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COMPARATIVE PERFORMANCE OF A CHARCOAL DUAL MEDIA FILTER AND A CONVENTIONAL RAPID SAND FILTER

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ABSTRACT

Filtration tests were conducted to assess the performance of a dual media filter (DMF) using charcoal in comparison to a conventional rapid sand filter (RSF) for the same kaolin solution in influent water. Assessment of media characteristics was based on appearance, size, relative density, acid solubility and physical stability. The dual media filter exhibited a turbidity removal capacity of 1.4 times that of the conventional rapid sand filter. Gradients obtained from plots of headloss against time for the RSF and DMF were 0.2 and 0.5 respectively indicating a higher rate of head loss development in the RSF than the DMF. About 86% of the accumulated material in both RSF and DMF was washed away during the first four minutes of backwashing with combined air and water scour. The DMF had a higher bed expansion rate of 40% more than the RSF. This could be attributed to the lower density of charcoal compared with sand.

Key words: Charcoal, Dual media filtration, rapid sand filtration

INTRODUCTION

A dual media filter differs from a conventional RSF in that RSF beds contain a single layer of filter bed of materials. Sand is always the major filtering material employed in an RSF while dual media filters contain more than one type of filtering material. These layers must differ in grain size and mass density (Terence, 1991). As a result, the rates of wear in the dual media filtering materials vary depending on the nature of filtering materials. Furthermore, in the dual media filter, the settling velocity of the filter grains increase and during backwashing no overturning nor mixing between the different layers occur which is normally a problem in RSF (Sanyaolu *et al,* 2004). Charcoal has relatively lower specific gravity than sand and may yield higher filtration rates and lower head loss (Schultz, 1990). In dual media filters, the lighter, coarser material is usually segregated towards the top of the filter and the heavier, finer materials are segregated towards the bottom. This arrangement of coarser to finer filter media has several advantages over the single medium filters and were listed by Gabriele (1985) as follows:

- Large solids storage capacity in the coarse layer.
- Good protection against break through of impurities in the fine grained layer.
- Good overall utilization of the entire filter volume.

- Lower head loss and longer run time before maximum head loss is reached.
- Higher permissible solids loading.
- Ability to filter large particulates without danger of straining and surface filtration.

Advances in the conventional RSF have been concerned mainly with the optimum choice of filter media to improve filter bed capacity and filtration rates. The down-flow hydraulically graded single medium filter was found to have low efficiency as majority of impurities present in the raw water were collected near the top of the sand bed with the consequence that the full depth of the media is not utilized as much as it should be and the loss of head through the filter builds up sooner than would otherwise be the case (Casey *et al*., 2005). It is this loss of head which is one of the factors determining the length of run of a filter that leads to reduced effluent output and rapid clogging of the filter (Morrison and Weber, 2004). To reduce this effect, it is possible to have a gradation from coarser media to finer media with downward filtration and the bed built up with the densest at the bottom and the less dense at the top (Lee and Lambert, 2007).

Packham *et al.* (2008) showed that a tri-media bed using ilmenite, silica sand and garnet gave superior impurity removal characteristics over a single medium down-flow filter; the drawback however being the high costs of running the filter media.

Otis *et al.* (2005) carried out a test involving the removal of 13cm depth of coarse sand of 0.5mm diameter and replaced it with anthracite of similar depth. At equal rates of filtration of 4.5m/hr, a conventional sand filter averaged 35hr runs and 2.7m headloss, while the anthracite capped filter averaged 120hr runs and a loss of head of 1.9m.

This paper investigated the degree of turbidity removal and length of filter run time of a dual media filter containing charcoal in comparison with the conventional RSF. Head loss development and backwash characteristics in the DMF and RSF were also monitored.

MATERIALS AND METHODS

The filter media used for this research were river sand and granular activated charcoal. The filtration tests were conducted using a solution of kaolin powder in water. The rationale behind the use of this compound was to analyze the response of the filters in terms of removal of very fine grains below 0.063μm in water. Kaolin mixtures were prepared in the range of 55-60FTU, 60-70FTU and 95-110FTU . The filtration rate was held at 5.4 m/hr for all filter runs.

Media characteristics namely effective size, uniformity coefficient, relative density, acid solubility and physical stability were carried out based on APHA (1992).

All filter runs were conducted for a period of 15-30hrs until turbidity removal was below 30% and terminal head loss reached. The data from the runs were used for the computation of relationship between turbidity removal and head loss development both with time and depth of media. The filtration rigs consisted of two identical columns of 200mm diameter; one for the DMF and the other for the RSF as shown in Fig 1. Each filtration column was made up of two components namely: the base, the medium and supernatant column.

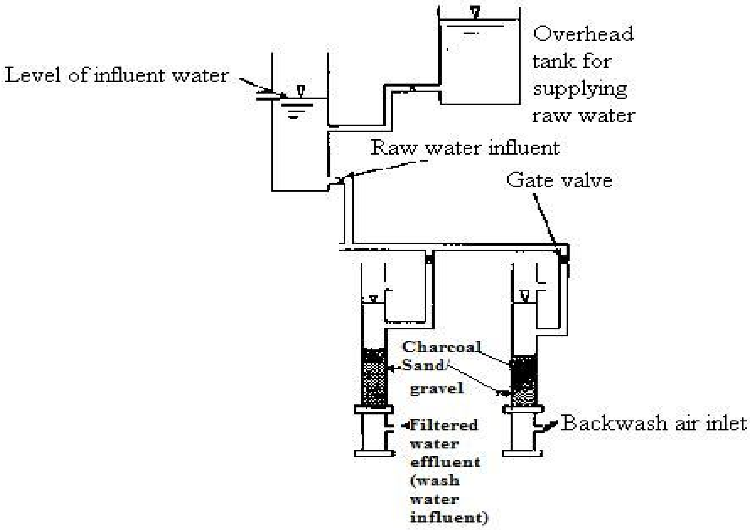

Fig.1: Schematic representation of the filtration bench scale model

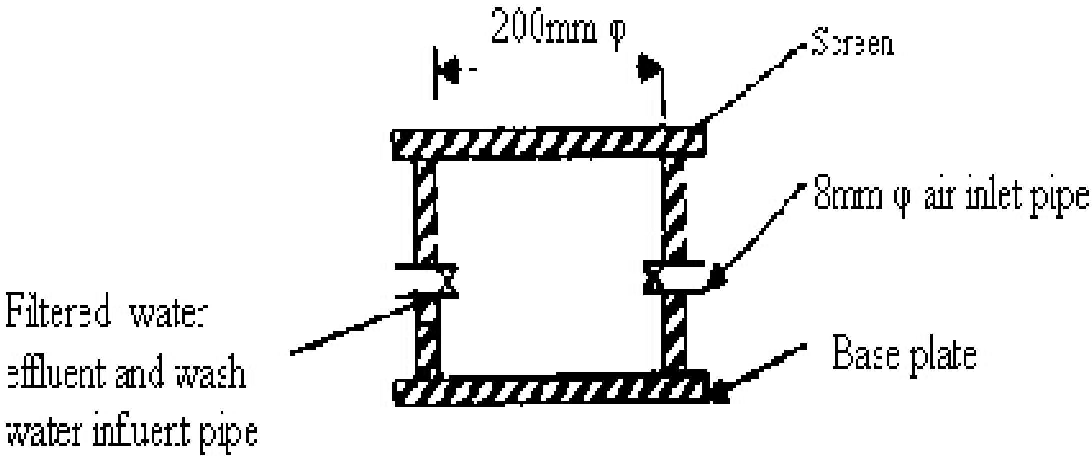

Fig. 2: Schematic representation of the base (underdrain)

Fig. 2 shows the base or underdrain chamber which was made up of a 200mm- diameter clear Perspex pipe section, 20cm deep. A perforated transparent screen was used to cover the top of the base in order to support a 10cm gravel layer which prevented the movement of sand into the underdrain chamber as well as to distribute the backwash water uniformly across the cross-sectional area of the filter media.

The medium and supernatant column combined was 130cm high (Fig.1). It held the filter media above the underdrain. In the conventional RSF column, the sand was added to a depth of 60cm while the DMF was tested with depths of charcoal varying from 20cm to 30cm with an underlying sand depth of 30cm to maintain a filter media depth of 50 to 60cm.There were 4 ports spaced at 30cm centers along the height of the column with the bottom most port being 10cm from the top screen of the underdrain of each of the medium columns. These ports were connected using rubber tubings to manometers which were used to monitor the head loss. The columns were made up of 200mm diameter clear Perspex which enabled direct observation of the media depth for the purpose of monitoring the expansion of the fluidized bed during backwashing. Backwashing was carried out by subjecting the filters to combined air and water scour for four minutes, thus enhancing the expansion of the bed. This was subsequently followed by 10 minutes of continuous wash water alone. Backwash air velocity was fixed at 0.2m/s using while the backwash flow rate was varied slightly for the purpose of analyzing the relationship between bed expansion and backwash rate.

RESULTS AND DISCUSSION

Table 1: Media Characteristics

Media	Size range (mm)	Effective size (mm)	UC	Relative density	Acid solubility (%)
Sand	1.0-2.0	1.07	1.43	2.94	0.72
Charcoal	2.0-6.3	3.08	1.98	1.38	1.30

The media characteristics detailed in Table 1 were obtained after testing in accordance with specification.

Turbidity removal versus time

Filter depth of 50cm (Kaolin: 55-60 FTU)

The relationship between turbidity removal against time with the inorganic influent is plotted in Fig. 3. It can be observed that there was higher turbidity removal in the dual media filter compared to the conventional RSF. At the beginning of filtration, the DMF with charcoal removed 48% of the kaolin particulate while conventional RSF removed 40%. The turbidity removal capacity of the DMF (charcoal) is therefore about 1.2 times that of the conventional RSF. At the end of the filter run, the turbidity removals were 25% for the DMF (charcoal) and 15% for the RSF. Thus, the removal capacity at the end of the run for DMF (charcoal) was 1.7 times more than that of the RSF. The filter run was terminated when the turbidity removal was below 25%. It was observed that filter turbidity removal capacity fell with time, with the RSF registering slightly higher fall (gradient 1.31) than the pumice DMF (gradient: 1.297). The coefficient of determination shows a good correlation between the charcoal thickness and the extent of protection of the sand bed.

Filter depth of 50cm (Kaolin: 60-70 FTU)

From Fig. 4, it can be observed that the DMF exhibited slightly higher removal capacity than the RSF. At the beginning of the filtration 49% turbidity removal was registered by the charcoal DMF while the RSF registered about 45%. Therefore, the DMF (charcoal) had an initial removal capacity which was 1.1 times that of the RSF. At the end of the filter run, when the turbidity removal went below 25%, the removal rates were 27 and 14% respectively for DMF and RSF. Thus the removal efficiency of DMF for charcoal was 1.9 times that of RSF. Turbidity removal for inorganic particulates fell with time. RSF had a gradient greater than that of DMF indicating that the turbidity removal capacity fell faster with time. This is reflected in the strong correlation coefficients.

Filter depth of 60cm (Kaolin: 55-60 FTU)

An analysis was made for the variation of turbidity removal with time by increasing the charcoal depth in the DMF from 20cm to 30cm. The depth of sand in RSF was also raised to the same level as that of the DMF. A mixture of kaolin influent was then run through.

Fig. 5 shows that there was higher turbidity removal in the DMF compared to the conventional RSF. At the beginning of the filtration, DMF removed 50% of the kaolin inorganic particulates while the RSF removed 46%. The DMF was therefore 1.1 times more efficient than the RSF.

At the end of the filter run, the turbidity removal rates were 23 and 18% for the DMF and RSF respectively. This gave a removal factor of 1.3 for the DMF over the conventional RSF.

Head loss development

The change in head loss development was expressed in relation to depths of the filter media as well as time. For the kaolin influent, the relationship between the total head loss and time at a depth of 50cm is shown in Fig. 6. The RSF showed a higher head loss profile than the DMF throughout the duration of the filter run. There was a difference in the rate of head loss development as shown by the linear representations of the two curves. The RSF gave a gradient of 0.2 while the DMF had gradients of 0.5. This showed that although RSF showed a higher head loss for kaolin influent it developed slower head loss than the dual media filter. The data showed large variations in the differences in total head loss between the DMF and RSF at the beginning and at the end of the filter run.

The variation of head loss with time for charcoal depths at 20 and 30cm respectively for the DMF was analyzed for kaolin influent. The results of this analysis are presented graphically in Fig. 7. The 30cm charcoal depth runs maintained higher head loss throughout the duration of filtration while the 20cm depth demonstrated lower head loss. This showed that increasing the charcoal depth correspondingly decreased filter run times.

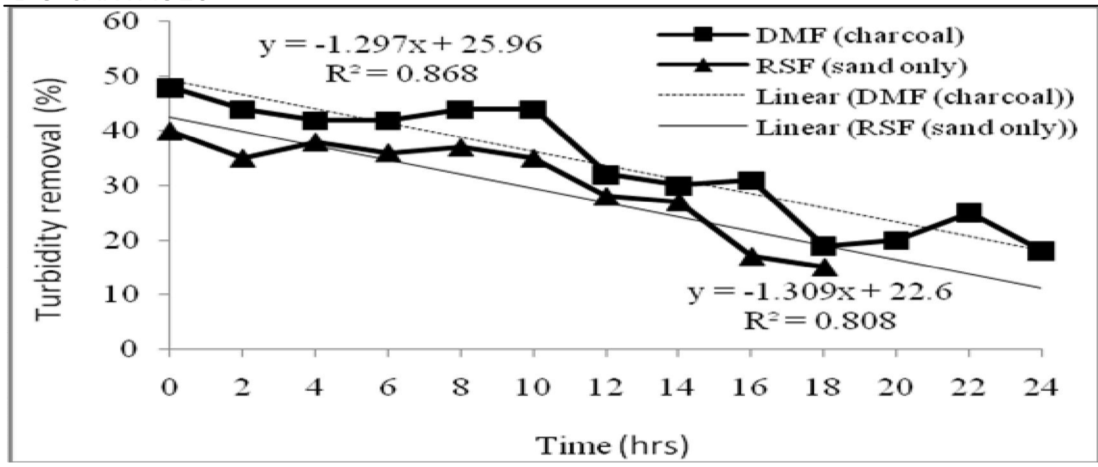

Fig. 3: Variation of turbidity removal with time (Kaolin: 55-60 FTU)

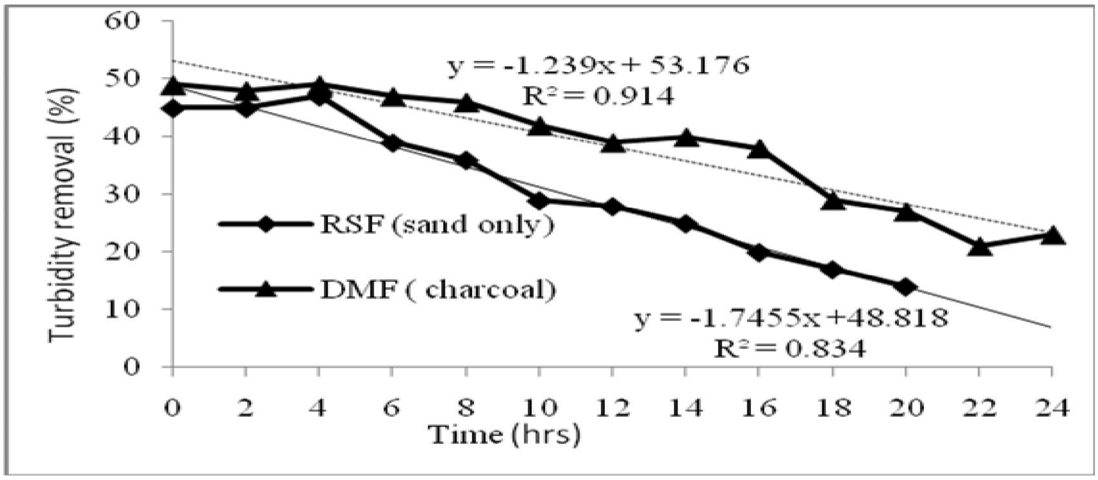

Fig. 4: Variation of turbidity removal with time (Kaolin: 60-70 FTU)

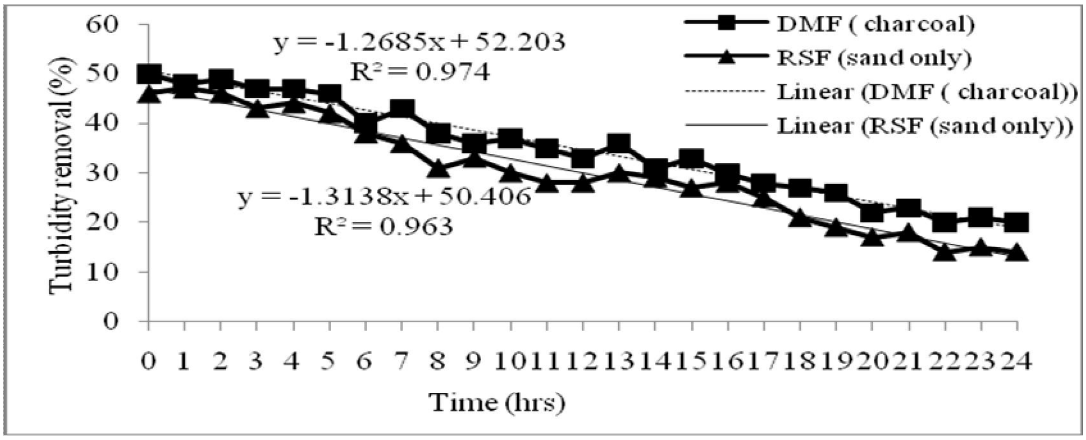

Fig. 5: Variation of turbidity removal with time, filter depth 60cm

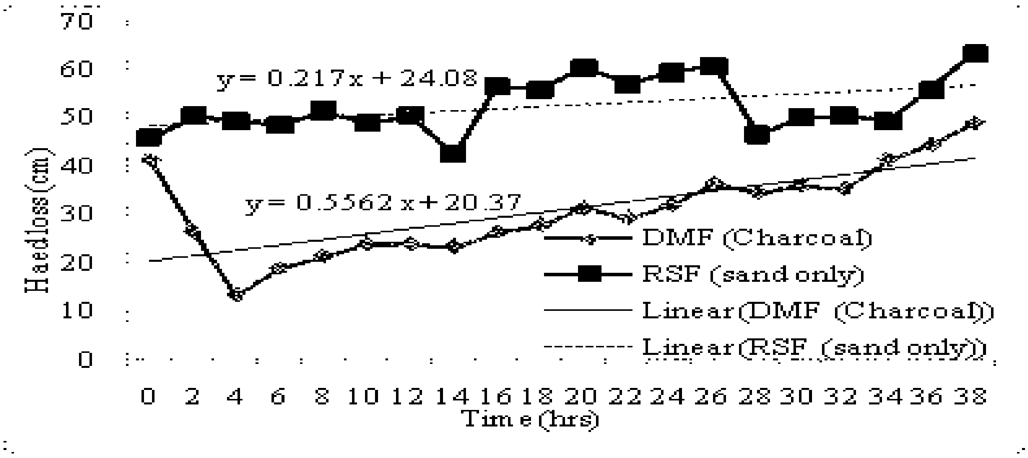

Fig. 6: Variation of total head loss with time (kaolin)

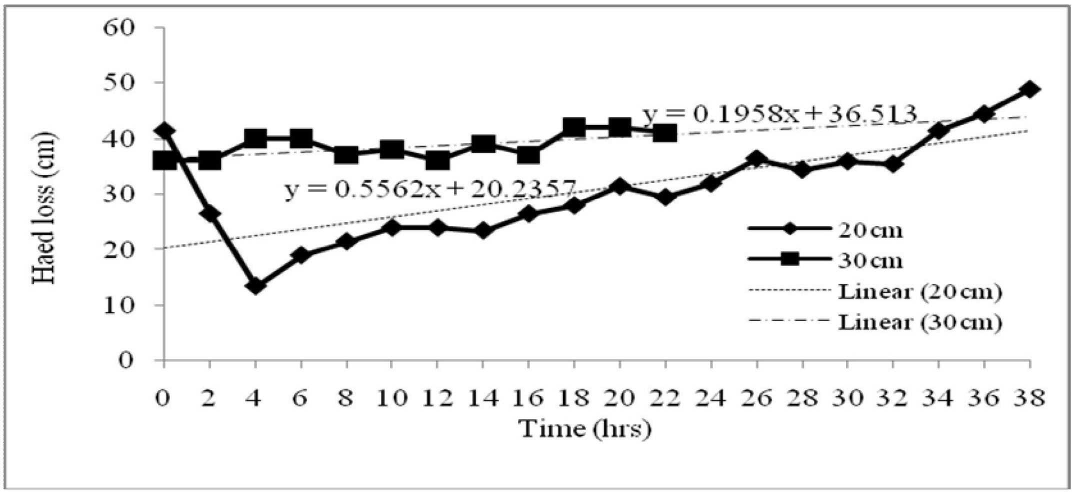

Fig. 7: Variation of total head loss with time for two depths of charcoal

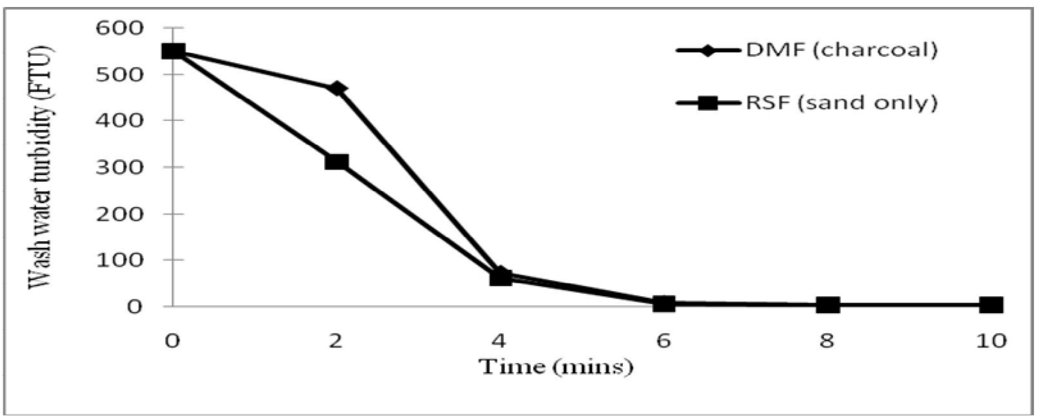

Fig. 8: Wash water turbidity versus time (kaolin)

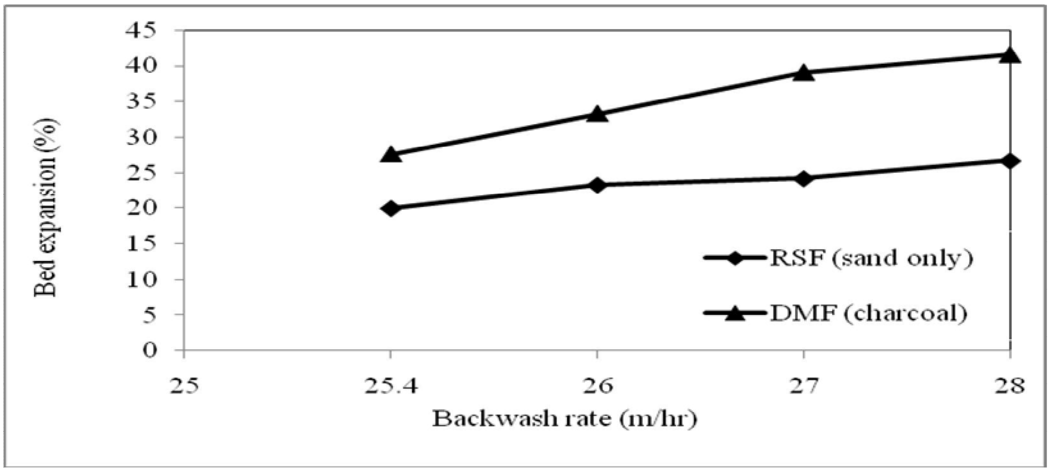

Fig. 9: Variation of bed expansion with backwash rate

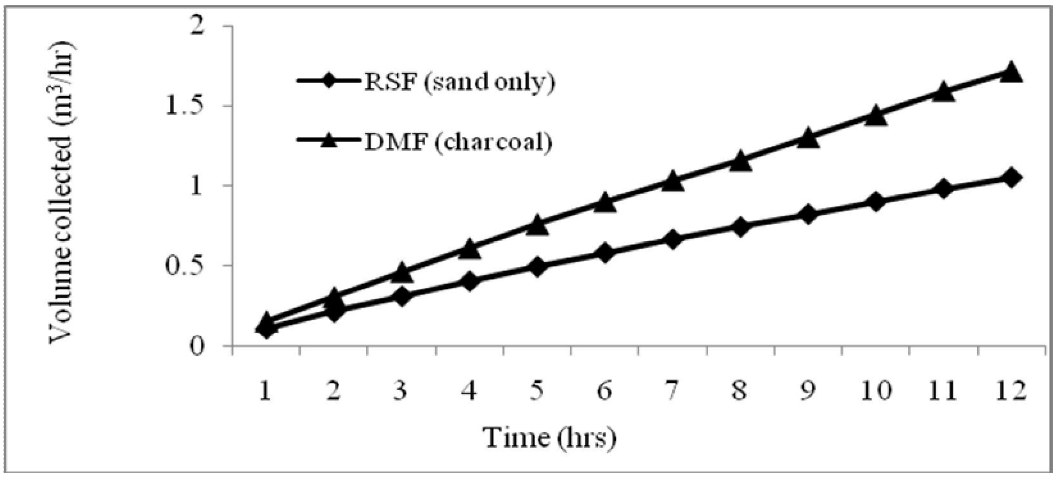

Fig. 10: Variation of the volume of water collected versus time (60-70 FTU)

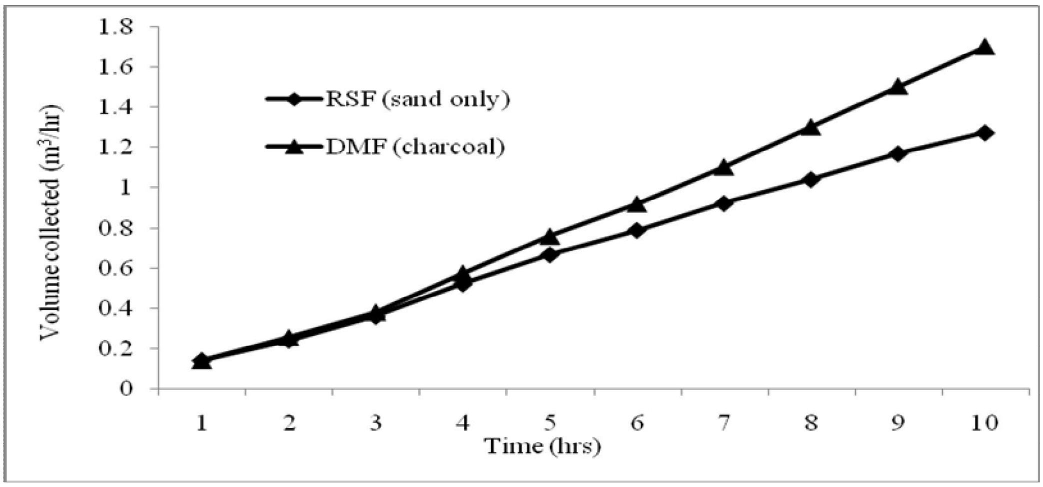

Fig. 11: Variation of the volume of water collected versus time (90-110 FTU)

Backwashing characteristics

The analysis of backwash rate was done by determining the variation of wash water turbidity with time as well as relating the bed expansion to the backwash rate.

The wash water turbidities in both filters were high at the beginning as a result of deep accumulation of particulates in the filter bed as shown in Fig. 8. It was noted that about 86% of the accumulated materials was washed away within the first four minutes of backwashing.

The variation of bed expansion with backwash rate is shown in Fig.9. A direct observation from Fig. 9 is that the DMF had higher bed expansion rate of about 40% than the RSF. This was due to the lower density of charcoal in comparison to sand resulting in the DMF bed being easily fluidized.

Volume of water filtered

Results for the volume of water collected after passing through each of the two columns of filter media over time are shown in Figs. 10 and 11. The volume of filtered water collected after 10hrs in the turbidity dosage of 60-70FTU was 0.9m^3 for RSF, while in the DMF it was 1.4m^3. At 90-110FTU, it was 1.3m^3 and 1.7m^3 respectively for the RSF and DMF. It can be inferred that the volume of filtered water collected from the charcoal DMF after 10hrs was about 1.3 times that of the conventional RSF for the same influent quality.

CONCLUSIONS

The analysis showed that the DMF exhibited higher removal capacity of 1.4 times that of the RSF. There was uniform turbidity removal throughout the RSF while most of the turbidity removal was done by the granular charcoal in the DMF. The length of filter run for the DMF was found to be 1.3 times the length of the filter run for the RSF. There was a good correlation between the extent of protection of the sand bed and the thickness of the charcoal layer. Thus the DMF attained head loss several hours after the RSF. The DMF absorbed a higher degree of particulates of the kaolin influent than the RSF. This was due to the fact that the activated charcoal used had more cavities, hence accumulated more dirt compared to sand. Due to the lower density of charcoal compared to sand, the DMF showed higher bed expansion. However, in general, the degree of bed expansion increased with increase in backwashing rate.

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