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Fabrication of rapid sand filter for water treatment using sand and activated carbon

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Abstract

It is pertinent to provide safe drinking water to the people as quality of water keeps deteriorating. According to World Health Organization (WHO), water and hygiene are the primary drivers of public health. Filtration is a water treatment process used for removal of microorganisms and colloidal matters from raw water, therefore this study aims at comparing the effects of sand and activated carbon when used separately in rapid sand filters for water treatment. Fabrication of two models of the rapid sand filters were carried out with 1.2mm stainless steel plates. One of the filters was loaded with gravel (grain size 5mm) at the bottom and this was followed by coarse sand (grain size 3mm) and fine sand (grain size 1mm) at the top. The second filter was loaded with gravel at the bottom and this was followed by coarse sand, fine sand and capped with activated carbon. Raw water, obtained from borehole was stored in a tank and made to pass through each of these filters independently. Sample of the raw water was collected for laboratory analysis in addition to samples of the treated water from each of the two rapid sand filters. The outcomes of the tests reveal that the filtration processes had positive impact on the raw water but the filter capped with activated carbon produced better quality water. The use of activated carbon as the topmost material in a rapid sand filter is recommended as it enhances the quality of treated water in parameters such as colour, conductivity, chloride, hardness, sulphate, total dissolved solids, sodium, magnesium, iron and total plate count. The rapid sand filters would afterwards be used for students' practical to explain filtration as a water treatment process.

Keywords: Filtration; Raw water; Treated water; Colloidal matters; Conductivity; Total dissolved solids

1. Introduction

Water is essential to living things. Safe water and sanitation are the primary drivers of public health (Hooijmans, n.d.). Without water, there would be no life on earth. No water is completely pure in its raw or natural state. Water needs to be purified before drinking. Exposure to bacterial pathogens in unsafe water constitute a major risk to health in several communities in developing countries around the world (Jenkins, 2011). Filtration is a water treatment process used in removing suspended particles, precipitated natural organic matter, hardness and microorganisms from water. Rapid sand filters (RSF) are known as mechanical filters because supplementary equipment like pumps and compressors are required to perform some operations of the system. They are mostly employed in today's contemporary municipal water treatment plants (Isah et al., 2022). Granular media is commonly used as filters for potable water treatment. Water is passed through the filter either by gravity flow or by pressure. When water flows through permeable medium such as sand, some of the suspended and colloidal impurities in the water are left behind in the pores or upon the medium itself. This process of separating impurities from the carrying liquid is called filtration (Vazirani et al., 2017). The type of granular media, size, shape and depth determine pore volume, pore size and pore distribution. This affects solid holding capacity, head loss characteristics, filtrate quality and backwash flow requirement. The performance of the filter depends on the rate of filtration. Water passes through the filter by gravity at a rate of 5-25m/h. Backwashing at regular intervals is important to maintain optimum effluent quality as well as to prevent gradual deterioration of the media and eventual replacement. Between 10% and 15% of the filtered water is utilized in the backwashing process of

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RSF (Beshr et al., 2022). Sufficient pretreatment and screening of larger particles are necessary for better filter performance. Two types of filtration are applied for water filtration namely: rapid sand filtration and slow sand filtration. Rapid sand filtration is a more common filter operation for treating water. During the flow when the filters are full of trapped solids, they are backwashed. Here, clean water and air are pumped back up the filter to dislodge the trapped impurities, and the backwash is pumped out as waste (Rahman, 2021).

1.1. Problem Statement/Justification

The justification for this research are based on the following:

- The need to ensure availability of wholesome water at all times;
- The need to enhance the filtration process for performance improvement;
- The need to train civil engineering students in the area of welding, plumbing and operations of rapid sand filters for water purification.

Objectives of the Study

The objectives of this research include:

- Comparing the effects of sand and activated carbon when used separately in rapid sand filters for water purification;
- Improving filtration technologies in order to make them more sustainable and accessible;
- Exposing students to filtration method of water treatment using prototype water filters;
- Training students with practical work**.**

2. Literature review

Sand filters are used globally for domestic purposes and have been shown to be very effective in controlling microorganisms in water (Abdul, et al., 2018). Sand filters are also able to remove solids from raw water. The evolution of rapid sand filters dates back to the 19th century in the United States of America and has been widely accepted for municipal application because of its high efficiency and flexibilities in treating waters of different turbidities (Tate, 1980). By the 1920s, rapid sand filters were widely used as a major water purification method since necessary facilities required less land area compared to the slow sand filters (Rafi, 2012). Rapid sand filtration is a purely physical drinking water purification method. The filtering process is determined by two rudimentary physical principles. The first, known as mechanical straining involves relatively large suspended particles getting stuck between the sand grains as they pass the filter medium. The second comprises smaller particles getting attached to the surface of the sand grains due to the effect of the van der Waals forces (Bruni, 2020). Coagulants, flocculants or chlorine might be added to promote further adhesion (Bruni, 2020). Rapid sand filtration is highly effective in removal of turbidity, odour, taste and organic matter (Brikke, 2003).

Sand, crushed anthracite coal and granulated activated carbon are commonly used as filter media. Capping is a process in which the upper sand layer in the rapid sand filter is replaced with other materials such as Polyvinyl chloride (PVC) granules, anthracite coal, bituminous coal, broken brick etc. (Sabale, 2014). Activated carbon is sometimes used in filter as an adsorbent of organic compounds thus, resulting in reduction of taste and odour. In a modified rapid sand filter where PVC granules and ferric chloride were used as capping materials, lower turbidity and total dissolved solids were achieved (Bibhabasu, 2017 and Sabale, 2018). When coconut shell was used in a filtration media, the results show 90% reduction in turbidity, 89% decrease in total solids and considerable decline in pH and biochemical oxygen demand (Singha, 2018). Activated carbon belongs to the charcoal family and consist of carbon, hydrogen and oxygen. The pH level of acidic waters was enhanced through the application of charcoal and the treated water qualified as drinking water by World Health Organization (W.H.O.) drinking water guidelines (Akinwunmi, 2022). Mechanical sand filters can reduce iron content in water by up to 99% (Hale, 1916).

2.1. Types of Filters

The various types of filters for water treatment are listed hereunder:

- Gravity vs Pressure
- Conventional vs Direct
- Rapid vs Slow

2.2. Theory of Filtration

Filtration is an important part of water purification process (Singh, 2012). Filtration is used for the removal of suspended matter and turbidity. It involves passing water through a thick layer of sand. During the passage of water through sand, the following things happen:

- A greater part of fine suspended and colloidal matter present in water are removed
- There is a change in the chemical characteristics of water
- The number of microorganisms is significantly reduced

Filtration can be described on the basis of the following actions (Singh, 2012):

- *Mechanical straining*: Sand consists of small voids. Water that is unable to pass through the voids gets trapped and removed through mechanical straining.
- *Sedimentation*: The spaces between the sand particles act as small sedimentation basins. The particles of impurities settle in these spaces due to physical attraction between the impurities and sand particles. Previously caught microorganisms and colloidal matter can also lead to the formation of gelatinous coating on the sand particles.
- *Biological metabolism*: This is the development of life process of the living cell. When water is passed through voids in the sand particles, the microorganisms are caught in the voids leading to the formation

3. Methodology

3.1. Study Area

The study area is the permanent site of Federal Polytechnic, Ile-Oluji, Ondo State, located at Kilometer 13 Ondo/Ipetu-Ijesa expressway, Ile-Oluji. Ile-Oluji is the headquarters of Ile-Oluji/Okeigbo Local Government Area in Ondo State, Nigeria. The fabrication was carried out at the Engineering workshop located near the School of Engineering building of the Polytechnic.

3.2. Materials

The following materials were procured for the fabrication of the two filters including plumbing works and consumables for the operations of the filters:

Fabrication materials	Plumbing materials	Consumables
1.5mm stainless steel plates	Thick PVC pipe	Activated carbon (1 bag)
50mm stainless steel pipes	Ball gauge	1mm fine sand (3 bags)
2” drainage and stainless nipples	Tee	3mm coarse sand (2 bags)
2.5mm stainless electrodes	Elbow	5mm gravel (2 bags)
Bolt and Nuts	Union	
Welding rod	Male and female socket	
Cutting disc	Adaptor	
Grinding disc	Gum	
Non-corrosive liquid chemical	1hp surface pump	
	Plastic water tanks	

3.3. Fabrication

Two models of the rapid sand filters were fabricated from experimental point of view. One of the filters was packed with 1 bag of gravel (as base material), 1 bag of coarse sand and 2 bags of fine sand. For the modified filter, 1 bag of gravel (as base material), 1 bag of coarse sand, 1 bag of fine sand and 1 bag of activated carbon were used. The activated carbon was prepared from coconut shell. The difference in the operations of the two filters is mainly in the addition of activated carbon to the second filter.

For the experiment, one raw water sample was collected from the borehole serving the engineering workshop and taken for laboratory tests at Federal University of Technology, Akure (FUTA). All necessary precautions were taken to prevent contamination, including the use of sterilized bottles to collect water samples for the laboratory tests.

One water sample each was also collected from the two rapid sand filters after undergoing treatments. Tests performed on all the water samples (raw and treated) include colour, turbidity, conductivity, pH, chloride, hardness, sulphate, nitrate, total dissolved solids, sodium, magnesium, iron and total plate count. The results of the tests were thereafter thoroughly analyzed.



Figure 1 Welding of steel plates



Figure 2 Smoothening of the edges of plates



Figure 3 Filter tank covers



Figure 4 Adjusting water pressure



Figure 5 Loading granular media into tank



Figure 6 Fabricated steel tank



Figure 7 The two filters with their respective treated water tanks Left side: Tank containing sand; Right side: Tank containing activated carbon

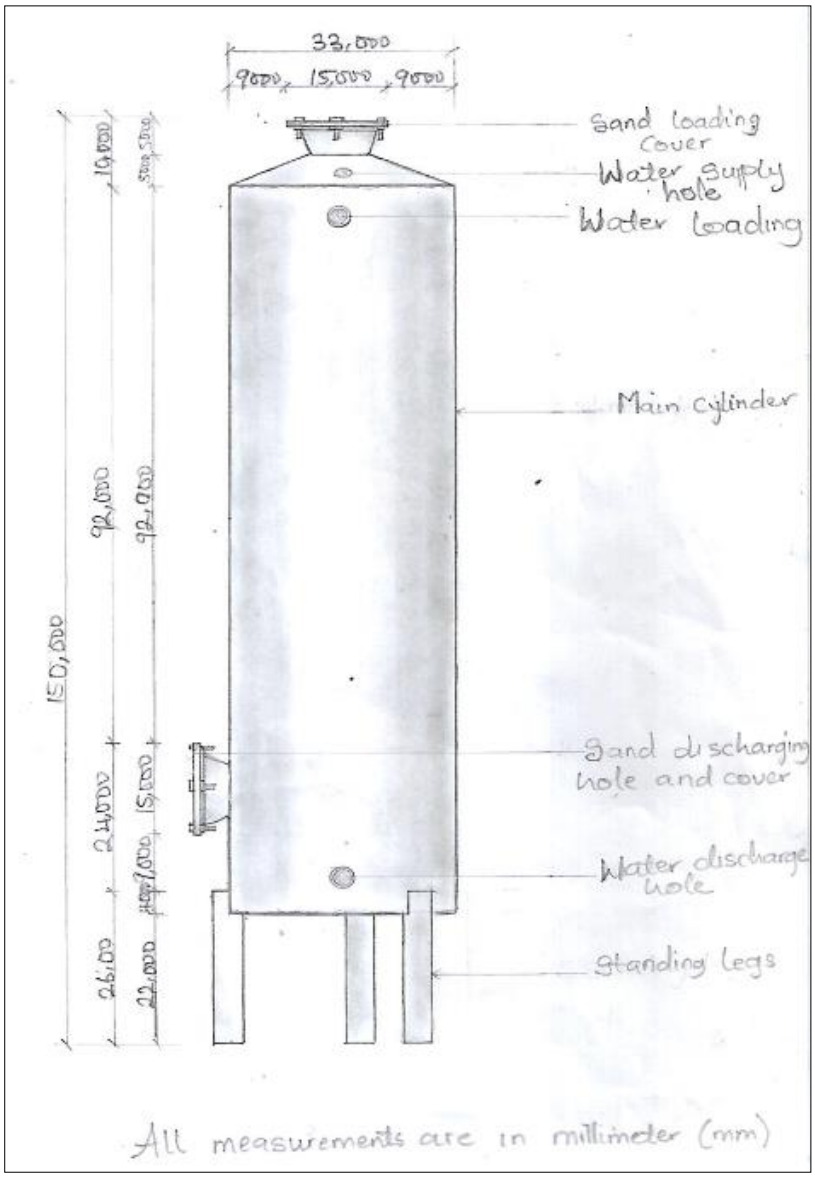

Figure 8 Schematic diagram of one of the fabricated filters

4. Results and discussion

Table 1 Results of Water Analyses

	Results			**Standard**
Parameters	**Raw Water**	**Treated Water (Sand Filter)**	**Treated Water (Carbon Filter)**	**NIS-554-2015**
Physical				
Colour (TCU)	1.21	1.17	0.93	3
Turbidity (NTU)	2.63	2.58	2.32	5
Conductivity (umhos/cm)	1.26×10^2	1.03×10^2	0.68×10^2	1.0×10^3
Chemical				

Ph	7.08	7.13	7.03	6.5 - 8.5
Chloride (mg/L)	56.8	56.8	45.2	100
Hardness (mg/L)	74	68	36	100
Sulphate (mg/L)	26.3	26.8	20.6	100
Nitrate (mg/L)	2.43	2.51	2.21	10
Total dissolved solids (mg/L)	142.8	126.4	97.2	500
Sodium (mg/L)	36.2	33.8	26.8	100
Magnesium (mg/L)	1.63	1.54	1.21	2
Copper (mg/L)	0.31	0.31	0.33	1
Zinc (mg/L)	2.46	2.36	2.33	5
Iron (mg/L)	0.18	0.21	0.16	0.3
Microbiological Aanalysis				
Total plate count (cfu/ml)	0.36×10^2	0.31×10^2	0.24×10^2	100

Table 2 Percentage efficiency of filters

Parameters	**% efficiency (sand filter)**	**% efficiency (carbon filter)**	**% efficiency of carbon filter over sand filter**
Physical			
Colour (TCU)	3.31	23.14	19.83
Turbidity (NTU)	1.90	11.79	9.89
Conductivity (umhos/cm)	18.25	46.03	27.78
Chemical			
Ph	-0.71	0.71	1.41
Chloride (mg/L)	0.00	20.42	20.42
Hardness (mg/L)	8.11	51.35	43.24
Sulphate (mg/L)	-1.90	21.67	23.57
Nitrate (mg/L)	-3.29	9.05	12.35
Total dissolved solids (mg/L)	11.48	31.93	20.45
Sodium (mg/L)	6.63	25.97	19.34
Magnesium (mg/L)	5.52	25.77	20.25
Copper (mg/L)	0.00	-6.45	-6.45
Zinc (mg/L)	4.07	5.28	1.22
Iron (mg/L)	-16.67	11.11	27.78
Microbiological Analysis			
Total plate count (cfu/ml)	13.89	33.33	19.44

5. Discussion

Several physical, chemical and microbiological parameters were examined. As shown in Table 1, the turbidity of the raw water was 2.63 NTU, whereas turbidity of filtered water with sand was 2.58 NTU and that of filtered water with activated carbon was 2.32 NTU. The rapid sand filter capped with activated carbon was found to be more effective in colour removal (representing 23% reduction) when compared with the one loaded with sand only (representing 3% reduction).

There were clear improvements in the water quality after undergoing the filtration processes from both rapid sand filters with the various parameters having values within the Nigerian Standards for Drinking Water Quality. However, the filtration tank capped with activated carbon had the better drinking water quality of the two filters.

Correlation analysis was carried out on the laboratory results obtained for the raw water, filtered water with activated carbon and filtered water with sand as depicted in Tables 3, 4 and 5 respectively.

Table 3 Symmetric measures for raw water vs treated water (carbon filter)

		Value	**Asymp. Std. Error[a]**
Interval by Interval	Pearson's R	0.983	0.008
Ordinal by Ordinal	Spearman Correlation	0.993	0.009
N of Valid Cases		15	

Interpretation: The correlation coefficient describes not only the magnitude of correlation but also its direction. Thus, from the above table, +0.983 mean that correlation is high and positive because the sign of r is + and the magnitude of correlation is 0.983. Summarily, there is high and positive correlation between Raw Water and Treated Water (Carbon Filter).

Table 4 Symmetric measures for raw water vs treated water (sand filter)

		Value	**Asymp. Std. Error[a]**
Interval by Interval	Pearson's R	0.997	0.001
Ordinal by Ordinal	Spearman Correlation	0.996	0.007
N of Valid Cases		15	

Interpretation; The correlation coefficient describes not only the magnitude of correlation but also its direction. Thus, from the above table, +0.997 mean that correlation is high and positive because the sign of r is + and the magnitude of correlation is 0.997. Summarily, there is high and positive correlation between Raw Water and Treated Water (Sand Filter).

Table 5 Symmetric measures treated water (carbon filter) vs treated water (sand filter)

		Value	Asymp. Std. Error[a]
Interval by Interval	Pearson's R	0.988	0.007
Ordinal by Ordinal	Spearman Correlation	0.986	0.017
N of Valid Cases		15	

Interpretation: The correlation coefficient describes not only the magnitude of correlation but also its direction. Thus, from the above table, +0.988 mean that correlation is high and positive because the sign of r is + and the magnitude of correlation is 0.988. Summarily, there is high and positive correlation between Treated Water (Carbon Filter) and Treated Water (Sand Filter).

6. Conclusion

The usage of activated carbon as a capping material in filter tanks is beneficial for carrying out efficient filtration work. The capping material also helps to prevent the direct contact between sand and water. Results obtained from the laboratory analyses indicate that the filtration process is efficient in reducing turbidity, conductivity, hardness, total dissolved solids, sodium, magnesium, zinc and total plate count.

The second filtration tank (i.e. the one with activated carbon at the top), was found to be better for raw water conductivity reduction. It also had greater reduction in chloride, hardness, sulphate, total dissolved solids, sodium and magnesium when compared with the filter containing only sand media.

The filter capped with activated carbon was about 20% more effective than the one without activated carbon in total plate count reduction. It therefore shows its efficacy in bacteriological treatment.

Going forward, the two fabricated filtration tanks will be available for students for their practical works as part of their learning process.

Recommendations

The following recommendations are hereby made:

- For effective filtration processes, rapid sand filter media must contain activated carbon (or any of its variant)
- Backwashing process must be carried out regularly in order to sustain the quality of treated water from the filter
- One filtration tank can be used for the purpose of water purification (instead of two units in series) if it is capped with a carbon based material as this has been proven to be effective

Compliance with ethical standards

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Disclosure of conflict of interest

The writers affirm that there is no known conflict of interest in this research paper.

Statement of Informed consent

All authors gave their consent to participate in the study and also gave their consent to this publication.

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