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REACHING THE UNREACHED: CHALLENGES FOR THE 21ST CENTURY

Optimization of slow sand filtration

Nur Muhammad, Ken Ellis, Jeremy Parr and Michael D Smith, WEDC

SLOW SAND FILTERS (SSF) are probably the most effective, simplest and least expensive water treatment process for developing countries. They require few technical components and usually no chemicals. They are very efficient in removing bacteria, organics, cysts, ova and viruses are effectively removed from filtrate water. The performance of SSF is not controlled by any mechanical system. It is a controlled ecosystem of living organisms whose activities are affected by the raw water quality, and in particular temperature. The quality of the treated water and maintenance requirements for the system also depend on the selected variables like sand size, flow rates and sand bed depth. The sand used is characterised by its effective size (ES or d_{10}) and uniformity coefficient (UC or d_{60} / d_{10}). The recommendations for ES vary between 0.15mm and 0.40mm (Ellis 1985). The UC should be between 1.7 and 3.0 but preferably not greater than 2.7 (Ellis, 1987). The initial depth of sand bed at commissioning or resanding, will frequently be as much as between 1.2 and 1.4m and reducing to an absolute minimum depth of 0.65m before resanding (Ellis, 1987). Bellamy et al (1985) suggested that the bed depth could be reduced to 0.48m without significant impairment of removal efficiency. The conventional rate of filtration is $2.4m^3 / m^2.d$ i.e. 0.1m / hr (Ellis, 1985). However, it is possible to increase the filtration rate considerably if effective pretreatment is given and if an effective disinfection stage follows the filtration (Ellis, 1987). The National Environmental Engineering Research Institute (NEERI, 1977), India used flow rates of 0.1, 0.2 and 0.3m / hr and found no significant difference in FC reductions. Huisman and Wood (1974) reported the use of higher filtration rates (0.25 and 0.45m / hr) without any marked difference in effluent quality.

The present work was undertaken to study the influences of sand size, sand bed depth and filtration rates by means of a laboratory scale investigation.

Experimental study

Three model SSF were developed in the laboratory. Vertical pipes made of transparent synthetic material and covered with black polythene paper to make the pipe dark in order to prevent the growth of algae. The filters were 2.62m high with a flanged joint at 1.07m from the bottom. The flanged joint was provided to assist filling of the filter with sand and gravel and also to facilitate cleaning of blocked sand surfaces. The detailed set up of the filter is shown in Figure 1.

Sands of effective sizes of 0.20, 0.30 and 0.45mm were used for the three different filters. All the uniformity coefficients were kept constant at 2. The total depth of sand was 0.73m for all three filters. A sampling tap was fitted at 0.40m depth to identify the effects of depth. The effects of filtration rate were studied by varying the filtration rate from 0.1m / hr to 0.2m / hr and then to 0.3m / hr. Surface water from a brook was taken as the feed water source for the filters. Settled sewage was added to keep the bacteria to a reasonably high level. Percentage removal of faecal coliform (FC), total coliform (TC), turbidity and colour were used to evaluate the filtration effectiveness and filter response at different test conditions.

Results and discussion

Effect of sand size on SSF performance at the conventional filtration rate of 0.1m/hr

Table 1 summarises the average percentage removal of FC, TC, turbidity and colour for filters containing sands of ES 0.20, 0.35 and 0.45mm respectively.

The results show that the treatment efficiency of SSF is not very sensitive to sand size up to 0.45mm. A slight increase in treatment efficiency was observed with decreasing sand size. This indicates the importance of straining and adsorption, because higher removals would be expected with the smaller interstices between smaller sand and with larger surface area of the smaller sand size. At this stage filter 1 was cleaned twice, whereas filters 2 and 3 were cleaned once. The results favour the use of sand size larger than 0.20mm (up to 0.45mm) in SSF.

Effect of filtration rates on the performance of SSF

Tables 2a, 2b and 2c summarise the effects of filtration rates on the percentage removal efficiency of filters 1, 2 and 3 respectively.

The results show that, in general, FC removal efficiency declined slightly as filtration rates increased. TC removal efficiency followed the same trend as FC. Turbidity and

Table 1: Effect of ES on filter performance at filtration rate of 0.1 m/hr

Filter	ES	Average % Removal			
	(mm)	FC	TC	Turbidity	Colour
Filter 1	0.20	99.60	99.70	96.50	95.10
Filter 2	0.35	99.30	99.30	96.50	95.10
Filter 3	0.45	99.00	98.60	96.20	92.00

Table 2. Effects of filtration rate on performance at constant ES

(a) Filter 1 (ES = 0.20mm)

Filtration Rate (m/hr)	Average % Removal			
	FC	TC	Turbidity	Colour
0.1	99.60	99.70	96.50	95.10
0.2	98.70	98.90	90.10	93.80
0.3	98.30	98.10	89.10	89.60

(b) Filter 2 (ES = 0.35mm)

Filtration Rate (m/hr)	Average % Removal			
	FC	TC	Turbidity	Colour
0.1	99.30	99.30	96.50	95.10
0.2	98.40	98.40	89.20	92.80
0.3	98.00	97.30	88.90	88.20

(c) Filter 3 (ES = 0.45mm)

Filtration Rate (m/hr)	Average % Removal			
	FC	TC	Turbidity	Colour
0.1	99.00	98.60	96.20	92.00
0.2	97.00	97.00	88.30	89.20
0.3	96.70	96.40	87.90	83.00

colour removal efficiencies decreased noticeable as filtration rates increased. The results show that bacterial removal is not greatly affected by the filtration rates. The adverse effects of higher filtration rates are more significant in the removal efficiency of turbidity and colour.

Effects of sand bed depth on SSF performance

The effect of sand bed depth on SSF performance were studied only at the conventional rate of filtration of 0.1 m / hr. Tables 3a, 3b and 3c summarise the effects of various sand bed depths on the removal efficiency of different filters.

In general, in the case of filter 1, the removal efficiency of FC declined from 99.6 to 98.4 per cent, turbidity from 96.5 per cent to 87.5 per cent, TC from 99.7 per cent to 99 per cent and colour from 95.1 per cent to 72 per cent for sand depths of 0.73m and 0.40m respectively. Similar deterioration of filtrate quality occurred for filter 2. In the case of filter 3, the filtrate quality deteriorated more than the other two filters. The results show that the most bacteriological purification occurs within the top 400 mm of sand bed. Turbidity and colour removal efficiencies are affected more by reducing depth, which shows the importance of adsorption throughout the filter column in purifying water by SSF. A decrease in sand bed depth causes a reduction in total surface area of the sand grains and ultimately total adsorption capacity is reduced. The ammonia content of filtrate water at 0.40m depth was measured for all three filters. It reduced from 1.5 to 0.5 mg / l which meant that nitrogenous organic compounds were not oxidised completely at 0.40m bed depth. This indicated that biological activity extended below 0.40m depth.

Conclusions

The following conclusions can be drawn from the project study on different aspects of slow sand filtration.

- Slow sand filters with finer sand produce better quality water but reduce the length of filter run. Filters with sand sizes larger than 0.2mm (up to 0.45mm) produce satisfactory quality water with a longer filter run. Hence, from the standpoint of removal efficiency the argument for using very fine sand is not strong.
- The bacteriological quality of filtrate water does not deteriorate significantly with the filtration rates higher than the conventional figure. Turbidity and colour removal efficiency decline considerably with higher filtration rates, although the filtrate quality remains reasonably good. Filtration rates higher than the conventional one can therefore be adapted in slow sand filters (SSF) for a good quality of raw water. However, filters at higher filtration rates require more frequent cleaning.
- Bacteriological treatment efficiency by SSF is not highly sensitive to sand bed depth. A bed depth of only 400 mm can produce a satisfactory quality of water i.e. most bacteriological purification occurs within the top 400mm sand bed. Turbidity and colour removal efficiencies improve as bed depth increases beyond 400mm.
- Oxidation of nitrogenous organic compounds is not sensitive to sand sizes and filtration rates, but it is to sand bed depth. A sand bed depth of 400mm does not oxidise nitrogenous organic compounds completely, i.e. biological activity continues below 400mm of sand bed depth.
- Straining, adsorption and sedimentation appear to play an important role in purifying water by SSF.

Table 3. Effects of sand bed depth on SSF performance

(a) Filter 1 (ES = 0.20mm)

Sand Bed Depth (m)	Average % Removal			
	FC	TC	Turbidity	Colour
0.73	99.60	99.70	96.50	95.10
0.40	98.40	99.00	87.50	72.00

(b) Filter 2 (ES = 0.35mm)

Sand Bed Depth (m)	Average % Removal			
	FC	TC	Turbidity	Colour
0.73	99.30	99.30	96.50	95.10
0.40	97.40	98.70	86.50	72.00

(c) Filter 3 (ES = 0.45mm)

Sand Bed Depth (m)	Average % Removal			
	FC	TC	Turbidity	Colour
0.73	99.00	98.60	96.20	92.00
0.40	95.90	98.10	85.00	66.00

In conclusion, the results show that the depth of SSF can be reduced below the conventionally accepted value of 0.65m to 0.40m without adversely affecting the bacteriological quality of the water. In addition, the results show that the effect of using fine sand only marginally improves treatment efficiencies and therefore the extra cost of using finer sands is not usually justified (although there will be an upper limit to the ES which can be used - this study took 0.45mm as the maximum ES). The results show that there is scope for relaxation of typical values for the standard parameters for SSF design. However, the rationale for doing so must be clear or margins of safety for the operation of the SSF may be cut to unacceptable levels.

References

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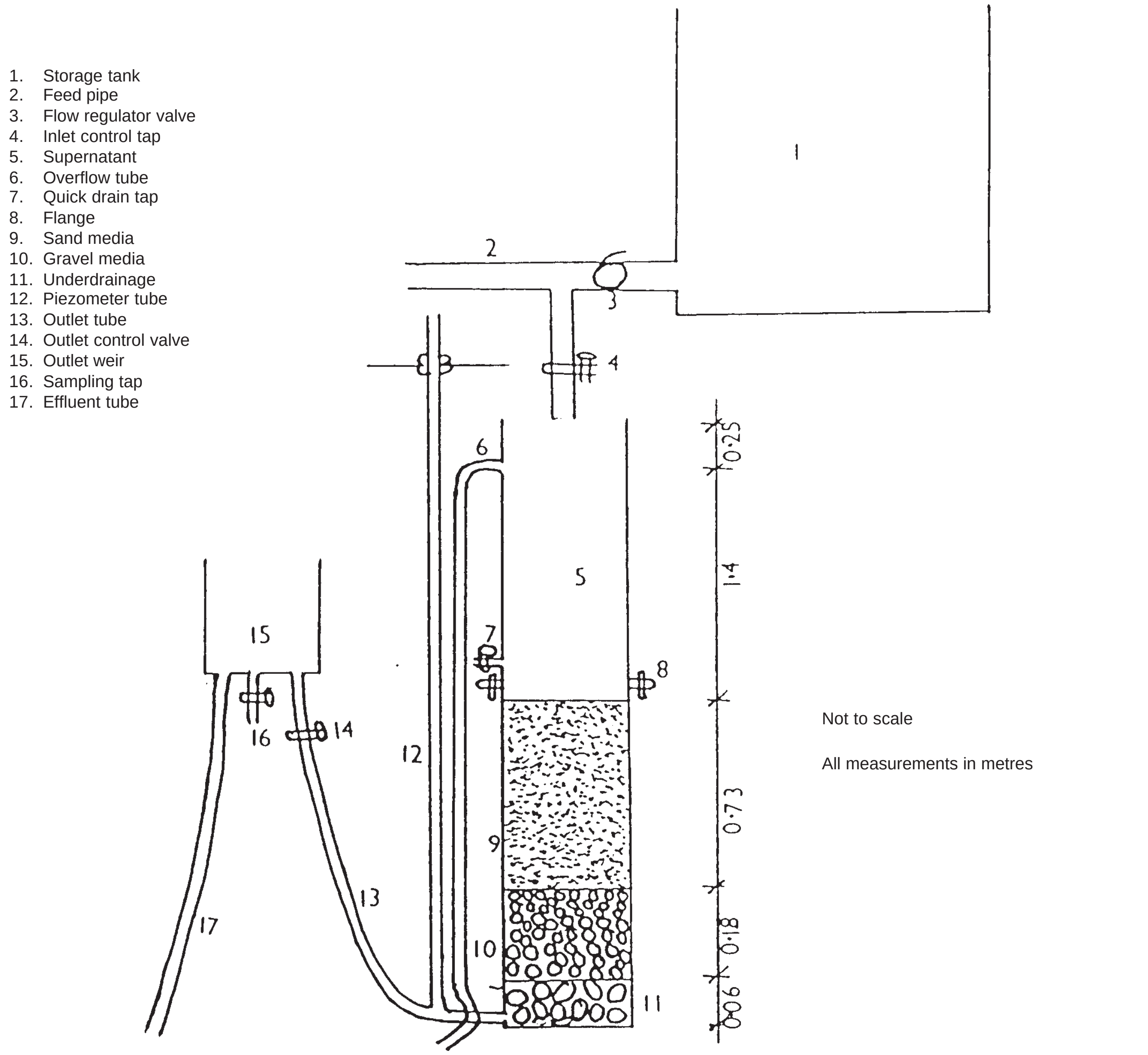

Figure 1. The detail setup of a test filter