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Performance of a Laboratory Scale Iron Removal System for RUET

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Abstract

Iron contamination in groundwater is a significant problem in many areas, including Rajshahi, Bangladesh. Rajshahi University of Engineering & Technology (RUET) faces the challenge of providing clean supply water to its students and staff due to the presence of high iron in its deep pumping water. This study focuses on the design and performance testing of a laboratory-scale iron removal system by the up-flow filtration technique. The aim of the study is to investigate the effectiveness of the up-flow filtration set up using different filter media combinations with their characteristics (type, depth and size) in removing iron from deep groundwater. The experimental set up consists of a laboratory scale column shape set up with the dimension of 12″x12″x42″ was prepared with a stainless-steel sheet, PVC pipe, water tape, glass, plastic, measurement tape, a perforated tank and an overhead water tank. In order to judge the performance of up-flow filtration system, water quality parameters such as iron concentration and turbidity were selected in this study. The study results showed that the filter media combination of fine sand (0.15-0.45 mm), Granular Activated Carbon (0.6-2.36 mm) and medium gravel (2.36-4.76 mm) was found most effective for removing iron and turbidity up to 97.85% and 96.28% respectively from the groundwater sample. The findings of this study provide information on effective filter media characteristics such as type, depth, and size and demonstrate that a laboratory-scale up-flow filtration system is an effective method for removing iron and can potentially serve as a foundation for the development of larger-scale filtration systems.

Keywords: *Groundwater, iron removal, up-flow filtration, turbidity removal, filter media combination.*

1 Introduction

Access to clean and safe drinking water is of paramount importance for human health and well-being (Barloková, D et al., 2010). However, water sources often contain contaminants that can compromise its quality (Mohammadi et al., 2020). Among these contaminants, elevated levels of iron and turbidity pose significant challenges, as they can affect water aesthetics, taste, and potentially pose health risks. Groundwater with a high iron content clogs up distribution systems, shortens the lifespan of large appliances, and requires more energy to pump water through clogged pipes (Moser et al., 2021). Therefore, efficient water treatment methods are necessary to address these issues and ensure the provision of high-quality drinking water.

There are several methods available for water filtration, each with its specific application and efficiency. These methods include conventional filtration (e.g., rapid sand filtration), membrane filtration (e.g., microfiltration, ultrafiltration, reverse osmosis), granular media filtration (e.g., multimedia filtration, dual media filtration), and up-flow filtration (e.g., up-flow filtration with various media types) (Khatri et al., 2017). Each method employs different mechanisms and operational parameters to achieve water purification.

Up-flow water filtration has gained recognition as a promising technology for the removal of iron and turbidity in water treatment processes. This innovative approach offers several advantages over conventional filtration techniques, such as improved performance, reduced operational costs, and enhanced ease of maintenance. By utilizing the upward flow of water through the filtration media, up-flow filtration allows for more effective contaminant removal and reduced media fouling. These advantages make up-flow filtration a compelling solution for iron and turbidity removal in water treatment. The Up-flow design is good because it offers relatively more time to filter the water than the down flow which is little bit faster(Stephen Siwila et al., 2017).

Since numerous iron and turbidity removal systems exist, as previously said, using the best and most economical design would solve the problem by lowering iron and turbidity concentrations. The most effective design will be determined by its efficiency, affordability of materials, and ease of construction. The up-flow filter eliminates the problem of filter clogging, which affects performance and is a flaw in all current filtering techniques. As a result, maintenance expenses are lower than with downward flow filters. With this filter design, there is also no need for a power source at each installation location. This filtration technique uses no chemicals at all. It operates on the basis of the reverse osmosis idea.

The purpose of this study is to create various filter media combinations for the selection of a suitable one while constructing an up-flow filter set up to remove iron and turbidity from groundwater. Additionally, it focuses on analyzing how well certain filter media combinations function in the up-flow filtration system.

2 Methodology

2.1 Design and preparation of iron removal system:

Laboratory tests were conducted on an up-flow filtration set up consisting of 12" x 12" x 42", consisting of SS sheet, glass, plastic, PVC pipe, water tap, measuring tape, perforated disk, and overhead tank.

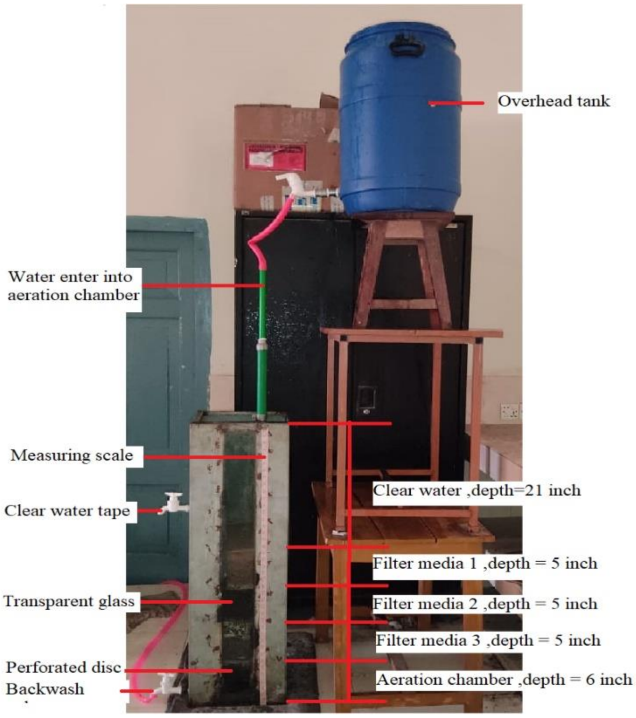

Figure 1. Design and Experimental set up of up-flow filtration unit

2.2 Experimental set up:

The up-flow filtration system consists of:

- An overhead tank (capacity 20 liters).
- A 50 mm diameter PVC pipe flowing water from the overhead tank to the aeration chamber.
- A 50 mm diameter backwash valve connecting to an outlet.
- An Perforated disk made of steel.
- Filter media 1 (depth 127 mm).
- Filter media 2 (depth 127 mm).
- Filter media 3 (depth 127 mm).
- Geotextile between each layer to prevent mixing of filter medias.
- A 50 mm diameter pipe connecting to an outlet for clear water (diameter 50 mm).
- A 380 mm depth at the top of the system to store clear water

Table 1: Filter media combinations

Combinations	Filter media 1	Filter media 2	Filter media 3
Combination 1	Fine sand (0.15-0.45) mm Depth 127 mm	Granular Activated Carbon (0.6-2.36) mm Depth 127 mm	Medium gravel (2.36-4.76) mm Depth 127 mm
Combination 2	Fine sand (0.15-0.45) mm Depth 127 mm	Zeomangan (2.00-4.00) mm Depth 127 mm	Coarse gravel (4.76-9.51) mm Depth 127 mm
Combination 3	Fine sand (0.15-0.45) mm Depth 127 mm	Granular Activated Carbon (0.6-2.36) mm Depth 127 mm	Zeomangan(2.00-4.00) mm Depth 127 mm

2.3 Sample collection and testing:

Water samples were collected from two source points to identify the iron level fluctuation. These are

(i) Withdrawal point of groundwater when the pump is running.

(ii) Water from laboratory tape flowing from overhead tank.

2.4 Methods:

An up-flow filtration system was used in this study to remove turbidity and reduce Iron (Fe) concentration. Since the water from the RUET overhead tank had the highest iron concentration, it was chosen for the filtration system. In order to determine the initial iron concentration and turbidity prior to filtration, the collected water sample was first tested in the RUET Environmental Engineering laboratory. It was then stored in the overhead tank of the up-flow filtration unit shown in figure 1. For three different combinations, same flow rates were applied.
For Combination 1, 2 &3:

Flow rate (Q) = $\frac{volume(v)}{time(t)} = \frac{500ml}{17sec}$ = 9.72 mL/sec =35 L/hour

After then, water was allowed to pass through the filtering medium. Various intervals were used to collect the filtered water from the filtration unit's upper outlet. Turbidity and iron concentration were tested in Environmental Engineering laboratory for the filtered water. For three distinct filter media combinations, this process was repeated. For all combination, filtered water was collected at 1, 2, 3, 5, 10, 15, 20, 30, 60 and 120-min intervals to identify the iron removal trend. Backwash was done to prevent clogging after the experiment. The removal efficiency of turbidity and Fe concentration was measured for all combinations using these equations,

Turbidity removal efficiency (%) = $\frac{Initial\ turbidity - Mean\ turbidity\ after\ filtration}{Initial\ turbidity} \times 100$ (1)

Fe removal efficiency (%) = $\frac{Initial\ Fe\ concentration - Mean\ Fe\ concentration\ after\ filtration}{Initial\ Fe\ concentration} \times 100$ (2)

Collected filtered water was tested in the RUET environmental laboratory. Water quality parameters such as turbidity and Iron (Fe) concentration were measured using TN 100 turbidity meter & DR 900 colorimeter.

3 Results & Discussions:

The collection of filtration data was conducted for 2 hours. Initial turbidity and Iron (Fe) concentration of raw water were 9.79 NTU and 1.07 mg/L for test 1, 12.12 NTU and 1.23 mg/L for test 2 and 12.12 NTU and 1.23 mg/L for test 3 respectively. According to W.H. Organization, the permissible limit of turbidity and iron(Fe) concentration are 5 NTU and 0.3 mg/L (WHO, 2011) respectively for drinking water.
Turbidity and iron (Fe) concentration of collected filtered water for both combinations are given below:

Combination 1:

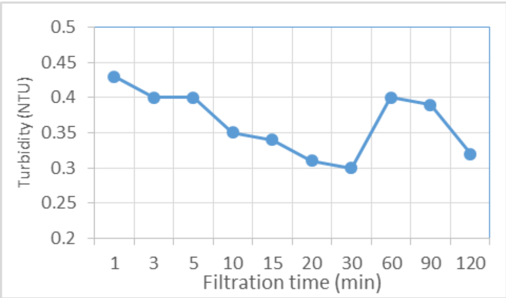

Figure 2. Turbidity with respect to filtration time

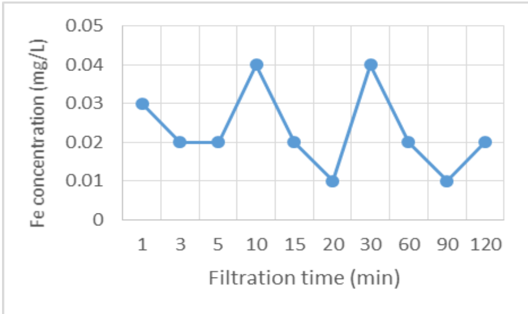

Figure 3. Fe concentration with respect to filtration time

Data collected from combination-1 shows abrupt turbidity and Iron (Fe) concentration changes. After Starting data collection there was a rise in turbidity from (30-60)min. Again from (5-10) min & (20-30) min there was also a rise in the iron (Fe) concentration which was unusual and it was due to the distance of outlet valve from the filter bed which was later reduced.

Turbidity removal efficiency (%) $= \frac{Initial\ turbidity - Mean\ turbidity\ after\ filtration}{Initial\ turbidity} \times 100$

$$= \frac{9.79 - (\frac{0.43+0.40+0.40+0.35+0.34+0.31+0.30+0.40+0.39+0.32}{10})}{9.79} \times 100$$

=96.28%

Fe removal efficiency (%) $= \frac{Initial\ Fe\ concentration - Mean\ Fe\ concentration\ after\ filtration}{Initial\ Fe\ concentration} \times 100$

$$= \frac{1.07 - (\frac{0.03+0.02+0.02+0.04+0.02+0.01+0.04+0.02+0.01+0.02}{10})}{1.07} \times 100$$

= 97.85%

Combination 2:

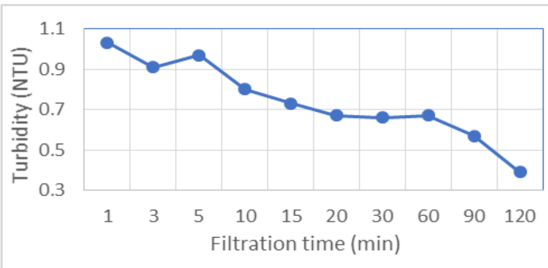

Figure 4. Turbidity with respect to filtration time

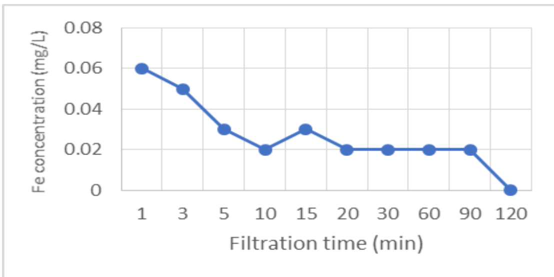

Figure 5. Fe concentration with respect to filtration time

Data collected from combination-2 also shows sudden rise of turbidity within (3-5) min and iron (Fe) concentration within (10-15) min after the first sample data collected. It was due to clogging in the filtration unit (Thinojah et al., 2020) which was later cleaned by backwashing.

Turbidity removal efficiency (%) $= \frac{Initial\ turbidity - Mean\ turbidity\ after\ filtration}{Initial\ turbidity} \times 100$

$$= \frac{12.12 - (\frac{1.03+0.91+0.97+0.80+0.73+0.67+0.66+0.67+0.57+0.39}{10})}{12.12} \times 100$$

=93.89%

$$\text{Fe removal efficiency (\%)} = \frac{Initial\ Fe\ concentration - Mean\ Fe\ concentration\ after\ filtration}{Initial\ Fe\ concentration} \times 100$$

$$= \frac{1.27 - \left(\frac{0.06+0.05+0.03+0.02+0.03+0.02+0.02+0.02+0.02+0.00}{10}\right)}{1.23} \times 100$$

=97.805%

Combination 3:

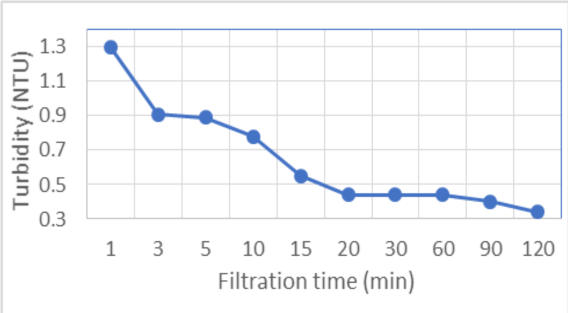

Figure 5. Turbidity with respect to filtration time

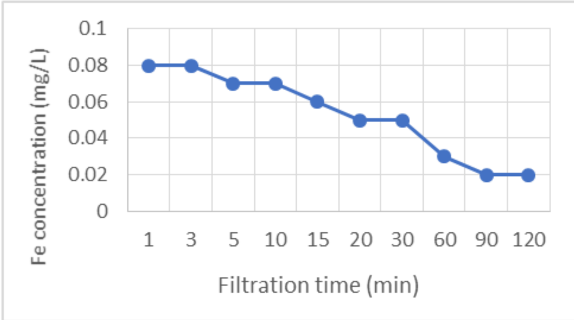

Figure 6. Fe concentration with respect to filtration time

The above figures showed consistent results because the distance of the outlet valve from the filter bed was reduced significantly and there was no clogging in the filtration unit. The results of combination 3 are more stable than combination 1 & 2 as it indicates a downward movement.

$$\text{Turbidity removal efficiency (\%)} = \frac{Initial\ turbidity - Mean\ turbidity\ after\ filtration}{Initial\ turbidity} \times 100$$

$$= \frac{12.12 - \left(\frac{1.30+0.91+0.89+0.78+0.55+0.44+0.44+0.44+0.40+0.34}{10}\right)}{12.12} \times 100$$

=94.65%

$$\text{Fe removal efficiency (\%)} = \frac{Initial\ Fe\ concentration - Mean\ Fe\ concentration\ after\ filtration}{Initial\ Fe\ concentration} \times 100$$

$$= \frac{1.23 - \left(\frac{0.08+0.08+0.07+0.07+0.06+0.05+0.05+0.03+0.02+0.02}{10}\right)}{1.23} \times 100$$

=95.69%

The depth of each filter media was kept same for all three combination which was 127 mm. The filter set-up removed approximately 96.28% and 97.85% of the turbidity and iron (Fe) concentration, respectively for combination-1. Using combination-2, the turbidity and iron (Fe) concentration were removed at approximately 93.89% and 97.805% respectively. It indicates that Granular Activated Carbon performs slightly better than zeomangan in case of turbidity and iron (Fe) removal if all other factors remain same. After filtration using combination-3, the turbidity and iron (Fe) concentration were removed at approximately 94.65% and 95.69% respectively. It was found from the result that Granular Activated Carbon works better with medium gravel than Zeomangan.

So, comparing all three combinations with each other, combination-1 achieves the highest turbidity and iron (Fe) removal efficiency among them.

4 Conclusions

The study aimed at designing a laboratory scale up-flow filtration system for removing iron from RUET deep pumping water. Study conclusions were drawn following:
(i) Filter media combination-1 prepared by fine sand, Granular activated carbon, and medium gravel layer showed the maximum performance for turbidity and iron removal efficiency which is 96.28% and 97.85%, respectively.
(ii)The Up-flow design is good because it requires no electricity for operating the test which is economical.
(iii) The distance of the outlet pipe from the filter bed is an important factor for obtaining higher efficiency. The lesser the distance, the higher the efficiency.

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