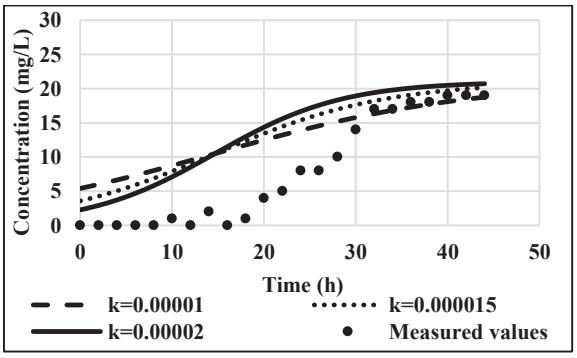


Figure 8 - Sensitivity 'k' on the Model Output

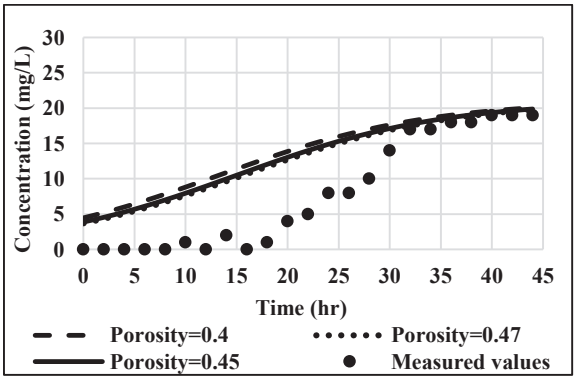


Figure 9 - Sensitivity of Porosity on the Model Output

3.5 Estimated Correlation Between the Volume of Water Treated and the Filter Bed Depth

Using the derived Eq. 23, a correlation graph between the volume of water treated and the filter bed depth can be created by substituting the desired flow rate and effluent TSS concentrations. The graph will be a straight line, indicating that the filter bed depth is proportional to the amount of water that can be treated before clogging. This graph can also be used to determine the volume of water that can be treated for a given filter bed depth, flow rate, and desired effluent TSS concentration.

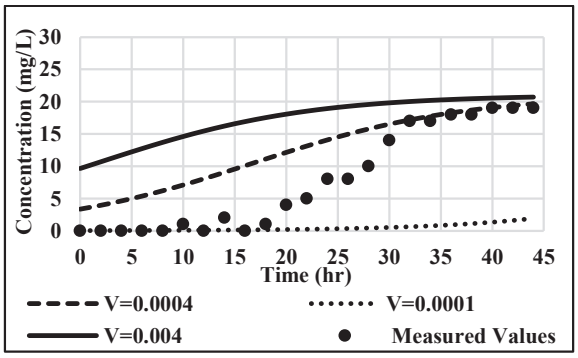


Figure 10 - Sensitivity 'v' on the Model Output

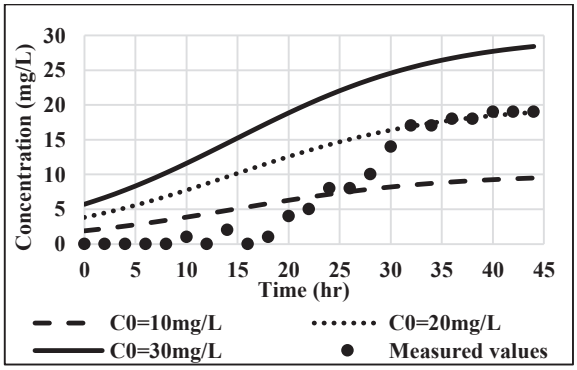


Figure 11 - Sensitivity of 'C_0' on the Model Output

4. Conclusions

The study aimed to investigate the applicability of peat as a filter medium in water filters to treat river water by determining removal efficiencies and developing a particle capture model to aid in designing and operating such water filters. The experimental phase involved using water from a river and employed two columns to generate calibration and verification data for the development of an analytical model. Two filter columns filled with peat as the filter medium were run for 45 hours by continuously applying river water. After about 16 hours, the breakthrough of total suspended solids occurred. The suspended solids removal efficiency until 16 hours was 100%. The variation patterns of pH and conductivity remained the same until the end of the run, without being interrupted by the breakthrough of suspended solids.

The reduction in pH and conductivity in the effluent can be attributed to the inherent properties of peat, including its acidity, ion exchange capacity, and high adsorption potential. The release of organic acids from peat lowers the pH, while the adsorption and binding of ions reduce the conductivity of the treated

water. These mechanisms continued even after the breakthrough of the suspended solids.

In a conventional granular sand filter, the primary treatment goal is the removal of total suspended solids. A peat medium inside a filter, possessing different physical, hydraulic, and mechanical properties, could exhibit treatment potential for other contaminants as well. However, the filter operation is governed by the particle capture mechanisms of the filter medium. Even if the filter medium has the capacity to target other contaminants through different treatment mechanisms, its operation would cease once the particle capture ability of the medium reaches its breakthrough point. At this point, the head loss would also have reached alarming levels, causing a considerable reduction in porosity and hydraulic conductivity.

The developed particle capture model overestimated the effluent total suspended solids concentration until about 30 hours into the run, after which it coincided with the measured effluent suspended solids concentrations until the end. The disagreement of the model during the initial phase could be due to several factors related to the dynamics of particle capture in peat medium, such as filter clogging, particle size distribution, and changes in flow patterns over time. The governing equation on which the model was developed is usually applied to sand as the filter medium. Since the developed model does not closely match the predictions of the previous model, further refinement may be necessary. This refinement should focus on the peat medium in relation to the traditional governing equation for particle capture inside a porous medium, primarily sand.

The present study has several limitations: a limited experimental duration, a focus mainly on total suspended solids (TSS), the absence of regeneration capability in the filter medium, the lack of replicate column experiments under varied test conditions (e.g., different flow rates and pollutant concentrations), and variations in peat properties across different sites, etc. Therefore, further investigation of these points is recommended.

To improve the long-term efficiency of peat soil columns in removing suspended solids, some strategies could be considered. Allowing periods of no flow can help in redistributing the captured particles and restoring the porosity. Implementing backwashing techniques can help in removing clogged particles from the soil matrix and restore its filtration capacity. Using a pretreatment step to remove larger particles before the water enters the peat soil columns can help in reducing the load and extending the operational life of the peat filter.

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