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Deep Bed Column Design Using South Sabrattah Sand and Granular Carbon in Urban Stormwater Filtration

Riyad Mahfud*, Salem Sakal
Zawia University, Department of Chemical Engineering, Sabaratta, Libya
*Corresponding Author: ram190@case.edu

Abstract

The study utilize south Sabrattahs' sand and granular carbon (GC) as filter media in a deep bed column design for storm water filtration. Combination design of Sabrattaha Sand (SS) and granular carbon (GC) were tested to obtain the removal of total suspended solid and turbidity, focusing at 1290 mg/L of total suspended solid (TSS) which are determined based on sample preparation at unit operation lab to represent storm water. This value is classified as a measure to evaluate the performance and reduce variation of filtration on the laboratory condition. The two groups of both SS and GC filter media at range of 2 mm- 1 mm and fine 0.5 mm- 0.75 mm filter media were explored to find the efficiency based on the TSS removal percent. The deep bed column with finer filter media with combination media design has shown to have good result in removal of suspended solids. The filtration results indicate that the 96% TSS removal occur of SS and GC deep filter column design.

Keywords: Deep bed column, stormwater filtration, Sabratta sand, granular carbon, total suspended solids.

1. Introduction

Rapid granular filtration is one of the widely implemented treatment methods for relatively dilute aqueous suspensions. In this method, the grains of a porous medium, like sand, anthracite, tuff, etc., adsorb up to 85% by mass of suspended particles [1], transported by water inside the filter bed. To ensure a high quality of the tap water, it is essential to understand filtration kinetics and to predict filter performance through physically sound modeling. Deep bed filter is equipment with particulate media beds to remove dirt and other solid contaminant from water. The beginning of deep-bed filtration theory dates back to more than a half-century ago and is associated with the works of Iwasaki [2] and Minz [3]. Deep bed filtration is an effective process in removing particles from range 0.01 (μ m) to 100 (μ m) in size [4] Removal of these particles by deep bed filtration involves complex mechanisms. First; particles in suspension are transported near filter grains by mechanisms such as sedimentation, interception, diffusion, inertia and hydrodynamic effect. The effective removal of these particles depends on the attachment mechanism, which depends on the surface forces acting between particles and filter grains. The factors, which affect these forces eventually, it will effect of the performance of deep bed filtration. In deep bed filtration, particles are removed when passed through beds of granular or fibrous filter material. Deep bed filtration differs from other kinds of filtration in that the solid particles suspended in the fluid are generally smaller than the pores of the filter medium, as shown in Figure 1.1. As the suspension travels through the filter, the particles deposit at differing depths on the filter grains, which constitute the bed. In engineering practice, deep bed filtration usually is used to treat raw water after the processes of coagulation, flocculation and sedimentation.

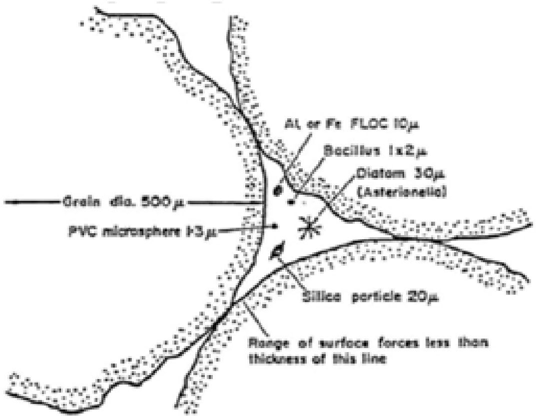

Figure 1.1: Typical dimensions of particles and filter grains in aqueous deep-bed filtration

In Libya, Storm water can be an excellent harvested surface water resource, especially due to the high rainfall intensity. Furthermore, the impervious surfaces in urban areas usually produce high storm water, which may comprise of runoff from ground level run-off. Hence this study proposes a modified deep bed filter utilizing dual media such as; fine sand and granular carbon particles as media bed as a basic treatment of storm water to be safely used for non-drinking purpose. In this research, utilizing laboratory scale of deep bed column, sand media brought from south Sabrattaha and granular activated carbon were used as filter medias to explore and investigate the removal of total suspended solid (TSS) and turbidity efficiency based on the fineness of the filter media. The filtrating media were used after the clarifiers, to remove carried-over suspended solids and thus improve water quality. This work focuses on the filtrate water quality, filter media properties and its effective size, and the mix ratio of design filter column. The packing of the media in the columns is in accordance with size - the largest on top andthe smallest at the base. This ensures the removal of the largest particles by the top layer. Themedia is further differentiated by particle densities to assist in the settling of the media afterregeneration - the lightest on top and the heaviest at the base, this research does not focus on the regeneration study of the filtrating media. A laboratory investigation wasundertaken to determine the potential for the use of the south Sabrattaha sand and the granular activated carbon.

2. Depth Filtration Mechanism

The small fine particles are too small to settle efficiently by sedimentation. One strategy that used to remove these solids is gravity filtration. In this process, water containing solid impurities (e.g., precipitates from water softening) is passed through a porous medium, typically layers of sand and gravel. The force of gravity is used to push the water through the medium. The small water molecules pass through the holes between sand and gravel pieces. However, the solids get stuck in the holes, and retained in the porous medium. The water that passes through the bottom of the filter no longer contains those solid impurities. Depending on the particle size, the prevailing effects of retention are summarized in Figure 2.1, [3].

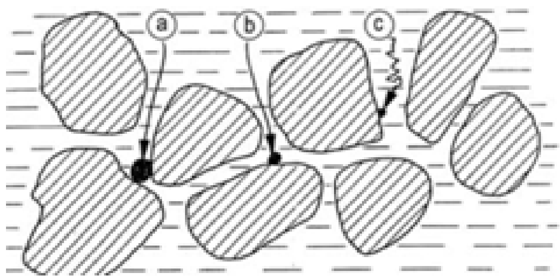

Figure 2.1: Retention mechanisms in a deep bed filter

1. Particles > 10 μm are retained by mechanical interception;
2. Particles of ca. 1 μm size are subject to inertial impact and adhesion;
3. Particles <1 μm follow mainly Brownian diffusion and adhesion.

Thus the transport of particles to the solid surface is rather well explained and can be described mathematically. The clarification effect summarized in an empirical filter coefficient λ describes the local decrease in concentration of the suspension flowing through the bed.

$$-\frac{\partial c}{\partial L} = \lambda . c \tag{2.1}$$

Where c is the concentration of the suspension and L is the distance from the inlet face of the filter. For uniform conditions, this differential equation can be integrated:

$$c = c_o.exp\,(\lambda_o.L) \qquad (2.2)$$

Here λo is the initial filter coefficient of a clean filter medium. As soon as the medium is loaded with solids, its efficiency will change and that is why the solution of the differential equation becomes rather difficult. Different models exist to describe the process, but they are rarely used for practical purposes. To find a suitable filter medium in a depth filter, which shows good retention efficiency over a long cycle time, laboratory tests over a realistic cycle time have to be carried out with filter layers of realistic depth.

3. Materials and Methods

Figure 3.1 shows the layers of the deep bed filtration (DBF) column and the storm water tanks. The plant rig consist layers arranged as follows; starting from the bottom: 6 cm rock, 11 cm grain I, 10 cm sand, 13 cm carbon I, 10 cm sand, 9 cm grain II, 6 cm grain I, 11 cm carbon II, 12 cm rock. However, the filtration media characteristics are given in Table 3.1, with a column total height of 88 cm.

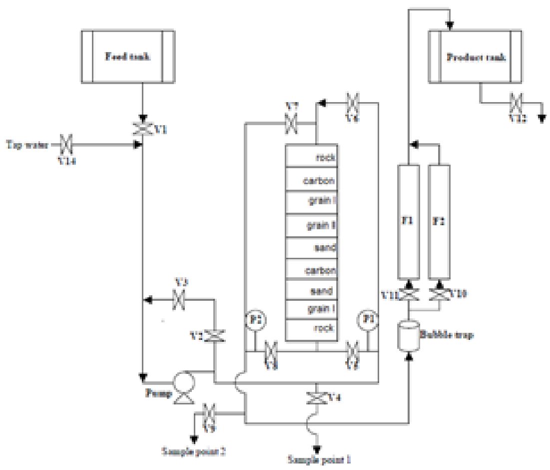

Figure 3.1: Schematic diagram of the DBF pilot plant

3.1. TheFilter Media Preparation

The filter media prepared via different methods, the sand was collected from south Sabrattah and the garanular carbon prepared using olive oil woods. However, figure 3.2 shows the samples that used as a filter media.

Table 3.1: The filtration media characteristics

Material	Height (cm)	Size
Rock	6	2 - 3.5 cm
Carbon I	13	1- 2 mm
Carbon II	11	500 - 750 µm
Sand	10	355 - 500 µm
Grain I	6	1 - 2 mm
Grain II	9	500 - 750 µm

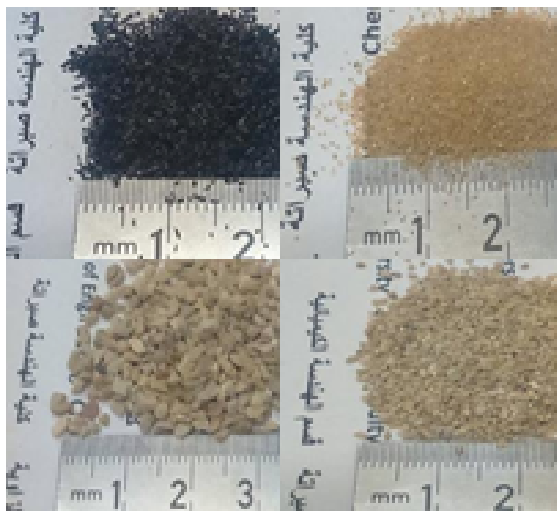

Figure 3.2: Top left (granular carbon), top right (sand), bottom left (grain I), bottom right (grain II)

The storm water samples were prepared in our lab using fine powder as a suspended solid; the size of the powder is less than 60 µm. A specified amount of the powder was added to a known amount of pure water (tab-water). Then, the sample turbidity was measured using JENWAY 6305 UV Spectrophotometer at our Laboratory (Unit operation lab) at room temperature. Furthermore, five more samples with different concentrations were prepared completely and cap tightly. The samples were tested for total suspended solid (TSS) (ASTM D5907) to classify the storm water. The average TSS and turbidity value were taken as the reference for feed tank water properties for deep bed filtration testing. To determine the efficiency of filtration filter bed design, before and after filtration (filtered at effluent tank) was analyzed in terms of suspended solid, and turbidity properties. Filter media prepared for deep bed column prior to filtration as filter bed; both granular car-

bon (G.C) and sand were prepared, collected and sieved to acquire the specific effective size. The type and the size of filter media were shown in Table 3.1 and Figure (4). Both filtration efficiency between the sand layers and the G.C layer were analyzed based on the removal of physical suspended solid and turbidity. The carbon blocks first crashed by using Ball Mill, into different sizes ranged from powder till 5 mm. The G.C and the grain layers (I and II) were sieved and rinsed in deionized water to remove impurities. Then, all the previous layers kept on the oven over night. The sand was brought from south Sabrattah city and the carbon block was bought from Sabrattah. The carbon block was prepared from olive woods via burning in air-free atmosphere for 10 days at about 400°C. The water, oxygen and hydrogen removed from logs due to the excess heat, which lead to create a huge surface area in form of fine pores that help in adsorption process when used as a filter media. The deep bed filter column (Model: armfield) at the laboratory of chemical engineering department has been utilized to study the efficiency of filter media design. The unit consists of a column packed with filter media, a transfer pump, two sump tanks, a flow meter and a bank of manometer tubes and various valves for flow control and samplings, figure 3.1.

4. Results and Discussions

Water containing solid impurities enters the filter through an inlet at the top and is forced by gravity through layers of sand, carbon and gravel. The solids get trapped between the sand, carbon and gravel pieces. The water that emerges into the under drain at the bottom of the filter is cleaned of these solids and exits the filter through an outlet at the bottom.The water quality is primarily dependent on the existing urban storm water characteristic. The storm water like samples were prepared in the unit operation lab of the chemical engineering department, Sabrattah faculty of engineering. To determine the concentration of the unknown samples a calibration curve must be used. Measure the intensity of transmitted light for known samples and plot the line-of-best fit through the experimental points. The Table 4.1 shows the effect of the increment on suspended solids concentration on the light absorbance. Five samples were used, Figure 4.1, the solid concentration values are ranged from 98 mg/L to 1430 mg/L, and the increment of the turbidity is clear by eye vision. The turbidity is determined based on the amount of the total suspended solids (TSS). Figure 4.2 created based on the data obtained from measuring light absorbance of each sample using the spectrophotometer, and the data tabulated in Table 4.1. Further, based on the empirical equation shown in Figure 4.2, an extension of the experimental data was obtained. The sampling of storm water were done by measuring known amount (296.65 gm) of fine sand like a powder with size smaller than 63µm. the particles size were measured using a sieve of Mesh no of 230 and size of 63µm. the measured weight was added to 130 L of tap water from the unit operation lab, to give an inlet TSS concentration of 2276 mg/L. The range of TSS and turbidity of the storm water like samples were quite large and hence this work only focused on the TSS in the influent as a control to measure the performance and reduce the variation of filtration. The result of storm water influent in real nature is probable in similar range to the used concentration.

Table 4.1: The TSS and the Abs

Sample No.	Concentration of TSS (ppm)	Absorbance
1	0	0
2	89.37	0.007
3	178.75	0013
4	357.5	0.026
5	715	0.056
6	1430	0.112

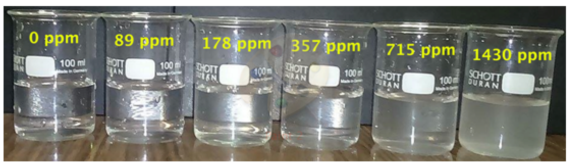

Figure 4.1: Shown the used samples of different TSS concentrations to find the calibration curve of Abs vs. TSS

4.1. Evaluation of The Depth Filtration Length

The depth length of the filtration layer was determined based on the Equation 2.2. The empirical equation suggested herein is based on the following physical picture. An aqueous dilute colloidal

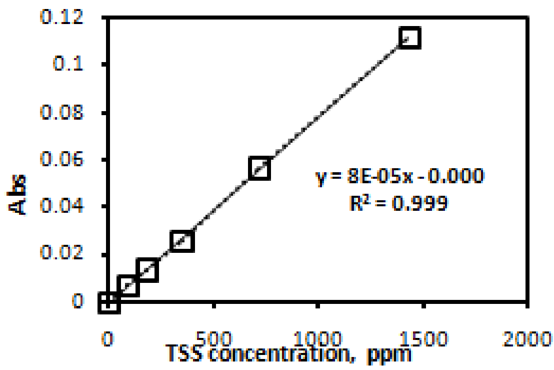

Figure 4.2: The absorbance of the samples of known concentration from TSS and the concentration of the TSS

suspension is fed through, a filter bed which contains deposit. The passing colloids settle as separate particles covering filter grains with a monolayer deposit. The concentration of the TSS in the outlet stream is depended on the length of the filter. However the filtration coefficient of the used filter layers was determined based on Equation 2.2. Several experiments were run to find the relation between the filter media height and the effluent TSS concentration.

4.2. Sand filtration Coefficient

Figure 4.3 shows the experimental data that used to determine the sand filter coefficient. However, The sand filtration coefficient was found 0.823. Therefore based on the Equation 2.2 the maximum efficient sand height is 8 cm.

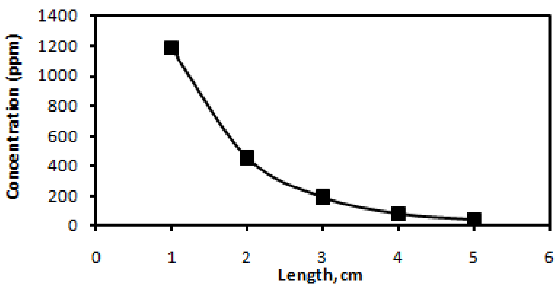

Figure 4.3: The TSS concentration related to the sand layer height

4.3. Carbon Filtration Coefficient

Figure 4.4 shows the experimental data that used to determine the carbon filter coefficient. However, The carbon filtration coefficient is 0.556. Therefore based on the Equation 2.2 the maximum efficient carbon height is 10 cm.

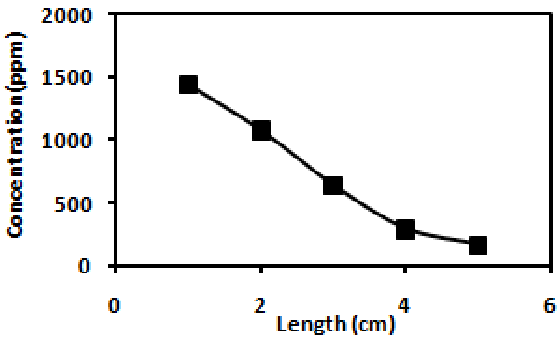

Figure 4.4: The TSS concentration related to the carbon layer height

Figure 4.5 shows the arrangement set of the filter media and the samples collection positions.

Figure 4.5: Arrangement set of filter media in the column filter design

The flow rate was adjusted at 0.5 L/min by using a flow rate control valve. After starting the operation for about 30 minutes, seven samples were collected from the positions shown in figure 4.5.

The % removal of TSS for each layer were determined and compared with the other layers. The amounts of the outlet TSS from each layer were shown in Figure 4.6 and the percent removal of TSS by each layer was shown in figure 4.7. Because of the packing of the media in the column was in accordance with size (the largest on top andthe smallest at the base), the removal of the largest particles by the top layer.

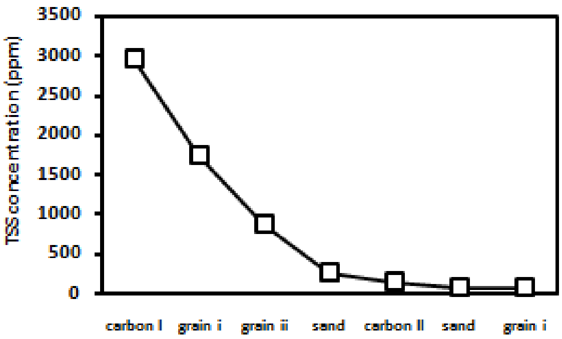

Figure 4.6: The amount of TSS out from each layer

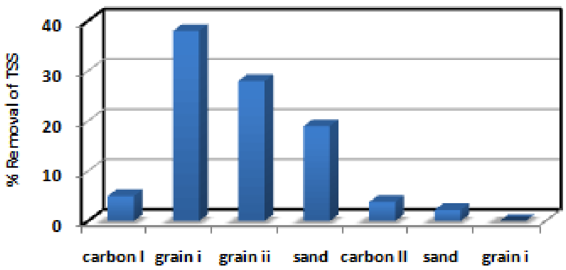

Figure 4.7: The % removal of TSS by each layer

The % removal of TSS of each layer was determined as follows:

(4.1)

$$\begin{aligned} &\textit{The Total} \\ &\textit{removal of TSS} = \sum \% \textit{ removal} \\ &\quad \textit{of each layer} \\ &= 5 + 38 + 28 \\ &\quad + 19 + 3.8 + 2.2 \\ &= 96\% \end{aligned} \quad (4.2)$$

Therefore, only 4% from the overall amount of TSS remained in the effluent stream as a suspension of fine particles. These fine particles create intermolecular forces with the neighboring water molecules that lead to escape the filter medium as an effluent. These fine particles can be treated by adding coagulants that make them unite and finally precipitated. When coagulants such as $Al_2(SO_4)_3$ are added to the water supply, they form solid precipitates. These precipitates catch other impurities in the water, forming a solid mass containing the precipitate formed by coagulation and the trapped impurities. This mass will settle to the bottom by sedimentation.

5. Conclusion

Based on the percentage of removal TSS and turbidity, it is suggested that dual SS/GC with the combination of fine grains and fine rocks as deep bed filter column has provide good filtration efficiency filter media design to produce removal of TSS up to 96% for a storm water stream and applicable to upgrade the storm water to pure water, which suits to recreational use and body contact. The potential for the use of the south Sabrattaha sand and the granular activated carbon in storm water purification was laboratory investigated.

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