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EVALUATING THE DEPOSITION OF POLLUTANTS IN THE PORES OF GRANULAR MEDIA DEEP-BED FILTERS

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Abstract

This paper focuses on a study related to the rate of removal of pollutants (suspended solids or particulates) from granular media deep-bed (depth) filters designed and constructed for the production of potable water. An approach was developed for computation of quantities of solids deposited in the pores of granular media filters. The continuity equation was applied in assessing the deposition (accumulation) of pollutants within the interstices of mono and dual-media filtration beds in space and time. Normalized turbidity removal-ratio curves were developed for the dual-media and mono-media filters using data from pilot filters that exhibited high efficiency. The results of the study indicate that deposit morphology decreases with media depth and increases with time. The total quantities of material obtained from the summation of deposits in individual layers are substantially equal for the dual and mono-media filters up to the end of filter run time (14 hours) for the mono-media sand filter. The results and findings from this study will be useful to designers and managers of water treatment works in developing and developed countries.

Keywords: Pollutants, suspended solids, deposition, filtration, potable, water

Introduction

Granular media deep-bed (depth) filtration is of unique importance in the development of water treatment infrastructures considering the fact that it is the final solids-liquid separation process in the treatment of water for domestic and industrial uses. Water purification is one of the most important investments in the field of water resources and environmental engineering. The benefits derivable from procuring facilities and skilled manpower for water treatment and supply cannot be over-emphasized.

In deep-bed granular filters, the water quality, media depth, media grain size distribution (GSD), filtration rate (velocity), flow rate, head loss including the deposition (accumulation) of suspended solids in the pores of filter beds, vary with time and location.

The efficiency of depth filters is dependent on their capacity to remove suspended solids namely colloids, micro-organisms and other particulates from influent water and is measured in terms of turbidity or suspended solids removal efficiencies, the quantity of treated water that is produced per cycle of filter run and filter run time (length).

Removal efficiency increases with depth of media and run time but peaks faster at low-to-medium than high filtration rates when the same influent water and media are used (Ekenta, 2006).

This study will concentrate on the evaluation of the build-up (deposition or accumulation) of suspended solids (pollutants) in the pores of mono and dual-media deep-bed granular filters.

Materials And Methods

Materials

Filter media used were silica sand, pumice (porous volcanic rock), and anthracite coal. These are bulk filtration media, which are porous materials with pores used as particulate collectors.

Grain size (d) for silica sand (specific gravity 2.65, uniformity coefficient (uc) 1.5) varies from 0.5 mm to 1.0 mm. In most public water supplies, granular beds of silica sand are used. It is readily available in Nigeria, relatively cheap and satisfactorily purifies water.

Pumice used (specific gravity 1.6, uniformity coefficient 1.4 similar to values recommended for bituminous and anthracite coal) has a grain size of 1.0/1.1 mm. It is used as an upper layer. Pumice is available in Eritrea, Italy and Turkey in commercial quantities and has been proved suitable for dual-media and multi-media filtration (Kebreab, 2004).

Anthracite is available in substantial quantities in the numerous coal measures of Nigeria. Anthracite and pumice are used as upper layers on top of sand for dual-media filters.

The choice of media types for the investigation was based on current practices in the water treatment industry.

The raw waters used were of low turbidity.

Pilot scale deep-bed filters constructed to operate identically with full-scale granular filtration plants were used for the study.

Methodology

Conceptual Framework

The attributes of a functional and reliable filter include a good clarification of filtrate, a low rate of head loss development and a high flow rate per unit surface area. These elements when combined together provide a dimensionless Filterability Number (F), for which a minimum value is required for a filtrate of good quality (a filtrate of turbidity close to zero or WHO standard for drinking water quality).

$F = Hc_e/vc_ot$ . . . .(2.1)

where H is the total head loss, c_e is filtrate concentration, v being face velocity of bed, c_o the influent concentration, and t is time.

Ives (1983) indicated that this equation has some theoretical basis and may be regarded as the ratio of the output of the filter (head loss, filtrate concentration) to the input (quantity of suspension per unit face area). It has the advantage that it is a ratio. This means that the concentration can be expressed in any units that are significant to the observer.

Consider a granular media filter with n layers. Samples are taken at ports located at the base of each layer at several time intervals and analyzed for turbidity. Let the turbidity removed by the first and second layers be t_1, t_2, respectively. In the n^{th} layer the turbidity removed will be t_n.

Assuming the largest number of particles were removed in the first layer, then $t_1 > t_2$. The n^{th} layer will remove the least number of particles. This means that the removal rate is always changing with time and depth and is a function of the degree of treatment. The deposition of pollutants (suspended solids) within the layers of the filter bed results in clogging and eventual termination of filter run.

An approach will be developed for computing the quantity of solids deposited in the filter for each cycle of filter run.

Development of turbidity removal-ratio curves

Data used were obtained from dual-media (pumice/sand) and mono-media (sand) pilot filter test runs that have high efficiencies (Kebreab, 2004; Huisman, 1985). Data were also obtained from a study carried out by Quaye and Isaiah (1985) using anthracite/sand dual-media filters. Table 2.1 is a summary of results obtained from filter efficiency studies (Ekenta, 2006).

Table 2.1 Depth Filters of High Efficiency

Media Type	**Grain Size (mm)**	**Media Depth (cm)**	**Influent Turbidity (NTU)**	**Filtration Rate (m/hr)**	**Filter Run Length (hr)**	**Water Production/ Cycle (m^3/m^2)**	**Removal Efficiency %**	**Head Loss Rise (cm)**	**Terminal Head Loss (cm)**
Pumice/Sand	1.0/0.5	60/30	3.52	3.0	73.3	220	94.0	46.1	53.5
Pumice/Sand	1.0/0.5	60/30	3.8	5.5	44	242	92.9	44.0	56.0
Pumice/Sand	1.0/0.5	60/30	2.85	7.5	21.7	163	91	43.2	58.9
Anthracite/Sand	1.24/0.64	32/48	9.0	15.0	4/20*	60/300*	98.7	42	77
Sand	0.67	90	3.52	3.0	31.7	95	91.0	70	80.6
Sand	0.67	90	3.9	5.5	14	77	94.2	70.8	84.5
Sand	0.67	90	2.85	7.5	16	120	92	80.2	95.9
Sand	0.7	80	8.0	7.2	50	360	98.3	145	195

NOTE: * Extrapolated values allowing for recommended minimum Filter Run Length

Turbidity-ratio (effluent turbidity Te / influent turbidity To) was plotted as a function of media depth (x) for increasing depths of the filter media.

Figures 2.1 and 2.2 show the normalized turbidity removal-ratio curves developed for the dual-media and mono-media filters respectively.

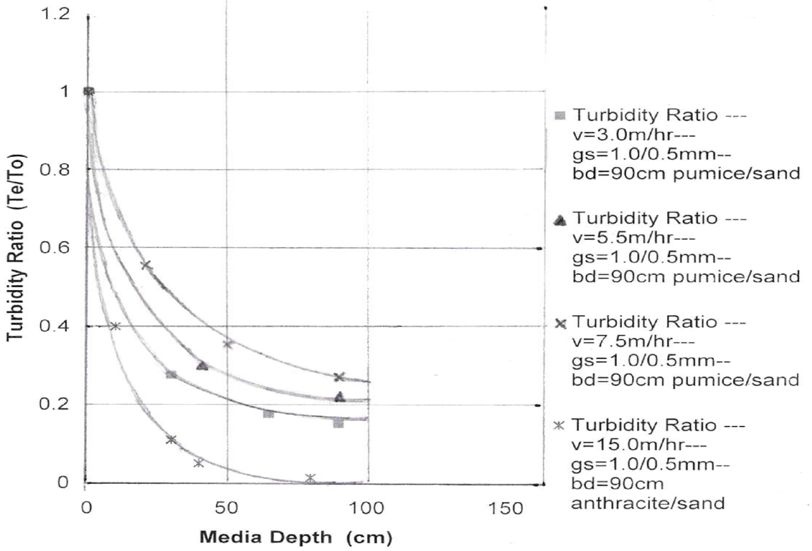

Figure 2 .1 Normalized turbidity removal-ratio curves for pumice/sand and anthracite/sand

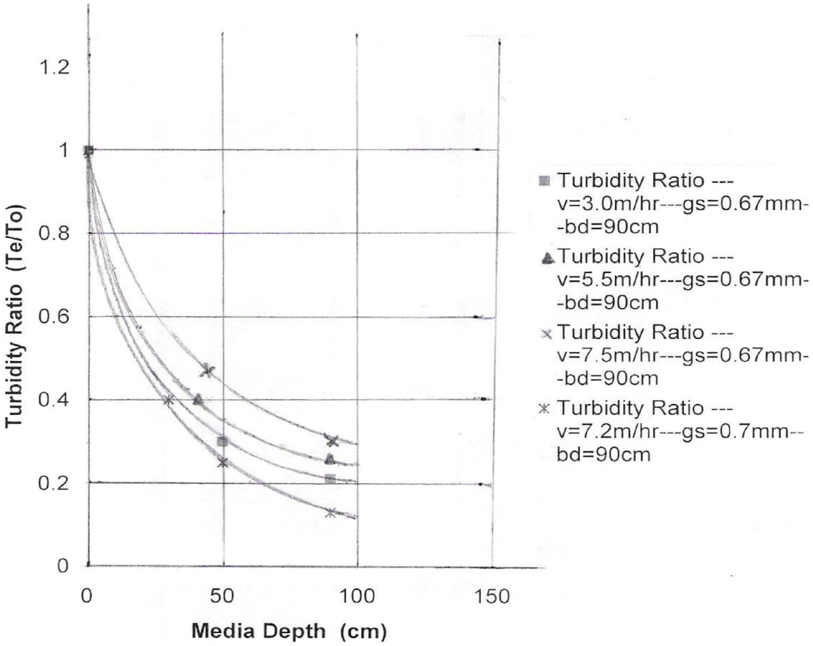

Figure 2.2 Normalized turbidity removal-ratio curves for sand filters

Computation of build-up (deposition) of suspended solids in dual-media filters

The classical deep-bed filtration model (CDBFM) originally proposed by Iwasaki (1937) assumes that the volume of suspended solids removed from water is equal to the volume of solids deposited in the bed and that the solids removed with depth in the filter is directly proportional to the concentration of the solids.

The accumulation (build-up) of suspended solids (turbidity) in the pores of a filter bed was assessed using the continuity equation, which can be stated as

1. Inflow – Outflow = Storage + Deposition . . . . (2.2)

The mathematical form of this equation (Tchobanoglous and Burton, 1991) for which the storage term is considered small and assumed to be zero is

$- \quad v\, dc/dx = dq/dt$ . . . . (2.2a)

where v = filtration rate (m/hr)

dc/dx = difference between the mass of suspended solids entering and leaving the filter media (advection term) (g/m^3hr).

dq/dt = time rate of change in quantity of solids deposited within the filter (deposition term) (g/m^3hr).

For studies on filtration of suspensions, suspended solids concentration is the most important influent characteristic. Turbidity is easy to measure when compared with suspended solids concentration and gives a more accurate measure for suspended solids at low concentrations. Turbidity is therefore used as a surrogate measure for suspended solids (Ekenta, 2006).

Equation 2.2 can therefore be written as

$- v\, dT/dx = dq/dt$ . . . . (2.3)

where T stands for turbidity of suspension.

The numerical form of this equation is

$- v\, \Delta T/\Delta x = \Delta q/\Delta t$ . . . . (2.4)

Or $- v\, T_{X-1} - Tx / X_{X-1} - X_X = q_2 - q_1 / t_2 - t_1$ . . . . . . (2.5)

Equation 2.4 will be applied in assessing the accumulation of solids in pumice/sand and sand filters using the turbidity-ratio curves developed in figures 2.1 and 2.2 respectively for a filtration rate of 5.5 m/hr.

Dual-Media Filter for Filtration Rate of 5.5 m/hr (Fig 2.1)

Table 2.2 shows the computed values for turbidity difference ΔT ($T_{X-1} - Tx$) for indicated filter media depths (x). Turbidity ratio values were extracted from Figure 2.1. Te and To represent effluent and influent turbidities respectively.

Table 2.3 shows the values for build-up of suspended solids (Δq) in each layer of the filter for run time of 5, 10, 14, 20, 30, 40 and 44 hours respectively calculated using the difference equation

$\Delta q = - v \Delta T * \Delta t / \Delta x$ . . . . (2.6)

where Δt = filter run time (hr)

Δx = media depth for each layer of filter

<u>Note:</u> For Alum suspensions, suspended solids concentration ss (mg/l) = 1.91 * Turbidity (NTU) (Brouckaert, 2004) . . . . (2.7)

Table 2.2 Computed values (dual-media filter) for turbidity difference (ΔT) for filtration rate of 5.5 m/hr

x (cm)	**Te/To**	**Te (NTU)**	**ΔT (NTU)**
0	1.0	4.61	
			1.24
10	0.72	3.3	
			0.9
20	0.52	2.4	
			0.6
30	0.38	1.8	
			0.45
40	0.29	1.35	
			0.10
50	0.27	1.25	
			0.05
60	0.24	1.20	
			0.01
70	0.23	1.10	
			0.09
80	0.22	1.01	
			0.0
90	0.22	1.01	

Table 2.3 Build-up of suspended solids (Δq) in layers of dual-media (pumice/sand) filter for filtration rate of 5.5 m/hr

		Δt = 5 hr	**Δt = 10 hr**	**Δt = 14 hr**	**Δt = 20 hr**	**Δt = 30 hr**	**Δt = 40 hr**	**Δt = 44 hr**
x (cm)	**ΔT (NTU)**	**Δq (g/m^3**	**Δq (g/m^3)**	**Δq (g/m^3**	**Δq (g/m^3)**	**Δq (g/m^3)**	**Δq (g/m^3)**	**Δq (g/m^3)**
0								
	1.24	651	1302	1822	2605	3907	5210	5730
10								
	0.9	472	945	1323	1890	2835	3780	4158
20								
	0.6	315	630	882	1250	1890	2532	2772
30								
	0.45	236	473	662	946	1419	1892	2081
40								
	0.1	52	105	147	210	315	420	462
50								
	0.05	26	53	74	106	159	212	233

60								
	0.01	5	11	15	22	33	44	48
70								
	0.09	47	95	133	190	285	380	418
80								
	0.0		0		0	0	0	0
90								
∑ Δq	=	**1804**	**3614**	**5708**	**7218**	**10843**	**14470**	**15902**

Mono-Media Filter for Filtration Rate of 5.5 m/hr

The computed values for turbidity difference ΔT ($T_{X-1} - Tx$) using mono-media (sand) are shown in table 2.4, while the values for build-up of suspended solids (Δq) in each layer of the filter for run time of 5,10, and 14 hours respectively are displayed in table 2.5.

Table 2.4 Computed values for turbidity difference (ΔT) for mono-media (sand)filter for filtration rate of 5.5 m/hr

x (cm)	Te/To	Te (NTU)	ΔT (NTU)
0	1.0	4.61	
			1.29
10	0.72	3.32	
			0.78
20	0.55	2.54	
			0.47
30	0.45	2.07	
			0.23
40	0.4	1.84	
			0.23
50	0.35	1.61	
			0.11
60	0.325	1.5	
			0.19
70	0.285	1.31	
			0.1
80	0.25	1.2	
			0
90	0.25	1.2	

Table 2.5 Build-up of suspended solids (Δq) in the layers of mono-media (sand) filter for filtration rate of 5.5 m/hr

		Δt = 5 hr	**Δt = 10 hr**	**Δt = 14 hr**
x (cm)	**ΔT (NTU)**	**Δq (g/m^3)**	**Δq (g/m^3)**	**Δq (g/m^3)**
0				
	1.29	678	1355	1897
10				
	0.78	410	819	1147
20				
	0.47	247	494	691
30				
	0.23	121	242	338
40				
	0.23	121	242	338
50				
	0.11	58	116	162
60				
	0.19	100	200	279
70				
	0.1	53	105	147
80				
	0	0	0	0
90				
Σ Δq		**1788**	**3573**	**4998**

Results and discussion

The total quantities of material obtained from the summation of deposits in individual layers (Table 3.1) are substantially equal for the dual and mono-media filters up to the end of filter run time (14 hours) for the mono-media sand filter [11126 g/m^3 and 10359 g/m^3 for dual and mono-media respectively]. The difference in weight for the two values [767 g/m^3] accounts for the storage term in the continuity equation 2.2. The more porous dual-media stores a little quantity of the suspension when the pores of the mono-media are completely clogged up at the end of its run time of 14 hours.

The results show that the deposition of pollutants in the individual layers of filter beds differ to some extent.

These differences could be attributed to the fact that the mechanisms operative within granular media filters, namely straining, sedimentation, impaction, adhesion, including flocculation and biological growth are interactively at play.

The rate of deposition of solids is dependent on media size that determines the size of pore spaces that serve as particle collectors within the filter bed.

Media with smaller pore spaces (sand) will clog at a faster rate than media with larger pore space (pumice/sand).

The larger pores of the top layer of the dual-media took a longer time to fill with solids, resulting in a longer filter run length (44 hours) than is the case for the mono-media filter (14 hours).

It can also be observed that deposit morphology decreases with media depth and increases with time. Towards the end of the filter run time, the porous media tends to behave like a cake filter especially within the first filter layer.

Table 3.1 Comparative summaries of quantities of material deposited per cycle of filter run (filtration rate = 5.5 m/hr)

	Dual-Media (Pumice/Sand)	**Mono-Media (Sand)**
Run Time dt **(hr)**	**Suspended solids deposited (g/m^3)**	**Suspended solids deposited (g/m^3)**
5	1804	1788
10	3614	3573
14	5708	4998
20	7218	--
30	10843	--
40	14470	--
44	15902	--

Conclusion

The objective of this study has been realized. Pilot scale filters designed to operate identically with full-scale filtration plants could be applied in studies for determining the rate of deposition of particulates in filters.

This method of computing pollutant deposition will serve as a management tool for assessment of suspended solids loads on granular filters. Filter backwash water requirements for dislodging of particulates in clogged filters can now be estimated more accurately.

The findings from this work will facilitate the work of environmental engineers responsible for the design, development and operation of depth filtration plants.

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