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Evaluating Performance of Different Filter Media Stratification for Tertiary Treatment of Wastewater

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Abstract

The use of treated wastewater for agricultural irrigation is one of the methods used to reduce the scarcity of fresh water. In this study, the different filtration media of sand, anthracite, granular activated carbon (GAC) and rice straw with a sub-base of gradual gravel supported each were used. In addition, the filtration efficiency was evaluated according to the treated water quality tests. As such, different filtration rates were parameterized to obtain the best operating conditions after ensuring that treated wastewater meets with the standard specifications for irrigation. The results indicated that the optimal filtration rate is 175 m / day, which achieves the appropriate quality of treated wastewater for the water characteristics examined according to the standard specifications of irrigation water. In addition, rice straw supported by a sand base is considered a practicable filtration media. However, the results of analyses of total solids in water did not match to Egyptian standards when using rice straw with sand as a filtration medium. Therefore, it is recommended to follow the filtration process using rice straw as a filtration medium with another stage of sand filtration to ensure the total solids comply with the standards.

Keywords: Anthracite; filtration; GAC; irrigation; rice straw; tertiary treatment; wastewater treatment.

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1. Introduction

The water shortage has become one of the most important issues facing many countries due to the lack of freshwater resources with its annual population increase. Therefore, solving this problem necessitates the development of new water resources to reduce this gap. Reuse of the tertiary treated wastewater for irrigation is one of the approaches used in this trend. The tertiary treatment of wastewater involves several techniques, for example, chemical precipitation, carbon adsorption, filtration, and ion exchange. Moreover, the filtration system can be applied by such technologies as rapid filtration, membrane filtration, micro-filtration, ultra-filtration, Nano-filtration and reverse osmosis [1-8]. Boehler and his colleagues [9] added different doses of powdered activated carbon (PAC) ranged from 10-20 mg/L as a coagulant with the secondary treated wastewater, which was followed by a pilot textile filter. The treatment results indicated that the optimum PAC dose of 15 mg/L can remove 90% of the total suspended solids (TSS). Moreover, the filtration system can be applied by such technologies as rapid filtration, membrane filtration, micro-filtration, ultra-filtration, nano-filtration and reverse osmosis. Furthermore, Wang and his colleagues [10] established the tertiary treatment of wastewater by the chemical precipitation followed by filtration system using the sand and/or cloth as filter media. The PAC was utilized with different doses for completing the coagulation, flocculation, and sedimentation process. In addition, the investigated wastewater parameters were the chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP). Wang and his colleagues [10] demonstrated that the tertiary treatment system removes 25% of COD, 50% of TSS, and 55% of TP from the secondary treated wastewater as well as, the economic feasibility of the filtration system was evaluated in this study. Hegazy and his colleagues [11] used cement kiln dust as a coagulant with a dosage of 2 g/L followed by a filtration system for tertiary treatment of wastewater. The rice straw was utilized as a filter medium because of its porosity, which contributes to pollutant reduction of 5-days biochemical oxygen demand (BOD_5), COD and TSS to about 50% for each parameter while disposing of the rice straw in an environmentally safe manner. Furthermore, Hegazy [12] compared between different materials, i.e. rice straw, rice straw and luffa, bricks shale fragments, and the lightweight expanded clay aggregate (LECA) as a filter media to treat effluent of the oil-water separator. Consequences of the investigation demonstrated helpful utilization of the rice straw and luffa for achieving high removal efficiencies of BOD_5, COD, TSS and turbidity ranged between 87- 97% for each parameter. Yamina and his colleagues [13] tested 7 columns of the sand dune and activated carbon as filter media with different height of each column. Results of the study revealed the strong relationship between a depth of the activated carbon layer and the removal efficiency of BOD_5 and COD as 95% and 80% respectively where the depth was 0.24m. Therefore, the activated carbon is recommended to be used in the filtration for the tertiary treatment of wastewater. On the other hand, Gherairi and his colleagues [14] compared two different granular media, i.e. the crushed glass and natural sand dunes with a height of 60 cm for each filter media. The study showed that the sand media results are higher in BOD_5 and COD removals as 92% and 90% respectively than the crushed glass because of grains of the sand are rougher than the particles which have the ability to gather more suspended solids. Jiang and his colleagues [15] compared between 4 different media i.e. the anthracite, biological ceramist, shale and quartz sand. Jiang and his colleagues [15] proved that the anthracite media has the highest removal efficiency of TP. Similarly, Xu and his colleagues [16] conducted a comparative study between the anthracite, coking coal and lignite as mono media of the filter. The results show that the anthracite media result in the

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highest removal efficiency at 98% of BOD_5. Furthermore, Baraee and his colleagues [17] utilized columns of dual media, granular activated carbon (GAC) - sand and anthracite - sand as two different media filters. The obtained results show that the GAC-Sand pilot filter at a low hydraulic loading rate (HLR) increases the empty bed contact time to be 72 hours and records the highest production of heterotrophic bacteria and biofilm, which increases the treatment efficiency. The undertaken work aims to investigate the tertiary treatment of wastewater using a filtration technique and evaluate the validity of the treated wastewater for use in agriculture irrigation. In addition to developing a filter model for tertiary treatment of wastewater, determining the optimum operating conditions, and evaluating the sustainability of the filter media materials. In the present study, sand, anthracite, granular activated carbon (GAC) and rice straw were selected as filter media. The filtration efficiency was assessed according to removal efficiencies of the wastewater parameters and the head loss accumulation for each run, which is subjected to various filtration rates to obtain the best-operating conditions after ensuring that the treated wastewater is conformed to the standard specifications of the agricultural irrigation water.

2. Materials And Methods

2.1. Collection and characteristics of secondary treated wastewater

The secondary treated wastewater samples were collected from Saft-Trab wastewater treatment plant (WWTP) at the end of the sedimentation tank. This WWTP is located in Saft-Trab village, El-Gharbia Governorate, around 120 Km to the north of Cairo, Egypt [18]. Saft-Trab WWTP was designed to treat 10000 m^3/day of municipal wastewater where the activated sludge system via oxidation ditches used for secondary treatment of wastewater as appeared in the figure (1). Table (1) represents the quality of the secondary treated wastewater, collected for implementing the experimental program.

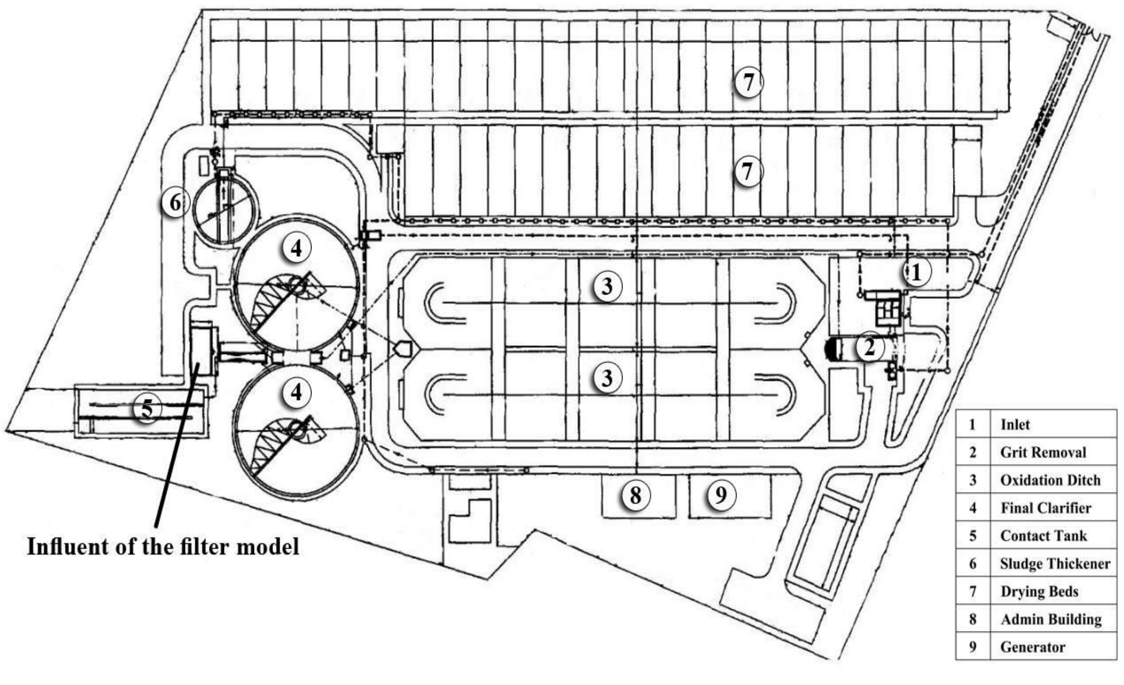


Figure 1: Layout of Saft-Trab WWTP

Table 1: Characteristics of the final effluent of Saft-Trab WWTP

Parameter	The Secondary treated wastewater*		
	Max.	Min.	Average
BOD_5 mg/L	27	18	22.5
COD mg/L	66	39	52.5
TSS mg/L	62	50	60.5
Phosphate - PO_4 mg/L	28	21	24.5
Nitrate - NO_3 mg/L	22.5	17	19.75
TDS mg/L	1270	1100	1150
pH	7.7	7.0	7.3

*Notes: Samples of the secondary treated wastewater were collected after the sedimentation tank, and the measurements due to the experimental program were completed within 3 months.

2.2. The rapid filter model

In the present study, the designed filter model was considered to handle up to 18 m^3/d of secondary treated wastewater with dimensions of 30cm×30cm×200cm. The filter model was made of fabric glass with a thickness of 12 mm for bearing the pressure of the water as shown in figure (2). The rate of filtration (R.O.F) ranged between 125-200 m^3/m^2/day to evaluate the impact of changing R.O.F on the removal efficiency for all the parameters. The filter model was designed to receive the secondary treated wastewater via the inlet pipe at top of the filter model for down-flow filtration. The filtered water discharges from the outlet pipe at the bottom of the filter model. In addition, a sluice valve is used for controlling the filtration and washing rate. A pump with a power of 0.5 HP was utilized as a part of this model for backwashing water pipes. A fabric sheet was installed at top of the model with regular holes for regular distributing the influent wastewater in the model. Another sheet was installed at the bottom of the filter media to retain the media from getting filtered out with the wastewater. At the bottom of the model, there were plastic pipes of 6.35 mm diameter with 2 m in height to measure the total head loss (piezometers).

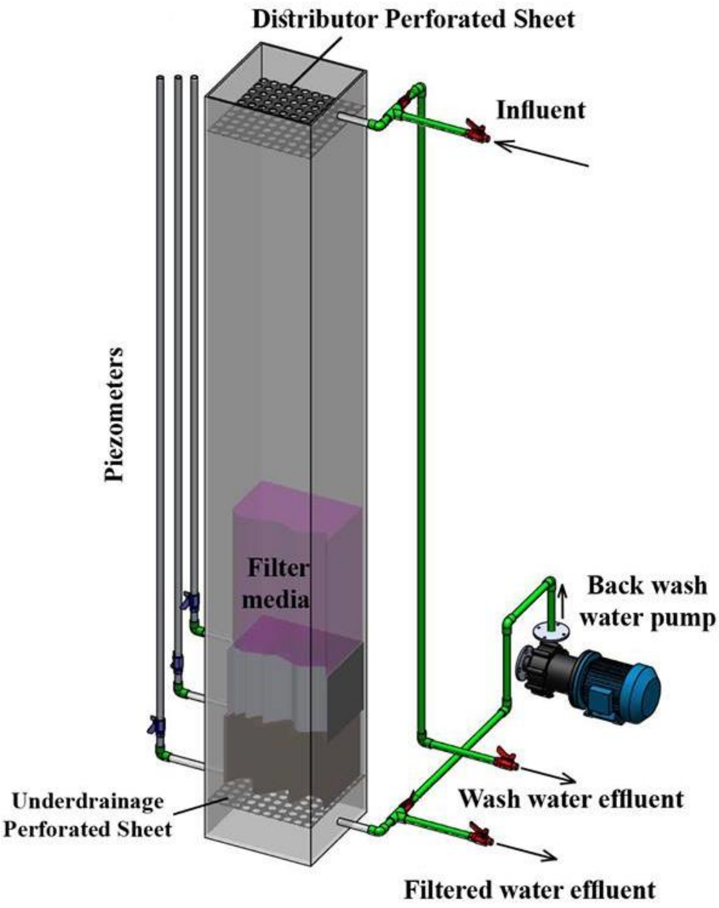


Figure 2: The experimental model of the filter

2.3. Properties of materials used in the filter model

In this study, the utilized materials in the filtration process were sand, anthracite, granular activated carbon (GAC), and compressed rice straw with a depth of 60 cm for each material media and followed by a supporting sand medium. Likewise, a layer of gravel was used with a depth of 20 cm to support the filter media and prevent leakage of the filtration media from exiting with the filtered water. The characteristics of each material are shown in the table (2).

Table 2: Characteristics of the material of the filter media

Parameter	Material of the filter media			
	Sand	Anthracite	GAC	Rice straw
Particle size (d_c)mm	0.3-1.25	1.4-2.5	0.6-2.36	--
Effective size (d_{10}) mm	0.63	1.4	1.1	--
Uniformity coefficient (UC)	1.58	1.7	1.9	--
Density kg/m^3	1500	750	500	300
Porosity %	42	56	47	70

The experimental work carried through four arrangement as shown in figure (3). The sand medium was used in the first arrangement with a depth of 60 cm. The second arrangement was anthracite and sand. In the third arrangement, granular activated carbon and sand were used. At last, the rice straw and sand were used in the fourth arrangement. The anthracite, granular activated carbon and rice straw were used with a constant height of 40 cm and the sand material in each form were with constant height 20 cm in addition to the supportive under drainage medium [19]. These dimensions were compatible with Metcalf and Eddy [2]. Each arrangement had 4 runs. Each run had a different filtration rate i.e. 125, 150, 175, 200 m^3/ m^2/day with total runs 16 for all the arrangements. The samples were taken from the influent and the effluent of the filter in each run of the four arrangement. For each sample, BOD_5, COD, TSS, NO_3 and PO_4 parameters were measured according to the Standard Methods for the Examination of Water and Wastewater [20]. All experiments were conducted in Sanitary Engineering Laboratory, Faculty of Engineering, Tanta University, as well as the Laboratory of Saft-Trab WWTP.

2.4. Determination of the filter run length

The filter run length limited by the smallest of breakthrough time (t_B) and time to limiting head (t_{HL}) [21], while breakthrough does not occur in the range of filtration rate between 5 to 10 m/hr (120-240 m/d) [22]. Hence, the filter run length is limited by the time to limiting head (t_{HL}) in the present study where the filtration rates were ranged between 125-200 m/d. The total head loss was measured in each run of the four arrangements. In this study, the equation (1) was applied to calculate the time to limiting head of 2 m water height for each run in every arrangement as the following [21]:

$$t_{HL} = \frac{(H_T - h_{L,0}) \times L}{K_{HL} \times v_f \times (C_0 - C_E)} \rightarrow (1)$$

Where,

- t_{HL} = time to limiting head (hr),
- H_T = Limiting head loss (m),
- $h_{L,o}$= Initial clean bed head loss (m),
- L = filter bed length (m),
- V_f = filtration rate (m/hr),
- K_{HL}= head loss increase rate constant (L. m/mg),
- C_O = Influent concentration (mg/L), and
- C_E = Effluent concentration (mg/L)

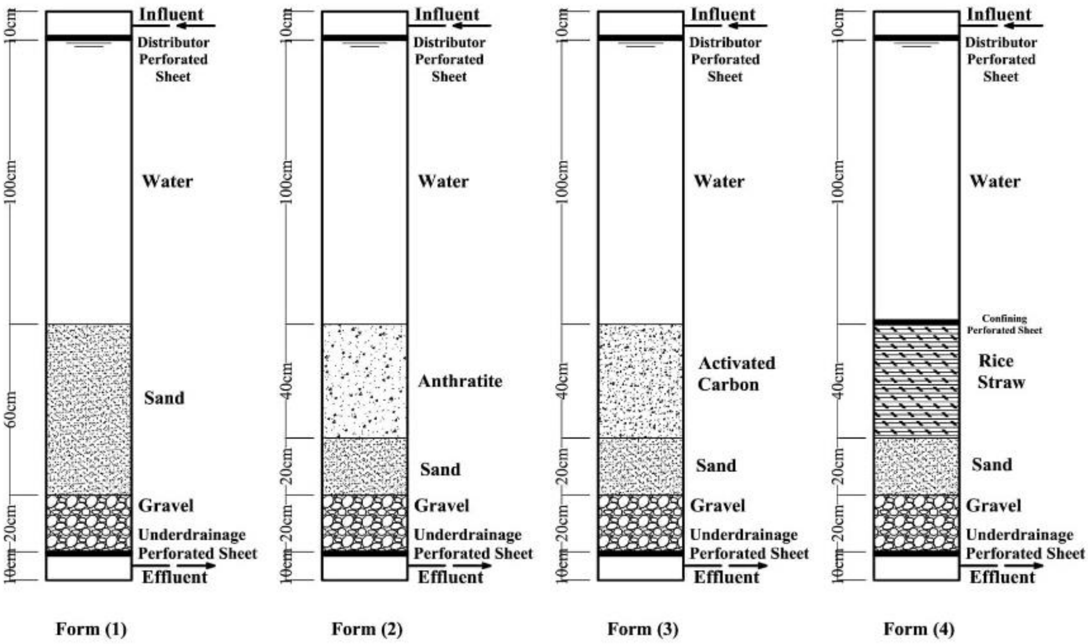
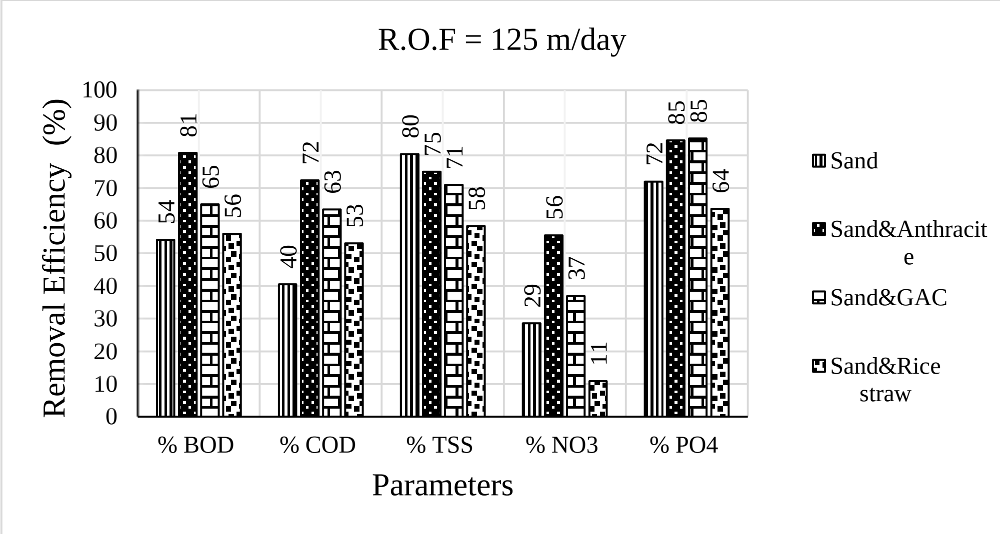


Figure 3: The different arrangements of filter media

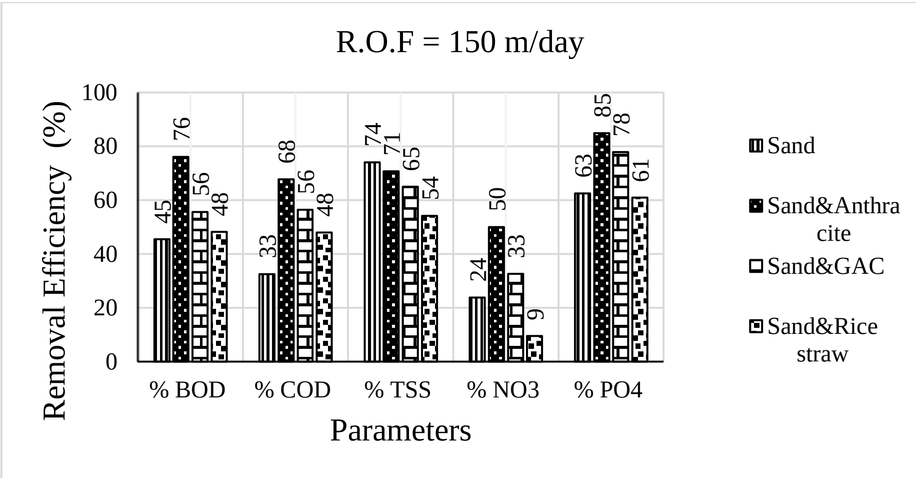
3. Results And Discussion

3.1. Effect of filtration rate on removal efficiency of pollutants

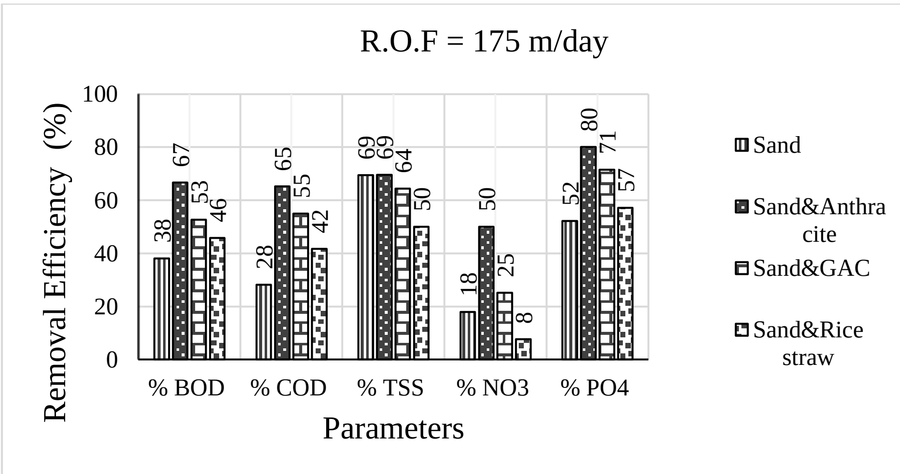
Figure (4) represents the different removal efficiency of pollutants as indicated by BOD_5, COD, TSS, NO_3 and PO_4 in accordance with varying the filtration rates to investigate its impact on the treated wastewater quality. It was found that the highest BOD_5, COD, NO_3 and PO_4 removals of 81%, 72%, 56%, and 85%, respectively, were obtained with the use of sand with anthracite as a filtration media. While sand filtration achieves the highest TSS removal of 80% only because of the relative roughness of the sand, which is the reason for the more attracting the suspended solids more than others filter media. The anthracite-sand media and the granular activated carbon (GAC)-sand media filters have a moderate difference in removal efficiency of the effluent parameters such of BOD_5, COD, TSS, NO_3 and PO_4 as shown in figure (4). At filtration rate of 125 m/day BOD_5, COD, TSS, NO_3 and PO_4 removal of the anthracite-sand media were 81%, 72%, 75%, 56% and 85%, respectively. Filtration rate of 150 m/day resulted in removal efficiency of 76%, 68%, 71%, 50% and 85% of the same previous order of wastewater parameters as shown in figures (4 a,b). These results were well-matched with that obtained by Jiang and his colleagues [15] and Xu and his colleagues [16], while the results were higher than those obtained by Baraee and his colleagues [17], where the low filtration rate and depth of granular activated carbon or anthracite of the study that operated by Baraee and his colleagues [17] might be the reasons of variance between the both results. As a result, it was noticed that the removal efficiency of each parameter was inversely proportioned with the filtration rate. Similarly, results of BOD_5, COD, TSS, NO_3 and PO_4 removal at rate of 175 m/d for the anthracite-sand run were 67%, 65%, 69%, 50% and 80% and 53%, 55%, 64%, 25% and 71%, for the GAC-sand run respectively. However, removal efficiency of the same parameters significantly diminish with the corresponding filtration media at a filtration rate of 200 m/day, where 55%, 63%, 67%, 25%, 77% for the anthracite-sand pilot and 44%, 53%, 64%, 13% and 62% for the GAC-sand pilot respectively as shown in figures (4 c,d). Results of filtration rates of 150 and 175 m/day were close to each other with slight differences in each run. Subsequently, anthracite has higher results than the GAC with a difference of 20%, 10% and 25% for BOD_5, COD and NO_3 respectively, as well as, 5% and 15% for TSS and PO4, respectively. This may be referred to that the porosity and surface area of anthracite is being higher than that of GAC, which enhances the anthracite for more attraction of the substances on its surface. Hence, the anthracite-sand pilot has advantages over the GAC-sand pilot, which can be described by its high removal efficiency, and low material cost, as it is widely known. As appeared in figure (4), anthracite- sand and GAC-sand media have higher removal results than those obtained from the sand and rice straw-sand media. These results are compatible with those obtained by Yamina and his colleagues [13]. Also, it is clear that the sand medium has a higher removal efficiency results than rice straw-sand media filters on some parameters as shown in figure (4). At filtration rate of 125 m/day, removal efficiency of BOD_5, COD, TSS, NO_3 and PO_4 from the sand pilot were 54%, 40%, 80%, 29% and 72%, respectively, while rice straw-sand pilot were 56%, 53%, 58%, 11% and 64%, respectively. Moreover, the running with a filtration rate of 150m/day removes 45%, 33%, 74%, 24% and 63% for the same parameters of the sand filter, and 48%, 48%, 54%, 9% and 61%, respectively, for rice straw-sand filter as shown in figures (4 a,b). It is noticed that rice straw-sand filter has much better results than the sand filter for BOD_5, COD and NO_3 removals, this may be referred to that rice straw has an organic nature, which could allow the bacteria to grow up and feed on the substances, which gives a comparative advantage of rice straw for sand in the removal efficiency of organic pollutants besides that, rice straw-sand media has a positive effect on the environment which can be disposed of safely. On the other hand, at a filtration rate of 175 m/day, rice straw-sand pilot resulted in removal efficiency of 46%, 42% and 57% for BOD_5, COD and PO_4, respectively, which are higher than those obtained from sand filtration (i.e. 38%, 28% and 52% for BOD_5, COD and PO_4, respectively) as shown in figure (4-c). While removal efficiency of the rice straw-sand filtration for TSS and NO_3 (i.e. 50% and 8%) are less than those obtained from sand filtration (i.e. 69% of TSS and 18% of NO_3). In the sand and rice straw-sand filters, it was found that the same inversely proportional between the removal efficiency of each parameter and the filtration rate. These results are compatible with those obtained by Hegazy and his colleagues [11]. On the other hand, at a filtration rate of 200 m/day, the rice straw-sand pilot results,42%, 40%, 47%, 4% and 52% and the sand pilot results, 25%, 25%, 68%, 17% and 48% of BOD_5, COD, TSS, NO_3 and PO_4, respectively, as shown in figure(4-d). It can be noticed that the rice straw-sand pilot results are higher removal efficiency than the sand media at the various filtration rates in BOD_5, COD and PO_4 parameters. Moreover, the rice straw-sand at a filtration rate of 200 m/day keeps almost the results of 175 m/day. Generally, the range of filtration rates between 150 to 175 m/day can be considered as the optimum filtration rate in this study since the obtained removal efficiency from the different wastewater parameters are conformed to the standard specifications of the irrigation water. Therefore, the optimum filtration rate is 175 m/day, which achieves removal efficiency for all the parameters according to the standard specifications of the irrigation water as shown in figure (4). Regarding the results of the four arrangements throughout the optimum rate of filtration 150 to 175 m/day, the rice straw-sand pilot is the perfect model to proceed which affects the environment positively, since a second sand stage will be used to maintain the effluent TSS and NO_3 values. Thus, the sand pilot is secondly ranked. However, the anthracite-sand pilot has the highest removal efficiency, the sand, as a filter material is cheaper than the anthracite as it is globally known.


R.O.F = 125 m/day
Removal Efficiency (%)
Parameters
% BOD
% COD
% TSS
% NO3
% PO4
Sand
Sand&Anthracite
Sand&GAC
Sand&Rice straw
54 81 65 56
40 72 63 53
80 75 71 58
29 56 37 11
72 85 85 64

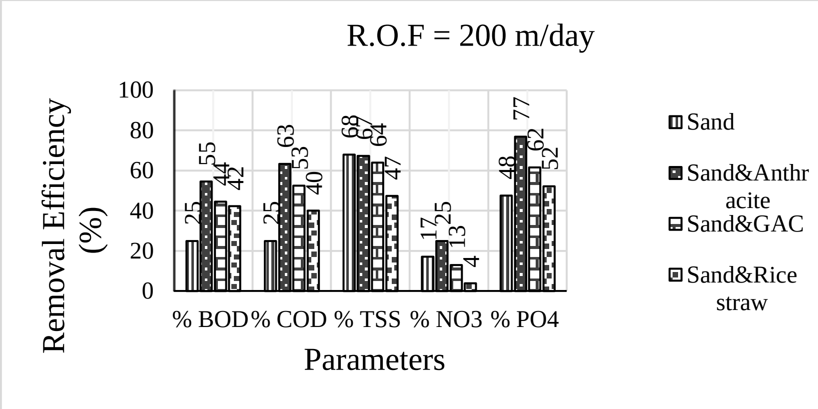
(a)


R.O.F = 150 m/day
Removal Efficiency (%)
Parameters
% BOD
% COD
% TSS
% NO3
% PO4
Sand
Sand&Anthracite
Sand&GAC
Sand&Rice straw
45 76 56 48
33 68 56 48
74 71 65 54
24 50 33 9
63 85 78 61

(b)


R.O.F = 175 m/day
Removal Efficiency (%)
Parameters
% BOD
% COD
% TSS
% NO3
% PO4
Sand
Sand&Anthracite
Sand&GAC
Sand&Rice straw
38 67 53 46
28 65 55 42
69 69 64 50
18 50 25 8
52 80 71 57

(c)



(d)

Figure 4: The removal efficiency of pollutants through different filter media with filtration rate of (a) 125 m/d, (b) 150 m/d, (c) 175 m/d, (d) 200 m/d

3.2. Effect of filter media on removal efficiency of pollutants

The nitrate (NO_3) removal is the lowest removal efficiency as shown in figure (4) with the different media and filtration rates. The main reason of this drop is that the conventional biological treatment is not so helpful for the nitrogen removal where most of the nitrogen exists as ammonia, which is being expelled from water into the atmosphere and the ammonium ion exists in the wastewater may also be oxidized to nitrate by bacteria but it takes a long hydraulic rate to be able to produce the nitrate. Thus, the final composite is the nitrate (NO_3), which remains in the treated wastewater. Therefore, the wastewater needs a post-treatment to remove nitrogen such as denitrification that requires an organic carbon compound to react with the nitrate and release it to nitrogen gas, which often employs the methanol as organic carbon. As a result, the sand runs and rice straw-sand filters resulted in lower NO_3 removal efficiency than the anthracite-sand and the GAC-sand filters as revealed in Fernández-Nava [23] and Yamashita and Yamamoto-Ikemoto [24]. However, the aerobic microorganisms consume a significant concentration of the phosphate (PO_4) in the aeration tank. As illustrated from the figure (4), it is noticed that the competencies of the TSS removal efficiency at close values in cases of the sand filter, anthracite-sand filter and GAC-sand filter, which are higher than the TSS removal efficiency of the rice-straw-sand filter. These results can be explained by the smaller voids of the sand, anthracite and GAC than the rice straw, which gives the opportunity for suspended solids to be attached between the voids of these materials more than the rice straw. Besides that, the anthracite-sand filter and GAC-sand filter were found more efficient in removal of TSS than sand, and rice straw-sand filter because of the absorptive feature of these materials wherever the molecules of the dissolved substances can be collected on and adhered to its surfaces, as an adsorbent. The results of BOD_5 and COD values from the sand media are lower than that from the rice straw-sand filter because of nature of rice straw as an organic material which permits bacterial growth, consuming the organic substances hence reducing BOD_5.

3.3. Filter running duration

The filter operating time (Run duration) is considered one of the most important factors governing the choice of filter media and filtration rate. As mentioned before, the filter run is limited by the time to limiting head (t_{HL}), in the present study, rates of filtration ranged between 125-200 m/d. Furthermore, the filter running times were investigated for the different filter media at a filtration rate of 175 m/d. The limiting head time (t_{HL}) in this investigation is characterized as the time it takes for the filter, reaching to the allowable head loss of 2 m where equation (1) was applied for this purpose [2, 21] which was compared with the regression equation as shown in figure (5).

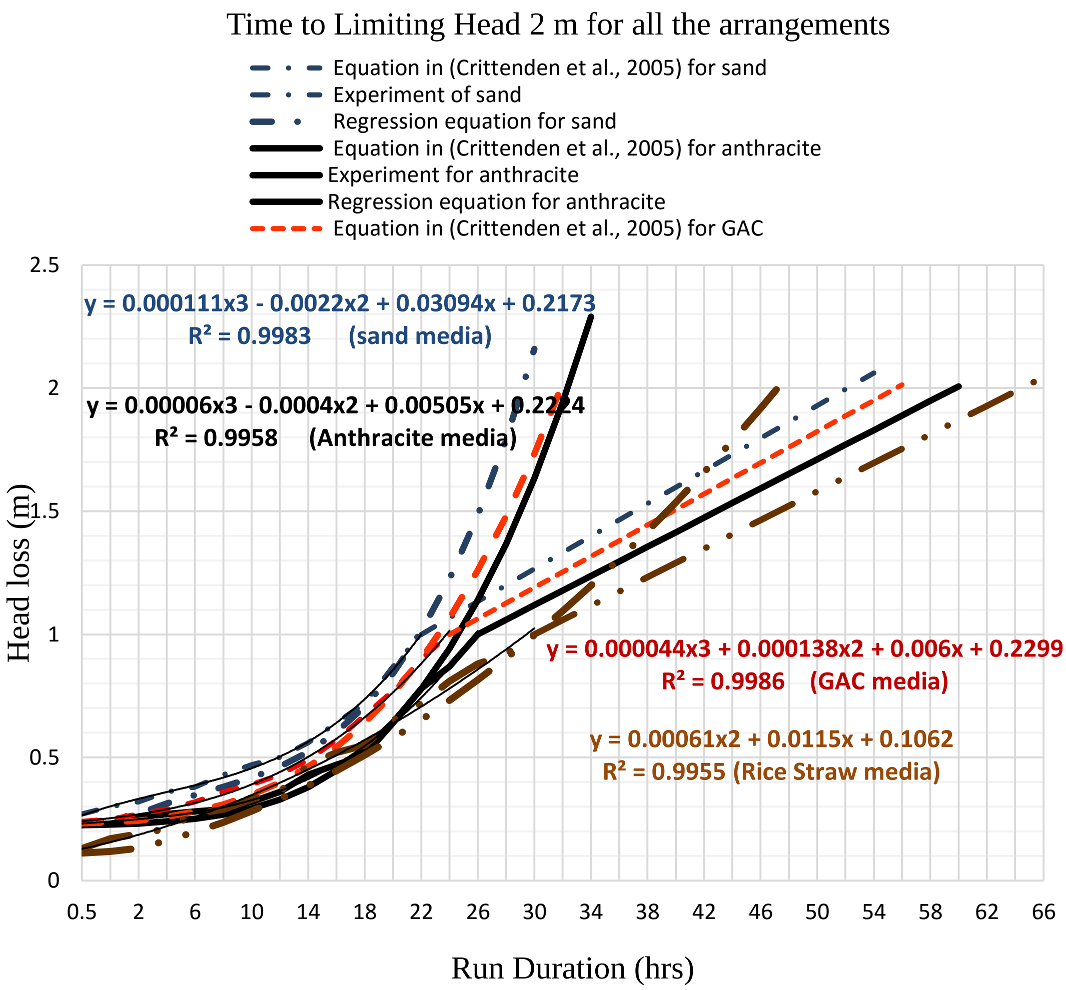


Figure 5: Accumulation of the time to limiting head of 2 m at a filtration rate of 175 m/d

It noticed that there is a slight difference between the sand, anthracite-sand and GAC-sand filters as shown in figure (6) in the expected t_{HL}. It is clear that the total hours of the limiting head time for each pilot is inversely proportional to the filtration rate. On the other hand, the rice straw-sand runs operated in steady-state for 30 hours experimentally. Therefore, its calculated time to limiting head (t_{HL}) by equation (1) is 66 hours comparing to 48 hours for the regression equation as shown in figures (5) and (6), which adds a comparative advantage to the use of rice straw for relatively long operational time. However, the removal efficiency of pollutants was not the highest through all the filters. Regarding the total hours for reaching the limiting head 2m, it noticed that gap between the equation (1) in Crittenden and his colleagues 2005 [21] and the regression equation was about 25 hours for sand, anthracite-sand and GAC-sand filters in comparison with the rice straw-sand filter which was 18 hours. The main reason for that variance was relative to the high value of rice straw porosity comparing to the other materials, which were neglected by equation (1). Therefore, it was considered to calculate the time to limiting head 2m for all the arrangements as the average value of the results of equation (1) and the regression equation, as shown in figure (6).

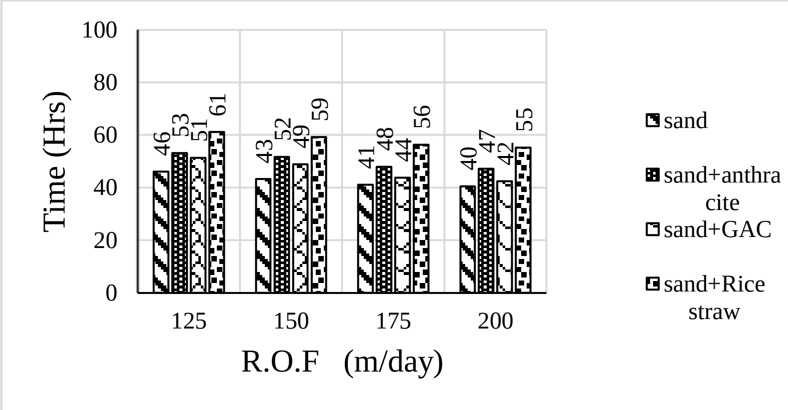


Figure 6: Time to limited head 2 m for different filters.

Table (3) describes the effluent characteristics of the tertiary treated wastewater from different filters at a filtration rate of 175 m / day. The tertiary treated wastewater is found valid for reusing in the agricultural irrigation purposes in accordance with the Egyptian Code, WHO, and FAO guidelines (e.g. 20 mg/L of BOD_5, 40 mg/L of COD, 20 mg/L of TSS, and 6-9 of pH range referring to the Egyptian Code guidelines) [5, 25-27].

Table 3: Characteristics of the tertiary treated wastewater

Effluent Characteristics	Filter media			
	Sand	Anthracite-sand	GAC-sand	Rice straw-sand
BOD_5(mg/L)	13	9	9	13
COD (mg/L)	28	23	18	28
TSS (mg/L)	15	18	21	29
(Phosphate - PO_4 mg/L)	11	5	8	9
Nitrate - NO_3(mg/L)	16	11	17	16
TDS –(mg/L)	1020	900	950	1050
pH	7.7	7.4	7.5	7.6

4. Conclusions

Tertiary treatment of wastewater was investigated via filtration technique. The rapid filtration experiments were piloted using different types of filter media arrangements, where filtration efficiency was assessed according to removal efficiency of the different pollutants and the head loss accumulation for each run, which is subjected to various filtration rates. The results indicate that the optimum filtration rate is 175 m/day, which achieves the proper quality of the tertiary treated wastewater for all the investigated parameters according to the standard specifications of the irrigation water. From the previous results, the rice straw is an appropriate option as a filter medium for the environmental viewpoint in the filtration as a technique of the tertiary treatment of wastewater for reuse in the agricultural irrigation purposes according to the standard specifications. However, the results of TSS are not conforming to specifications according to the Egyptian code limits for the rice straw-sand filtration. On the other hand, the anthracite-sand filter pilot is the best choice as a filter media in a viewpoint of the biological removal efficiency. However, the cost of the anthracite material is higher than the rice straw and sand materials. The sand filter is an appropriate media according to the cost factor and the effluent removal efficiencies viewpoints in the comparison with the other materials results. The results are more satisfactory in all biological parameters according to the Egyptian code limits. In addition, the cost of the sand media is lower than the anthracite and granular activated carbon. Finally, the granular activated carbon (GAC) filter has fair removal efficiencies for all the parameters, which are discussed in this study according to Egyptian code limits. The results of the GAC material are less than the anthracite material, which it is good cases to choose the anthracite material as a filter media.

5. Recommendations

Based on the results of the present study, it is recommended to follow the rice-straw sand filtration with extended sand filtration in a second stage to ensure the removal of TSS parameter conforming the standard specifications. As well as, the anthracite-sand pilot is recommended if there are financial support and a focus on the quality control of the treated wastewater effluent. In addition, the sand media is recommended to use for efficient treatment quality. On the other hand, the GAC is not recommended as a filter media because of its removal efficiency results, which are not much better than the anthracite material because of its relatively high cost.

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