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A Comparative study of Anthracite and Gravel as Media in Up-flow Roughing Filter (URF) for Turbidity Removal

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Abstract
Roughing filter hinged with slow sand filter boons sustainable and reliable treatment process mostly applicable for underdeveloped countries. This research was carried out to study the comparative turbidity removal performance of anthracite and gravel media. Two Filter columns with $(230 \times 230 \times 1570)mm^3$ in internal dimensions were upright fixed, having an inlet at bottom so that filter can be run for up flow mode of operation. Filter models were operated around 200 NTU influent turbidity passing through gravel and anthracite media until maximum allowable head loss was reached. A set of experiment were carried at 1 m/h flow rate. A full length of 120 cm of media reduced 200 NTU influent to the effluent turbidity decreased from 48 to 21 NTU in gravel model and from 39 to 14.6 NTU in the anthracite model with average efficiency of 88.12% and that for gravel model was 86.03%. Head loss development rate for gravel model was 3.69 mm/h and that for anthracite model was 3.91 mm/h.

Keywords
Anthracite, Gravel, Turbidity, Roughing filter, Water treatment

1. Introduction

All forms of water available in nature is not fitted for drinking as it contains impurities in excessive amounts that can make people ill or make it unsuitable for direct uses for certain purpose. Surface water is occasionally the only available safe water source for rural as well as urban sectors. Typical problems faced can be developed due to high suspended solids, turbidity, coliform bacteria, agricultural runoff [1]. Thus, it is mandatory of supplying safe drinking water. The necessity of water purification was agreed by man at the very beginning of civilization.

[2] mentioned that the drinking water can be considered as the emblem of power separation. Thus, there is a demand for clean, unpolluted water in significant supply. As a result, a prerequisite of sustainable development must be obtained to ensure that sources of water such as streams, rivers, lakes and oceans are uncontaminated. More people pass away from unsafe water than from all types of violence, including war [3]. Water supplies continue to ruin because of source depletion and contamination, while demand is rising rapidly due to socioeconomic respects because population growth is tied with rapid unplanned trade and industry growth, automation and urbanization.

Rivers are a major source for drinking water supply. Important quality concerns for drinking water are physical quality such as the suspended solids (SS) content, the chemical composition and the bacteriological quality. SS cause turbidity and are undesirable in drinking water. SS interfere with disinfection during water treatment by creating an isolated housing for disease causing organisms. SS are also considered a major pollutant transporter for many toxic heavy metals, organic pollutants, pathogens and nutrients [4].

Roughing filtration (RF) is one of the possible systems for the treatment of water. Previous studies have shown that roughing filtration to be an effective and reliable technique for removing suspended solids, turbidity and coliform bacteria [5]. Roughing filtration provides superior treatment to basic sedimentation methods for suspensions with particulates that do not readily settle and represents an attractive alternative to more costly conventional coagulation methods. For suspensions with particulates that do not freely settle, this filtration offers superior treatment to basic sedimentation methods [6]. Thus, roughing filtration represents an attractive alternative to more expensive conventional coagulation methods. Roughing filters are primarily used to separate the water from the fine solids that are only partly retained, or not at all, by settling tanks.

2. Roughing Filter

Roughing filters are demarcated as filters with grain sizes larger than 2 mm [4]. There are various types of roughing filters such as downflow roughing filters (DRF), horizontal flow roughing filters (HRF) and up flow roughing filters (URF). Vertical-flow roughing filters work either as down flow or up flow filters. They are therefore either provided by inflowing water at the filter top or at the filter bottom. The vertical-flow roughing filter combines a simple, self-cleaning mechanism and occupies minimal floor space when equated to horizontal-flow roughing filters. The filter material of up flow roughing filters is completely submerged by a volume of water equating to a depth of 10 cm [5].

The use of multiple grades of filter media in a roughing filter encourages the penetration of particles throughout the filter bed and takes improvement of the large storage capacities offered by larger media and high removal efficiencies offered by small media. The size of filter media decreases sequentially in the direction of water flow, and ideally the uniformity of filter media fractions is maximized to increase filter pore space (storage capacity) and aid in filter cleaning [7].

3. Design Parameters of Roughing Filter

Filtration tests resulted that neither the roughness nor the shape or structure of the filter media have a great influence on filter efficiency. Gravel from a river bed or from the ground, broken stones or rocks from a quarry, broken burnt clay bricks, plastic material either as chips or modules, burnt charcoal and coconut fiber could therefore be used as filter media [8]. Recommended guidelines for roughing filter design are presented in Table 1.

Most of the solid matter is removed by the coarse filter fraction, the medium sized gravel has the polishing effect, and the finest gravel ought to remove only the remaining traces of solid matters. Therefore, individual filter lengths of roughing filters are often designed in a 3:2:1 ratio. Uniformity coefficient $C_u = \frac{d_{max}}{d_{min}}$ for roughing filter should be equal or less than 2 [6]. The filter bed is composed of different kinds of local materials in different layers placed in the order of decreasing sizes in the direction of flow. Upflow roughing filters are more competent in solid removal than other kinds of roughing filter [9].

Table 1: Recommended guidelines for up flow roughing filter design

References	Filtration rate (m/h)	Filter length (m)	Filtration media (mm)
Okun and Shulz (1984)	4 – 8	1.5 – 3	0.7 – 60
Galvis.et.al (1993)	0.3 – 0.75	0.85 – 1.25	1.6 – 19
Weigwlin (1996)	0.3 – 1	0.6 – 1	20 – 4
Brikke and Bredero	0.6	1.5	25 – 3

4. Turbidity as challenge

Turbidity is the major parameter, represents to water containing suspended matters or impurities that interferes with the light transmission through water. It reduces aesthetic acceptability, filterability and disinfection potential of drinking water. It is recommended that treated water turbidity to be less than 0.1 NTU prior to chlorination [10]. High residual turbidity in the treated water would promote the re-growth of pathogens in the distribution system. Turbidity removal is a major challenge in community water supply schemes where ground water, streams or river are the sources of supply. The ever–increasing deforestation in many catchments has increased the landslides and soil erosion problems tremendously, thereby causing highly turbid streams and rivers.

The major water quality problem in Nepal for surface sources is connected to seasonal features like in wet seasons the turbidity in these sources increases radically which cause poor implementation of such water supply schemes. NDWQS limits turbidity within range of 5 NTU in normal condition and 10 NTU when other sources are not available [11]. In Nepal, although the basic water supply coverage is 86.5% only 29.1% of population are in access of safe drinking water [12]. Finally, this research was conducted to study the comparative turbidity removal performance of anthracite model and gravel media model of up flow roughing filter in terms of turbidity removal, head loss and unit filter run volume.

5. Material and Methods

Two URF were constructed using fiber glass material $(230 \times 230 \times 1570)mm^3$ in internal dimensions. The laboratory models consist of clear water tank of 1000 liter capacity and a mixing tank (constant head tank) of 200 liter capacity. Raw turbid water flows from clear water tank to mixing tank through 20 mm diameter pipe. After sustaining constant head, the water was passed through the inlet of both models established with appropriate ball valves and sampling ports. Schematic diagram of filter models is presented in Figure 1. and media detail is presented in Table 2. The models were setup in TU, IOE, Examination Control Division premises.

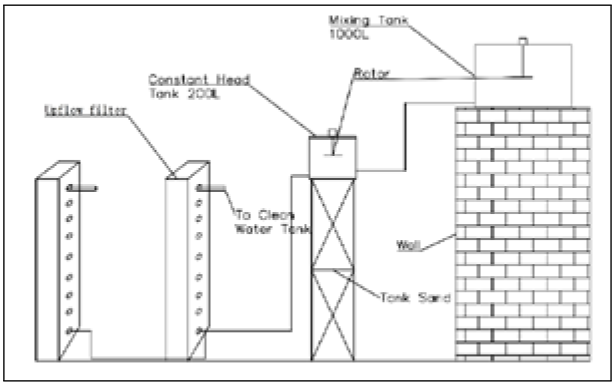

Figure 1: Schematic diagram of filter model setup

Table 2: Different media used in model

Category	Filter media size (mm)	Filter media depth (mm)
Media I	2 – 4.75	600
Media II	4.75 – 9.5	600
Base material	12.5 – 25	160

Filter media for this study had size between 9.5 – 2 mm diameter and required size was obtained by properly sieving. Both mediums were washed three times for removing mud and other organics attached with the media. In both the models, for base material aggregates used were of size ranging from 12.5 - 25 mm of 16 cm depth. Filter media used in gravel model consist of 2 - 4.75 and 4.75 - 9.5 mm diameter gravel and that used in anthracite model consists of 2 - 4.75 and 4.75 - 9.5 mm anthracite chips. All the sizes were achieved by properly sieving through standard sieve sizes (2, 4.75, 9.5, 12.5 and 25 mm). 20 mm diameter gate valves were used before the inlet zone in both models to control flow. There were 6 no of sampling ports each on both models excluding outlet ports placed 20 cm c/c in vertical direction and operated using 20 mm ball valves. Piezometer was connected in both models at separation of each layer of media to measure head loss occurred during operation. First sampling port was placed 16 cm above the base of filter and all others were placed at interval of 20 cm. 10 cm of clear water level was maintained in the up-flow filter and outlet was placed 10 cm above upper media. Fibre filter columns and washing of materials are shown in Figure 2 and Figure 3.

Figure 2: Filter columns

Figure 3: cleaning of Media

6. Operation and Test Procedure

The filtration rate was kept constant during each cycle which was obtained from the outlet discharge and the flow area. Operating in high rate causes poor effluent quality as well as a risk of turbidity breakthrough whereas low filtration rate increases the cost of production. Uniform turbidity of around 200 NTU was tried to maintain throughout the experiment, however it was difficult manually to do so. Hence a range from 150 NTU to 250 NTU was maintained to ensure uniformity throughout the experiment. A sets of the experiment were done at the rate 0.5 m/ h for ground water and 1m/h for artificial turbid water. In order to obtain desired rate, flow rate from constant head was controlled from gate valve and same rate was maintained on both the models using measuring cylinder and stop watch.

During the first run, both models were operated at 0.5 m/h flow rate and made to flow with natural ground water from tube well. Data were taken initially twice a day and consistency was maintained. After natural run, prepared turbid water was made to run on both models at same flow rate of 1.0 m/h and sampling was done every two hours. Sampling was done only after 15 seconds, to pass away accumulated solids at nozzle. Valves were opened slowly and drop wise sampling was done so as not to disturb the flow. The samples were collected in 100 ml bottles. Bottles were appropriately numbered, and sampling was done from both models at same time to maintain the same condition. Nephelometric turbidity meter manufactured by LUTRON ELECTRONIC ENTERPRISE CO., LTD. was used for the study. Section 2130 B, Standard Methods [13] was followed while measuring turbidity.

7. Results and Discussion

7.1 Effluent Turbidity during Filter Run

Two filter runs with loading of 1m/h for artificial turbid water were conducted. The influent turbidity was maintained around 200 (207.285 in average) NTU throughout the experiment. Effluent turbidity obtained by both filters at this flow rate is shown in Figure 4. From the results, it can be observed that the effluent turbidity was decreased with increase in filter run hours. This was due to occurrence of head loss increase with the increase in filter run time due to accumulation of deposits and constriction in the pores hindering the flow.

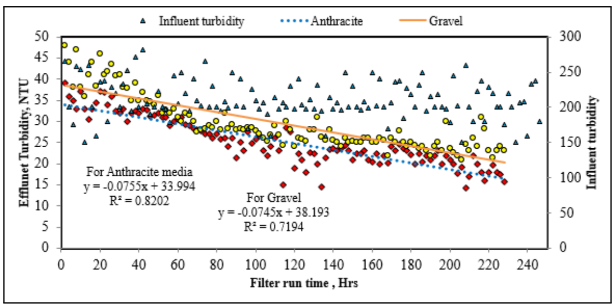

Figure 4: Turbidity vs Filter run time at 1.00m/h

At 1.00 m/h filter operation, the effluent turbidity was decreased from 48 to 21 NTU in gravel model and from 39 to 14.6 NTU in the anthracite model as shown in Figure 1. The time of termination of filter run was decided based on terminal head loss exceeding a certain specified maximum head. The average turbidity removal for anthracite was 88.12% and that for gravel model was 86.03 at 1 m/h flow rate.

7.2 Influence of Head loss on Effluent Turbidity

As presented in the Figure 4, which indicates effluent turbidity decreasing with filter run time, one of the key reasons for which is the rise in head loss. Basically, gradual improvement of turbidity removal efficiency with time or reduction in effluent turbidity with head loss is identical mechanism. Figure 5 shows the effect of head loss on effluent turbidity at 1.0m/h. From the results, with the increase in the filter run time solids are deposited in the pores or adsorbed on the grain surface, due to which pores are limited and flow needs to pass through smaller region and more energy is dissipated in the process which results increase in head loss. With increase in head loss with time, the turbidity in effluent water is decreased.

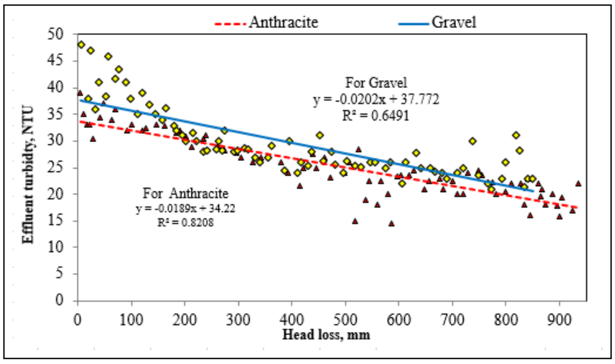

Figure 5: Effluent turbidity vs. Head loss

7.3 Head Loss Progress during Filter Run Time

During the first experimental run with natural ground water, development in head loss was not visible in both the models. Terminal head loss of 90 cm was allowable for both the filter models. In the entire flow rate Anthracite model attained the maximum allowable head loss earlier than that of gravel model. Figure 6 shows relationship between head loss and corresponding filter run time at filtration rate 1.0 m/h filtration rate. Head loss occurred in similar manner in both filter models. At 1.0 m/h head loss development was seen from the beginning. However, head loss development rate was higher on anthracite model than that of gravel model. Head loss development rate for gravel model was 3.69 mm/h and that for anthracite model was 3.91 mm/h. During the experiment, head loss development in middle and upper layer was not seen. Major portion of turbidity in both models were disbursed at base layer.

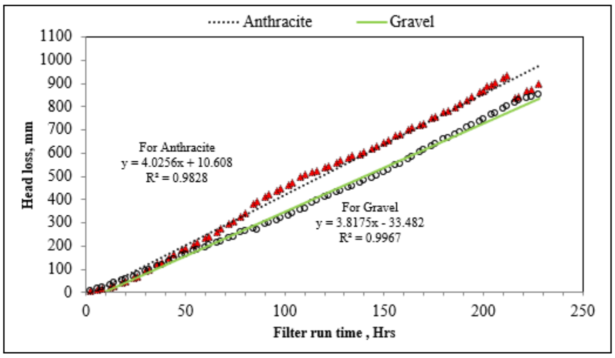

Figure 6: Head loss vs. filter run time at 1.00m/h

7.4 Turbidity Removal Profile Along Filter Media Depth

The total length of media was 120 cm with two categories, media I of depth 60 cm and media II of depth 60 cm. Influent turbidity was maintained uniform around 200 NTU all throughout the experiment. Base layer was of same media and of same size for both models. Figure 7 shows turbidity removal along filter length at 1 m/h.

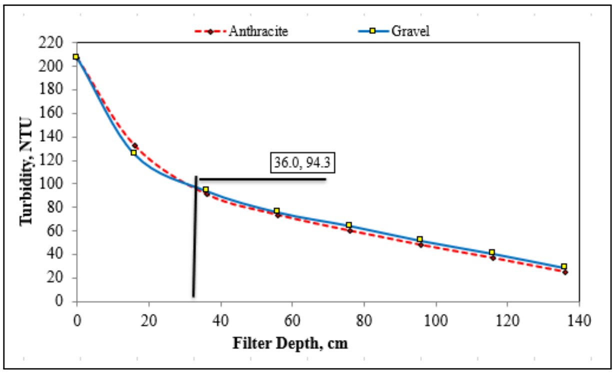

Figure 7: Turbidity Removal profile along filter depth at 1 m/h

Results showed that the removal of turbidity was high in coarse fraction and decreased gradually towards outlet. Up to filter depth 36cm, rate of compensating turbidity was less in anthracite model, above 36 cm its consuming rate of turbidity was more in anthracite model at flow rate 1.0 m/h. The anthracite media model slightly surpassed gravel model in terms of turbidity removal. Anthracite model surpassed the gravel model by 4.319 NTU in average throughout the experiment at 1.0 m/h.

7.5 Unit Filter Run Volume (UFRV) With Varying Filtration Rate

Another good way to compare filter runs is by using Unit Filter Run Volume (UFRV) technique (EPA, 1995). The UFRV is the volume of water produced by the filter during filter run divided by surface area of filter, expressed in ms/m^2. UFRV for gravel media filter was $246m^3/m^2$ and that for anthracite media filter was $228m^3/m^2$ at 1.0 m/h. Result shows that more volume of water can be treated by the gravel model.

8. Conclusion

This research was aimed to perform relative study of mono filter using gravel and anthracite to determine the effectiveness of anthracite in turbidity removal in the UGF. Based on the results obtained, following conclusions have been made:

- Head losses in URF during operation are inversely proportional to flow rate and directly proportional to influent turbidity. Head loss development rate for gravel model was 3.69 mm/h and that for anthracite model was 3.91 mm/h. During the experiment, head loss development in middle and upper layer was not seen. Head loss development rate in anthracite model was slightly greater than that of gravel model. In terms of head loss, gravel model was surpassed than anthracite model.
- Depth of filter media required to reduce turbidity to desired level is directly proportional to the filtration rate. At 1.00 m/h filter operation, a full length of 120 cm of media reduced 200 NTU influent to the effluent turbidity decreased from 48 to 21 NTU in gravel model and from 39 to 14.6 NTU in the anthracite model with average efficiency of 88.12% and that for gravel model was 86.03%. The anthracite model has more efficiency than gravel model which refers the anthracite model can be preferred regarding the effluent turbidity.
- Major portion of turbidity in both models were spent at base layer. The head lost during

operation can be recovered through back-flushing periodically. So, back-flushing results in extending the URF runs. UFRV for gravel media filter was on higher side with maximum of $246m^3/m^2$ and that for anthracite media filter was $228m^3/m^2$ at 1.0 m/h. This shows that more volume of water can be treated by the gravel model.

9. Limitations of Research

This study was limited to lab pilot model. Grain sizes of both media were limited from 2mm to 9.5 mm. Inlet concentrations of sediments was ignored.

Acknowledgments

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