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Evaluating the use of granular dual-media deep-bed filters for production of potable water

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Abstract
The objective of this study is to evaluate the use of granular dual-media deep-bed filters for production of potable water by applying filter materials (burnt oil palm kernel shell (BOPS) and sand) of varied proportions in assessing the effects of variations of influent raw water turbidity, filter media and flow rates on filtrate quality. Experiments were conducted to evaluate the effects of variations of influent raw water turbidity, bed composition, and filtration rate on the performances of varied percentages of 75%, 50% and 25% sand of dual-media (sand and BOPS) rapid gravity filters on filtered water turbidity and headloss development. Sieve analysis was carried out to characterize both media and to determine their effective sizes and uniformity coefficients. Filtered water turbidity was recorded with time during each experiment. The filter was operated on the principle of constant flow rate and variable head loss mode. Fifty (50) litres of raw turbid water (10, 30, and 50 NTU) from a tank was passed through rotameter at different flow rates (36, 48, and 60 l/hr) per experiment. Results obtained indicate that all the filters are capable of producing water with acceptable turbidity (< 5 NTU as prescribed by World Health Organization Guidelines) when the turbidity of the influent water is 10 NTU. The 75% and 50% sand dual-media filters proved effective at filtration rates of 36 l/hr and 48 l/hr for influent turbidity of 30 NTU. The mathematical models formulated in this work could be used as design and management tools for development of new filtration plants and operation, including upgrading of existing plants.

Keywords: Burnt Oil palm Kernel Shell (BOPS), Dual-media Filter, Filtration Rate, Turbidity, Models

1. Introduction
The Engineering Industry has been faced with continuously increasing and sophisticated demands, which calls for the most efficient use of the available resources. (Anyata and Omotoso, 2007). The local material development constitutes a special opportunity within the development process of the economy. It is therefore, very important that the control and sourcing of the most, if not all the inputs to water production industry be generated locally (Aniekwu and Ogunje, 2002). The mechanisms involved in filter bed are straining, adhesion, sedimentation, inertial impaction, hydrodynamic dispersion, diffusion and interception (Metcalf and Eddy, 2003).

In this study, the focus is on particulate removal since it can act as housing and food sources for bacteria which potentially affect the health of consumers. Moreover, particulates may cause distribution systems fouling at high bacteria level and corrosion (Cheremisinoff, 2002).

In developing countries like Nigeria, treatment plants are expensive, the ability to pay for services is minimal and skills as well as technology are scarce. In order to alleviate the prevailing difficulties, approaches should focus on sustainable water treatment systems that are low cost, robust and require minimal maintenance and operator skills. Locally available materials can be exploited towards achieving sustainable and safe potable water supply. Dual and Mixed-media filters have gradually replaced conventional gravity sand filters in many treatment plants in developed countries (Hindricks, 1974; Al-Ani and Al-Baldawi, 1986; Culp, 1974). The idea behind these filters is that the lighter media of larger size occupy the upper layers of the filter, allowing greater penetration of the floc. Floc that escapes the upper layer is caught in the finer sand at the bottom of the filter (Schulz and Okun, 1984).

A typical granular media filter used in water treatment plants is either single or dual media. Although the existing granular media filters are sufficient to treat turbid water, discovering alternative filter media from local sources is also highly essential since it will help to reduce the cost of treatment, as it can be processed and produced locally.

In this work, palm shell is identified as a potential filter medium. Palm shell is well known as a local solid waste material which is abundantly available in the palm oil industry. An investigation of the effectiveness of using dual media of sand and burnt oil palm-kernel shell (**BOPS**) for water treatment was carried out in a laboratory using experimental pilot filters after sedimentation stage.

2. Methodology

2.1 Materials

The Burnt oil palm kernel shells (BOPS) were specially treated and prepared for use as filter media. Burnt oil palm kernel shells (BOPS) are prepared from oil palm fruit shells that are solid waste by-products from oil palm factories which are abundantly available. BOPS granules were prepared by burning oil palm shells in a furnace at about 300^{o}C without oxygen. The carbon material formed was then ground into granules and sieved to establish the particles size distribution curve in order to determine the effective size. Burnt oil palm shell (BOPS) and sand were graded into specific uniformity coefficient and effective sizes as required. The sand material was supplied by the Regional Water Quality Laboratory, Minna, under the Federal Ministry of Water Resources at the Niger River Basin Development Authority.

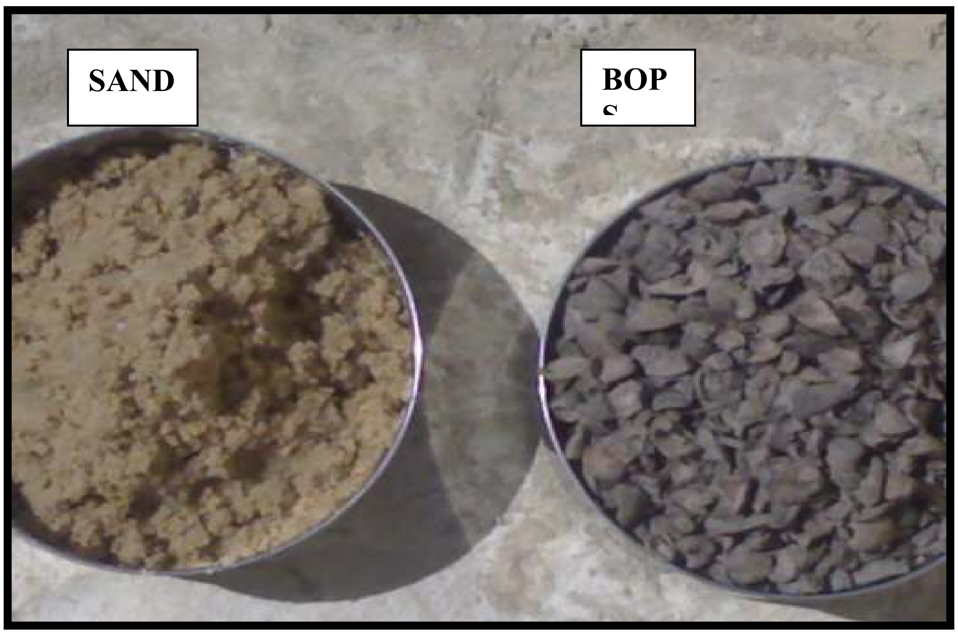

Fig. 1. Samples of Sand and Burnt Oil Palm Shell (BOPS)

Sand and the BOPS were backwashed thoroughly for a sufficient period of time after loading on the filter columns to clean the bed by removing particles of clay, dirt, etc. The process was continued until clean media and clear water was observed. Overall, there are six filters prepared for investigation: two each from BOPS/sand dual media filters of the different percentages of 50%-50%, 25%-75% and 75%-25% respectively.

2.2 Sieve Analysis

Sieve analysis consists of shaking a sample of 500 g (Sand or BOPS) using Endicot sieve shaker through a set of sieves (Camp, 2006), that have progressively smaller openings. Table 1 list the U.S. standard sieve numbers and the sizes of openings used during the analysis. First of all, a dry sample was taken and the lumps were broken into small particles before they were passed through the sieves. After shaking period about 25 minutes, the mass of sample retained on each sieve is measured using Sartorius BP301S precision balance. The results of sieve analysis are generally expressed in terms of the percentage of the total weight of sample that passed through different sieves.

Table 1. U.S. Standard sieve numbers and the sizes of openings

Sieve Number	Size Opening (mm)
14	1.41
16	1.19
18	1.00
20	0.84
25	0.71
30	0.50
40	0.42
45	0.35
50	0.297

2.3 Experimental Rig

An experimental rig was constructed in the laboratory as shown schematically in Fig.2. , Fig.3. and Fig.4. Tank T1 was used to collect the turbid water from surface water at three (3) different locations at Minna, Niger State, with different turbidities. The samples were agitated manually. After a sufficient period of time (about 30 min), large particles settled while the smaller ones remained suspended. Then, a quantity of the highly turbid water was transferred to the baffle feeding tank, T2, where the required turbidity was adjusted by addition of tap water and the amount was recorded.

A Perspex column (C1) of 1.5 m long and 7.62 cm internal diameter was used for dual media filter operation. This diameter was selected because wall effects are limited when the diameter of a filter is 50 times larger than the mean particle diameter (Prochaska and Zouboulis, 2003). The column was designed to operate as a gravity flow process with regulation valves to compensate for the increasing head loss thus maintaining a constant rate of flow.

The columns were filled with filter media via the media exchange port to fit 55 cm of media height, noting that under normal operation the media exchange ports should be closed. Each column contains two distributors: one at the top to distribute the water equally through the column section and also to prevent media loss under backwash; the other distributor which is fixed at the bottom and made from textile material acts to hold the filter media in place and to prevent sand leakage into the under drain system. Many valves were included in the experimental rig to control the system operation. Two calibrated rotameters were used for feeding water and air. Water rotameter, R1, had a scale that ranged from 0 up to 60 l/hr connected after valve V1. Air rotameter, R2, had a scale that ranged from 0.4 up to 1m^3/hr connected directly to the laboratory air supply system.

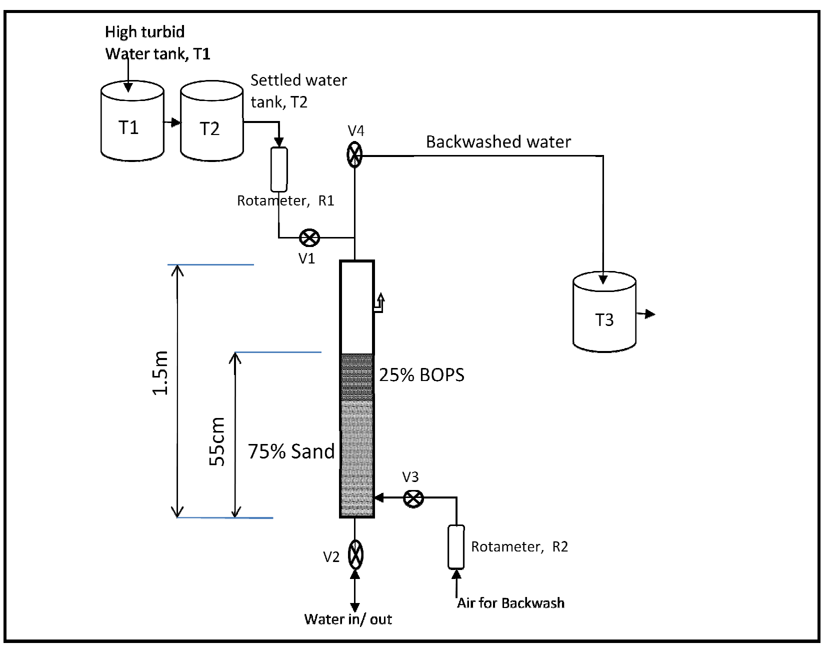

Fig. 2. Experimental rig for dual media filter of 25% BOPS and 75% Sand

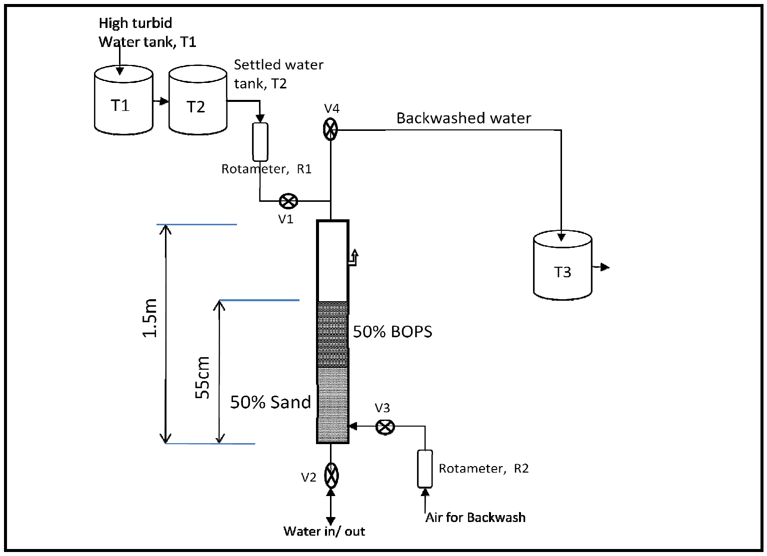

Fig. 3. Experimental rig for dual media filter of 50% BOPS and 50% Sand

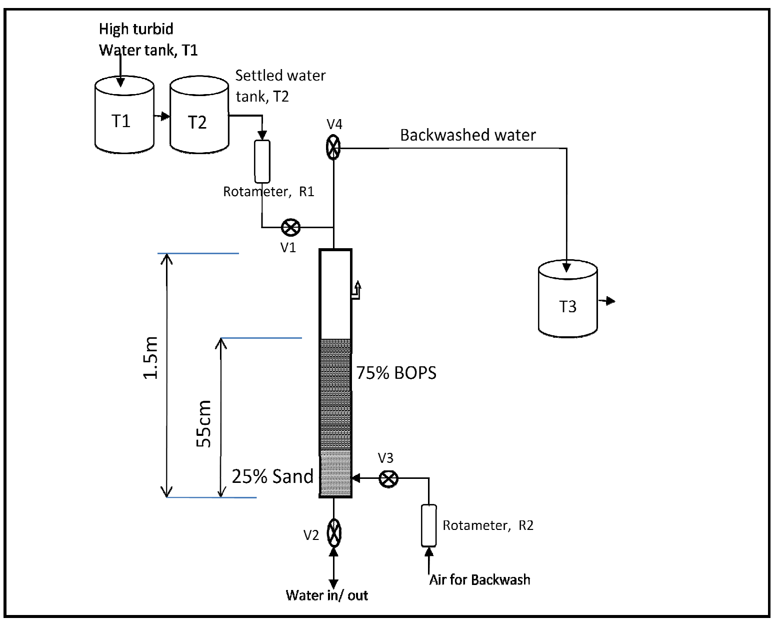

Fig.4. Experimental rig for dual media filter of 75% BOPS and 25% Sand

2.4 Normal Filter Operation

The filter was operated on the principle of constant flow rate and variable head loss mode. Fifty (50) litres of turbid water (10, 30, and 50 NTU) from tank T2 was passed through rotameter R1 at different flow rates (36, 48, and 60 l/hr) in each column per experiment. This quantity was selected experimentally and chosen to be the best value with respect to headloss development across the column. Turbid water was passed through the column and was distributed evenly through a clean media bed, starting the filtration operation. Filtered water then is collected from the bottom of the columns and discharged outside the system. Samples of the filtered water were collected periodically for turbidity measurements.

2.5 Filter Backwash

Filter backwash was accomplished by injecting tap water and air in the bottom of the columns at known flow rates (Fig 5a) controlling the fluidization level to be about 140-150% of the actual bed height.

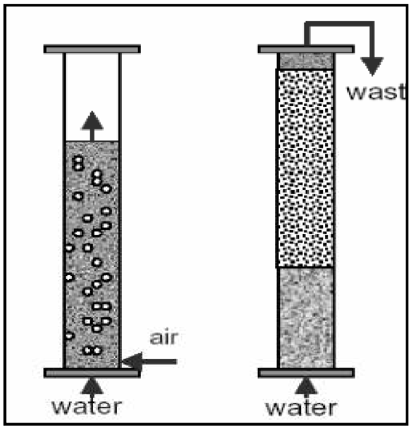

Fig.5. Backwash cycle**:**
(a) Air and sub-fluidization water injected to fluidize the bed.
(b) Fluidization with water injected to re-stratify the media.

This level seems to be sufficient to clean the filter and prevent media loss during backwashing (Kaeamura, 1999). The process started by injecting air only followed by sub-fluidization water. The process takes about 5 min and ends with the closing of the air stream followed by increasing of water stream flow rate to maintain the fluidization for about 1 min. This allows air bubbles within the bed to be expelled and to re-stratify the filter media (Fig.5b). The water stream then should be closed and the cycle finished with clean and well ordered media bed. Table 2 shows air and water flow rates applied during filter backwash for each filter type.

Table 2. Air and water flow rates for filter backwash

Filter media	**Air flow rate (m^3/hr)**	**Water flow rate (l/hr)**
Sand + BOPS (Dual Media)	0.4-0.6	250-260

2.6 Measurements

2.6.1 Turbidity:

Hach Model 2100A is a Laboratory Nephelometer used for turbidity measurement. The Turbidimeter has accuracy of $\pm$2% full scale error and less than one second response time. Samples were taken for measurement following the standard method.

2.6.2 Headloss:

Headloss development measurement was based upon the direct measurement of the water level over the filter media in fixed time intervals along the experimental duration using a meter rule. The recorded level had accuracy of $\pm$0.5 cm which was neglected with respect to the headloss.

3. Results and Discussion of Results

3.1 Sieve Analysis and Particle Size Distribution Curves

The geometric mean size, effective size (ES) and uniformity coefficient (UC) calculated from the sieve analysis for both sand and BOPS are tabulated in Table 3. The values listed fall within the desirable and usable parameter ranges for the dual media (Fair, et al., 1971 ; Visvanathan, 2004; Ekenta, 2007). The specific gravity and porosity are 2.6 and 0.4 for sand; 1.5 and 0.44 for BOPS respectively. The particle size distribution curves for Sand and BOPS are shown in Fig.6 and Fig.7 respectively. In the sieve analysis parameters curve, it was observed that both media cover a narrow range of particle sizes. This indicates that both sand and BOPS used during the experiments can be characterized as poorly graded media (Camp, 2006). It is evident that both media have good agreement with that desired (http://www.mcilvainecompany.com, Jan 2011).

Table 3. Sieve analysis parameters for Sand and BOPS

Parameter	**Sand**	**BOPS**
Geometric mean size, mm	0.615	1.360
Effective size, mm	0.51	1.000
Uniformity coefficient	1.427	1.487

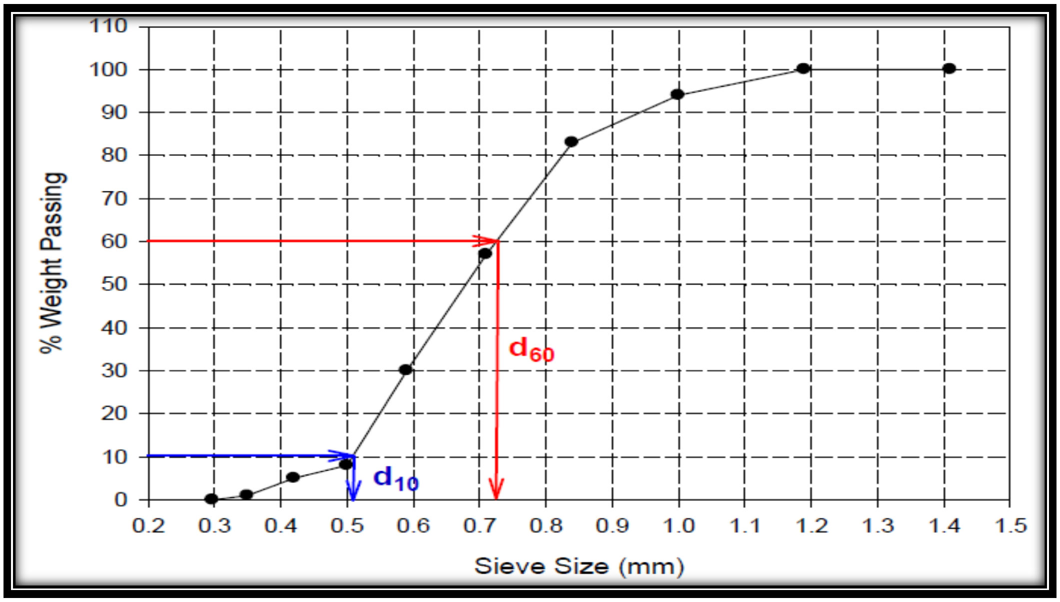

Fig.6. Size distribution curve for **Sand** at ES of 0.51 mm and UC of 1.43**.**

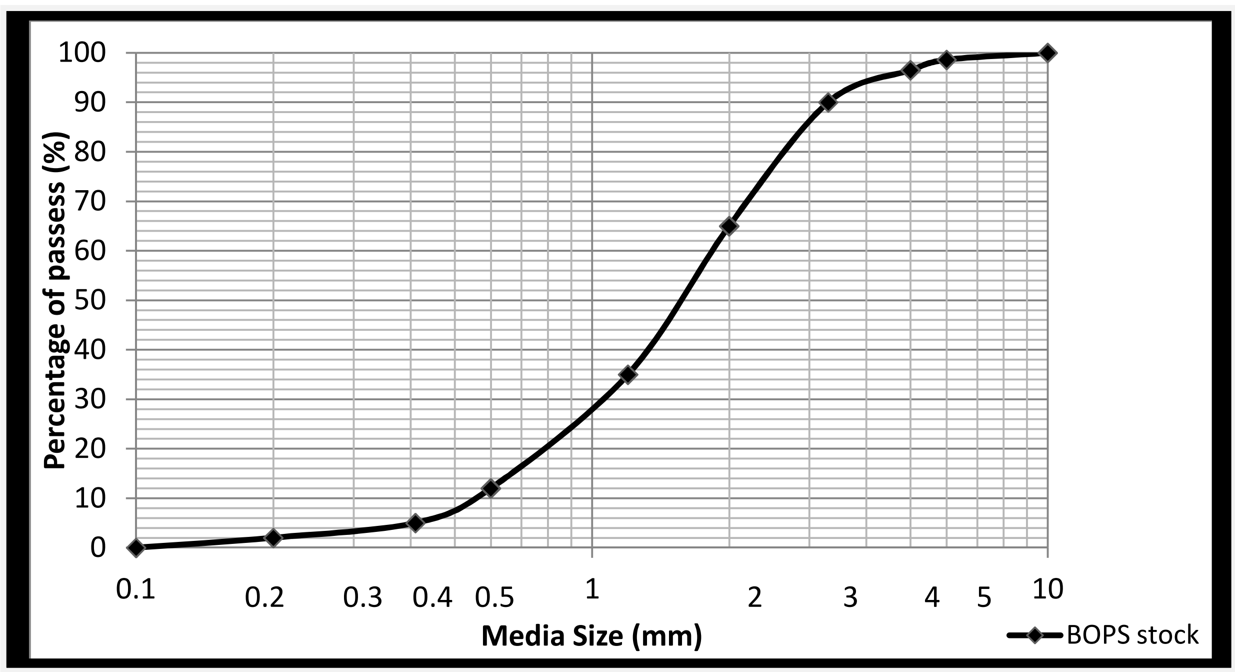

Fig. 7. Particle size distribution for BOPS

3.2 Effect of Filtration Rate on Turbidity

Figs.8. through Fig.10 show the effect of filtration rate variation on average filtered water turbidity at selected raw water turbidities in dual-media of the varied proportions of sand and BOPS filters. Generally, all curves show linear relationships, the rate of filtration increasing as effluent turbidity increases. The increase in hydraulic load on the filters resulted in a reduction of the free void area as the particles accumulate in the bed leading to an increase in resistance to flow of water through the dual-media filters.

3.3 Effluent Quality Model Development

The mathematical models formulated from the graphical plots of figs. 8, 9 and 10 indicate linear relationships between effluent turbidity (y), the dependent variable and filtration rate (x), the independent variable.

A summary of the model equations for influent turbidities of 10 NTU and 30 NTU is shown in Table 4. These models could be applied in design and operation of granular dual-media deep bed filters using BOPS and sand for production of potable water.

Table 4. Models of Effluent Turbidity(y) Versus Filtration Rate for Dual-Media Filters

Influent Turbidity (NTU)	**% Sand/BOPS**	**Model Equation**
10	75	Y = -0.15x + 2.133
10	50	Y = -0.115x + 2.556
10	25	Y = 0.13x + 2.52
30	75	Y = 1.6x + 2.0
30	50	Y = 2.1x + 0.8
30	25	Y = 1.75x + 4.033

Table 5. Effluent Turbidities (NTU) of Dual-Media Filters of Varied Proportions of Sand and BOPS at different Flow Rates and Influent Turbidities.

Flow Rate (l/hr)		**36**			**48**			**60**		
Percentage of Sand (%)		**75%**	**50%**	**25%**	**75%**	**50%**	**25%**	**75%**	**50%**	**25%**
Influent Turbidity (NTU)	**10(NTU)**	1.90	2.23	2.54	2.00	2.75	3.00	1.60	2.00	2.80
	30(NTU)	3.50	3.00	6.50	5.40	4.80	6.10	6.70	7.20	10.00
	50(NTU)	9.00	8.60	12.00	11.00	10.20	12.00	12.20	11.80	13.80

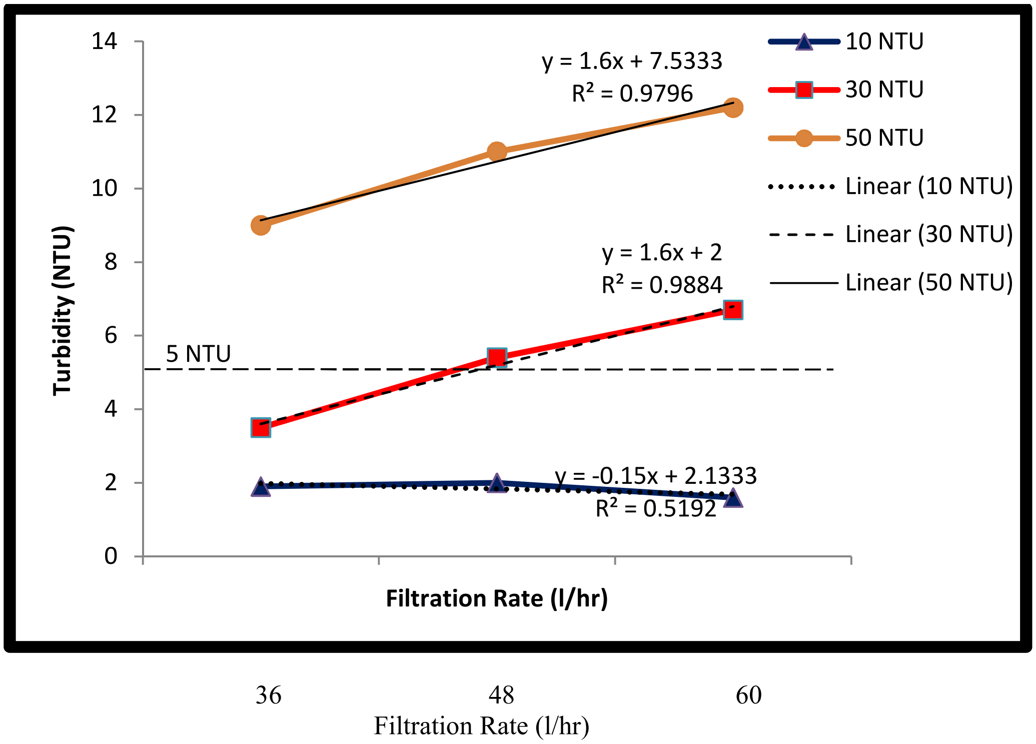

Fig. 8. Effect of flow rate on turbidity at different raw water turbidities (75% sand)

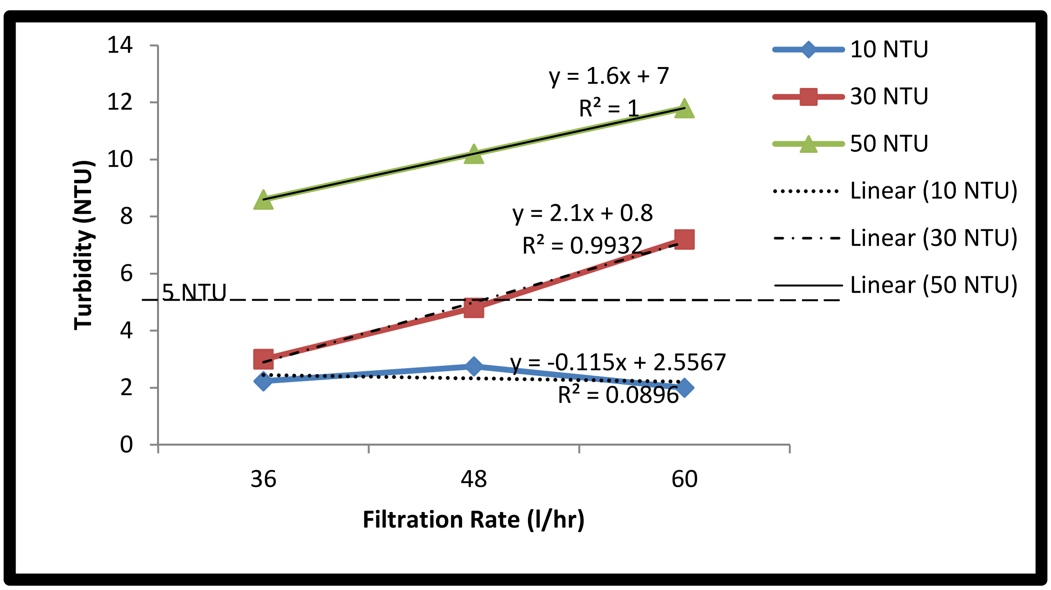

Fig. 9. Effect of flow rate on turbidity at different raw water turbidities (50% sand)

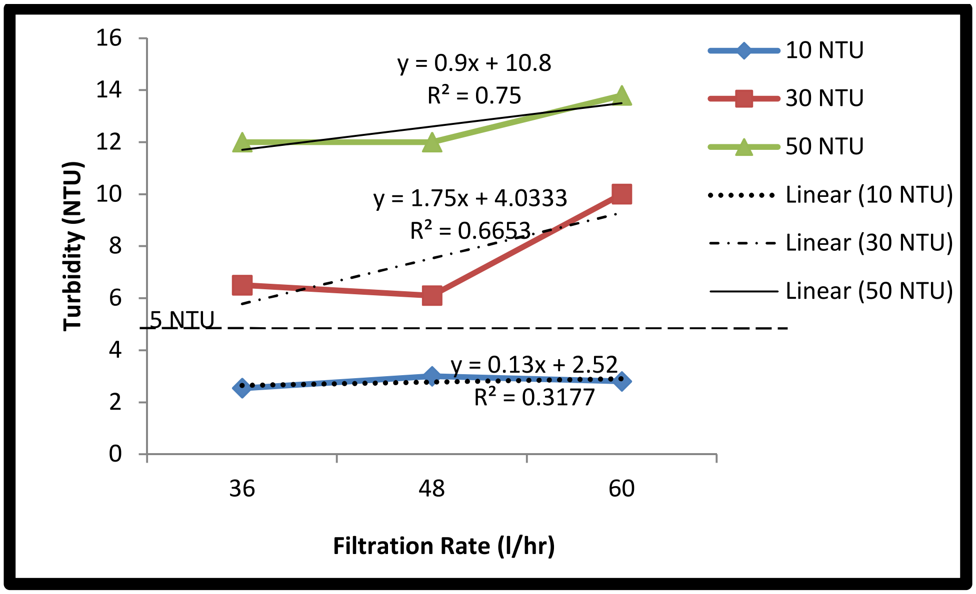

Fig. 10. Effect of flow rate on turbidity at different raw water turbidities (25% sand)

As the filtration process continues, the rate of flow increases through large openings and lessens through the smaller and partly clogged openings. This causes the larger passageways to remain nearly free of deposits (i.e., prevents the settling or attachment of suspended particles) and may remove the previously settled ones. Dual-media filter of 75% sand was observed to produce the lowest effluent turbidity at all filtration rates at 10 NTU influent turbidity with respect to the other dual media filter bed. This is due to the smaller particle size of sand with respect to BOPS, reduced bed height of sand in the other dual media beds. The shape of sand grains (rounded shape particles) also offer smaller porosity (i.e., smaller openings) with respect to that of BOPS (crushed shape particles) Finally the intermixing effect which acts to reduce the performance of the superficial layer of sand by introducing larger particles of BOPS within this layer which eliminates or reduces the effect of the fine sand particles found on the top of sand layer. The dual-media filter with 50% of sand was also observed to give a slightly lower effluent turbidity at filtration rates of 30 l/hr and 48 l/hr for influent turbidity of 30 NTU, with respect to the dual-media filter with 75% of sand. This indicates that the 50% of sand dual-media filter can also be adequate at these flow rates. These figures also show the type of filter that should be selected and the corresponding filtration rate for a given influent turbidity according to the maximum allowable effluent turbidity of 5 NTU required by World Health Organisation (WHO) standard [WHO, 1993], which is indicated as a dashed line in these figures.

4. Conclusion

The findings from this work are enumerated as follows:

1. BOPS - a locally available introduced material – has good characteristics that makes it a material that can be used as an upper layer in dual media filters constructed for water treatment works.
2. BOPS was found to be feasible for enhanced primary treatment at high filtration rates.
3. Considerable economic cost savings would be achieved by using BOPS as replacement media for imported anthracite and similar granular filter material.
4. This evaluation research showed that the 5 NTU effluent turbidity WHO standard for drinking water quality will not be achieved for raw water o
5. Effluent turbidity of acceptable standard at a fixed bed height was attained in the dual media-filters used. Also, the dual media filters generally gave long

5. Recommendations

High-rate filtration, in which the filtration rate is about 10-15 m^3/m^2.h, as compared to the rate of conventional rapid sand filtration, which is of the order of 5.0 m^3/m^2.h, is useful in upgrading existing plants. Such high filtration rates are possible, thanks to the development of dual-media and multimedia filters; and to control of flocculation by dosing polyelectrolytes, which produce relatively less sludge. High-rate filters with dual or coarse-medium arrangements have been successfully used in developed countries. This could be one of the economic solutions for the expansion of existing water treatment plants and for the construction of new plants. The filters should be designed to operate at the highest practical rates. The design should be such that even with the high frequency of washing, they are more economical. More attention should be paid to the selection of the filter media and filtration rates so that filtrate quality would conform with the required standard. Thus, this study strongly recommends the use of BOPS in water treatment

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