FILTER BACKWASH OPTIONS FOR RURAL TREATMENT PLANTS

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ABSTRACT

Rapid granular media filters are widely used in drinking water treatment to remove particulate and microbial contaminants prior to disinfection. In order to function properly, these filters must be backwashed regularly to remove accumulated deposits. Experience has shown that whenever filter influent is pretreated with coagulants (sometimes also referred to as flocculants), especially polymers, upflow water wash alone is insufficient to prevent mudballing. In South Africa, air scour is the auxiliary backwash systems of choice, however, many small treatment plants in rural areas (generally treating < 2 ML/day) have water wash alone. This is because of the greater costs, maintenance requirements and operational complexity of air scour systems. Surface wash systems, which are considered more appropriate for developing countries than air scour because they are simpler to operate and maintain, are practically unknown.

This paper discusses the relative advantages and disadvantages of the various types of backwash systems for rural applications and the effect of design and operating parameters on backwash efficiency. The advantages of using slow sand filters (which do not require backwashing) as opposed to rapid filters in rural applications is also discussed. Using coarser media sizes, higher backwash rates, inorganic rather organic coagulants and backwashing filters at least once a day may reduce the rate of mudballing in rapid filters. Non-routine methods can also be used periodically to remove or break up mudballs when they do form. Regular filter inspection and maintenance and proper operator training are critical regardless of the backwash method used. Nonetheless, treatment plants should expect to replace or chemically clean their filter media every year or two if they do not use auxiliary wash. If dual media is used, it may only be necessary to replace the top layer on a regular basis. An experimental approach to predicting the useful life of a filter bed is presented.

IMPORTANCE OF FILTER BACKWASH

During filtration, influent particles attach to the surface of the filter media grains and accumulate in the pore spaces resulting in a reduction in flow area and consequent increase in filter headloss. Once the filtrate quality begins to deteriorate and/or the maximum available headloss has been reached, the filter must be backwashed in order to continue operating correctly. Filters with inefficient backwash tend to accumulate aggregates of dirt, media and coagulant known as *mudballs* (1). These can grow into inactive sub-surface masses of clogged material, which increase local velocities in the filter with a potentially negative impact on filtrate turbidity and filter run time (2). Clogged regions of the filter also tend to contract as the headloss increases, leading to the development of cracks in the bed, which result in short circuiting of the filter influent and a decline in filtered water quality (2,3).

Deposition of floc on media grains during filtration results in the grains becoming cemented together, especially near the top of the filter where most deposition occurs. The first step of backwashing is to break up the clogged layer which forms in the top sections of the filter bed (and also at the media interfaces of dual and multimedia filters). Once the grains have been separated, it is then necessary to strip away most of the remaining film coating individual media particles. Note that it is neither possible nor desirable for every grain in the bed to be completely clean since a small amount of floc remaining in the bed is believed to improve the efficiency of removal of influent floc at the beginning of the next filter run. However, a large number of dirty filter grains in direct contact with each other at the end of backwash can lead to the development of mudballs as described in (4) and to filter cracking. Once floc particles have been detached from the filter grains, they must be transported out of the filter bed and out of the filter compartment to prevent them settling back into the filter at the end of backwash. Failure to flush these particles out will accelerate clogging in the subsequent run and may result in high initial filtrate turbidities. However, adding a sub-fluidisation wash step to the end of the backwash sequence can greatly reduce filtrate turbidity at the beginning of the next run (5).

OPTIONS FOR FILTER BACKWASH – ADVANTAGES AND DISADVANTAGES

For many years it was believed that rapid filters should be washed very gently so as not to remove the biological film that supposedly coated the media. However, during the first part of the 20th century it came to be appreciated that a clean filter bed performed better than a film coated one (6). Consequently, various methods for improving backwash efficiency have been developed. The most commonly used methods and their advantages and disadvantages are described below. Details on the design and operation of the different systems can be found in (1, 2, 7, 8).

Fluidised Backwash Without Auxiliary Wash

This method involves simply washing the filter with an upflow wash rate sufficient to fluidise the entire filter bed until the wash water is exiting the filter is reasonably clean. Extensive experience has shown that upflow water wash alone will not prevent mudballing and filter cracking in filters where the raw water is treated with coagulants regardless of the backwash rates used (7). Since most applications require the use of coagulants to achieve acceptable filtrate turbidities (8), upflow water wash alone is now seldom employed in treatment plants in the industrial world (9). However, many treatment plants in the developing world and many small treatment plants in rural areas of South Africa still use this system because of its lower capital cost and simpler operation. Unfortunately, owners and operators of small treatment plants usually do not understand that their backwash system is inadequate and fail to take appropriate action when problems arise.

Backwash With Air Scour

Backwash with air scour is the auxiliary backwash method of choice in Europe and also in South Africa. Air scour systems supply air to the full area of the filter from orifices under the filter medium (2). Air scour has been used alone (consecutive air and water wash) or together with low-rate water backwash in an unexpanded or slightly expanded bed (simultaneous air and water wash). Both types of air scour have been found to be very effective in preventing filter mudballing (8). Air scour alone followed by low rate water wash is typically used in monomedia filters with 0.6 to 1.2 mm effective size (media (8). The effective size, also known as d_{10}, is the sieve size through which 10 % of media mass passes. Air scour alone followed by high rate water backwash is used in dual and multimedia filters. Simultaneous air and water wash is usually reserved for deep bed coarse grained filters (effective size 1 – 2 mm).

The advantages of air scour systems are their relative cleaning efficiency and lower water requirements than the surface and subsurface wash systems described next. Their disadvantages include that they require the use of air blowers and that they are more complex to operate and maintain. Furthermore, improper operation (turning the air on too quickly, too high or at the wrong time) can result in excessive media losses and damage to the filter nozzles and underdrain. For these reasons, air scour systems are not recommended for rural applications where proper operation and maintenance cannot be guaranteed.

Surface And Subsurface Wash

Surface wash is a mechanism, which provides jets of water about 5cm above the fixed bed media surface to increase the agitation of the media during backwash and thus assist the release of attached particles (2). Surface wash systems may be either fixed or rotary. Fixed systems discharge auxiliary washwater from equally spaced nozzles in a pipe grid while rotary arms have pipe arms which swivel on a central bearing (8). Rotary systems provide a better cleaning action but are more likely to fail due to mechanical problems. Subsurface wash systems are sometimes used in dual or multimedia filters and have jets below the surface of the fixed bed. Nozzle plugging can be a problem with sub-surface systems.

Surface wash systems have been extensively used to improve the effectiveness of fluidised-bed backwashing in the USA, South America and Japan (7) but are little used elsewhere in the world (10). As far as the authors are aware, surface and sub-surface wash are rarely used in South Africa if at all. The effectiveness of surface wash has been found to be comparable to consecutive air and water wash (11). Both systems may be ineffective in cleaning certain areas of the bed (7, 8), especially if mudballs sink into the bed and away from the zone of maximum agitation.

The advantages of surface wash systems include that they are relatively simple to install (as compared to air scour) and only require a source of pressurised water in conjunction with a set of nozzles (12). Maintenance is also relatively easy as the system is located above the media surface. Fixed grid type of surface wash systems are recommended over air scour for developing countries because of their simplicity in design, lack of moving parts and lower energy requirements. Rotating surface wash systems are not recommended.

FILTER DESIGNS USED FOR SMALL TREATMENT PLANTS IN SOUTH AFRICA

The most common types of rapid filters used in rural treatment plants are conventional filters, pressure filters and valveless filters. Examples of each type of filter are shown in Figure 1. Conventional rapid gravity filters usually have air scour facilities. Pressure filters can be designed with or without air scour but all of the small plants visited by the authors in South Africa have upflow wash only. Valveless filters are able to backwash themselves automatically when a certain headloss is reached but the automatic backwash is limited to upflow wash only. In theory, a manually operated auxiliary backwash system could be added however this would detract from the valveless filter’s main advantage which is its simplicity of operation. For more information on the design, operation, advantages and limitations of these filters, see (4).

(a) Conventional rapid gravity filters

(b) Pressure filters

(c) Valveless filter

Figure 1. Types of rapid filters commonly used in rural treatment plants

Conventional gravity filters are relatively expensive to construct and tend to be used mainly in larger treatment works although they still exist in some older rural treatment plants. However, most contractors now prefer to install prefabricated package plant filters such as pressure filters and valveless filters at smaller treatment works. A few plants use upflow - downflow filtration. This type of filter will not be discussed in this paper, however, the same general principles about backwashing apply. The advantages of package plant filters include lower capital costs, relatively easy operation and maintenance and shorter design and construction periods (7). This means that they are likely to remain the preferred choice for small treatment works. However, in addition to the backwash limitations discussed above, a further disadvantage with respect to backwashing is that the operator cannot see the filter bed and therefore will not be able to observe the deterioration of the state of the media. This means that dirty filter problems are typically ignored until the filters became essentially non-functional.

Many small treatment plants still use slow sand filtration instead of or as well as rapid filtration. The advantages and disadvantages of slow sand filters, which do not require backwashing, are discussed later.

OPTIMISING DESIGN AND OPERATION OF FILTERS WITH UPFLOW WASH ALONE

Since it is important to keep the operation of rural treatment plants as simple as possible, upflow wash alone is likely to remain a common method of backwash for the foreseeable future. When this option is chosen, treatment plant owners must plan and budget for replacing the filter media once a year. In many cases, this may be a more cost effective option than installing and operating an auxiliary wash system. To reduce the risk of damaging the filter and causing delays in returning it to service, filter media replacement should preferably be undertaken or supervised by specialists. As an alternative to replacing the filter media, chemical cleaning of the bed may be considered and several local companies offer this service. However, appropriate arrangements for the disposal of the spent cleaning solution have to be made.

While regular servicing of upflow wash only filters is always critically important, the useful life of the filter bed will also depend on the filter design and operation. The most critical parameters are the choice of filter media, the backwash rate(s) and duration, the filter run lengths and the type of pre-treatment. In addition, where operators have access to the filter bed during backwashing, they may be able to manually break up or remove mudballs when they form. These issues are discussed next.

Filter Media

The shear forces involved in stripping deposits off filter media grains are roughly proportional to the buoyant weight of the grains therefore in general, heavier grains (coarser and/or denser) are more efficiently cleaned during backwashing than lighter grains (finer and/or less dense). Consequently, beds of finer media accumulate mud at significantly greater rates than beds of coarser media when backwash at the same rates (13). Kawamura (14) found that the sand encapsulated in mudballs removed from the upper portions of a sand filter was mostly of much smaller size than the d_{10} size of the bed and of very uniform size. He therefore recommended (a) skimming off the top 2.5 to 5 cm of the stratified filter media every time a new layer is added to a filter and (b) using coarser and more uniformly sized media in filters without auxiliary wash.

The disadvantage of using a coarser media sizes is that deeper beds are required to achieve the same filtrate quality and the backwash rates required to fluidise the bed are higher. This adds to both the capital and operating costs of the plant. Reasonable choices of filter sand sizes would be d_{10} = 0.7 mm to 1 mm requiring a filter bed depth of at least 0.7 to 1 m. Given that pre-treatment in rural treatment plants is seldom if ever optimised, deeper beds are preferred. For improved turbidity removal without the use of polymers, increasing the bed depth by 15 % is recommended. The uniformity coefficient ($UC = d_{60}/d_{10}$) should be less than 1.4 (7).

As an alternative to using a coarser sand size, designers may consider a reverse graded dual media bed. A dual media bed consists of a layer of relatively coarse, less dense media over a layer of relative dense finer media. The most common combination is anthracite coal (density = 1450 – 1650 kg/m^3) over sand (density = 2650 kg/m^3). However, alternative media manufactured from local materials have also been used successfully in various parts of the world (15). The coarser layer at the top of the bed allows deeper penetration of the floc and consequently lower rates of headloss development while the finer lower layer ensures the production of high quality filtrate with less bed depth required. Dual media may have an additional advantage in situations where the filter media will have to be replaced frequently. Brouckaert *et al.* (4) found that a dual media (anthracite and sand) filter and a 0.7 mm effective size sand filter operated in parallel performed similarly in terms of headloss development and turbidity removal and also accumulated residual deposited material (remaining in the filter after backwash) at approximately the same rate. However, in the dual media filter, mudballing was confined to the anthracite layer whereas mudballs in the sand filter sank deeper into the filter with each backwash. The same study found that the sand layer in a dual media bed remained reasonably clean after 7 months of operation whereas mudballing was found all the way down to the bottom of a sand bed operated with inadequate backwash rates for just a few months. This suggests that if dual media is used, only the anthracite layer would have to be changed on a regular basis. This would reduce both the down time required and the risk of damage to the filter nozzles when the filter media is changed.

If dual media is chosen, it is extremely important that the two media used are compatible, i.e. that they fluidise at approximately the same backwash rate. If the grains in the top layer are too heavy (too large and/or too dense) excessive intermixing of the coarse and fine layers will occur resulting in rapid clogging of the filter. If anthracite is used, it is particularly important to check that the density of the material used is the same as the design specification since it can vary from 1450 to 1650 kg/m^3. The density must be determined after soaking the anthracite in water overnight to eliminate air trapped in the pores of the media. If the anthracite is less dense than the design specification, it may wash out during backwashing. For details on charcterisation of filter media see (16, 17). For details on the design of dual media filters see (4, 7, 8).

Backwash Rate And Volume

In practice, the higher the backwash rate the more efficient the backwash. Amirtharajah (18) showed that for beds of uniform particles, the maximum backwash efficiency occurs at a fluidised bed porosity of ~ 0.7 while for graded beds the efficiency approached a maximum when the porosity of the layers of finer media at the top of the bed approached this value. However, since efficiency is not very sensitive to backwash rate close to the optimum, designers will typically select rates based on experience and economics. Appropriate backwash rates can be conveniently calculated as a function of mean grain size and water temperature using the following relationships (7):

$$V_{b,20^oC} = 0.47 d_{60} \text{ for anthracite with density 1550 kg/m}^3 \quad [1]$$

$$V_{b,20^oC} = d_{60} \text{ for silica sand} \quad [2]$$

$$V_b = V_{b,20^oC} \cdot \mu^{1/3} \quad [3]$$

$V_{b,20^oC}$ = Design backwash rate at 20°C, m/min

V_b = Design backwash rate at temperature other than 20°C

d_{60} = Sieve size through which 60 % of media mass passes, mm

μ = Water viscosity, cP

Design filter backwash rates should be based on the warmest water temperature expected, which in many places in South Africa, could approach 30 °C. Ideally, different backwash rates should be used in summer and winter but most small treatment plants do not have that flexibility.

Backwash should be continued until the turbidity of the effluent drops to about 10 NTU (1). Operators should be trained to measure the effluent turbidity towards the end of backwash on a regular basis and particularly when there has been an increase in raw water turbidity or disruption in settling tank performance. For design purposes, a backwash volume of least 4 m^3/m^2 is recommended (2).

One of the disadvantages of valveless filters is that the backwash rate declines as the level in the storage tank above the filter compartment empties. Brouckaert *et al.* (4) found that the filter bed was subfluidised for over half the backwash volume for typical valveless filter media sizes and backwash rates. Increasing the backwash rates requires increasing the height of the backwash reservoir and/or increasing the diameter of the backwash pipe. Ideally, the filter bed should remain fluidised for most or all of the backwash but the initial backwash rates should not be so high as to cause media losses.

Backwash rates in any filter may decline over time due to wear and tear on the backwash pumps, blockages or leaks in the backwash water lines and valves and clogging of the filter nozzles. Therefore it is important to check the backwash rates on a regular basis. It is also important that whenever the filter media is replaced, the new media meets exactly the same size specifications as the old media, or if a different media is used, it is compatible with the available backwash rates. This is true for both mono- and dual media filter beds and also for the replacement of filter nozzles. Installing nozzles with a different headloss characteristic to the original design can negatively impact both the backwash rates and washwater distribution (4).

Chemical Pretreatment

Most treatment plants and particularly those treating surface water require pre-treatment with coagulants (also known as flocculants) to achieve acceptable filtrate turbidities. An increasing number of South African treatment plants both large and small are switching from the traditional inorganic coagulants alum (aluminium sulphate) and ferric chloride to proprietary blends which include organic polymers. The advantages of these blends include the following: (i) lower doses are required and smaller volumes of waste sludge are produced; (ii) the liquid dosing systems are less prone to clogging than the dry feeders used for alum and ferric and do not pose the same dust hazard; (iii) polymeric blends may produce better filtrate qualities (but only if the correct doses are used). However, international experience has shown that the use of organic coagulants accelerates filter mudballing. Unfortunately, most local treatment plants owners are not aware of this when they decide to switch to polymer blends.

From the point of view of maximising backwash efficiency, plants without auxiliary filter wash should ideally use only alum or ferric chloride in the smallest doses able to achieve adequate filtrate turbidities. However, since the microbial safety of the treated water is strongly related to filtrate turbidity, improving turbidity removal must be given the highest priority. Improvements must however be sustainable during routine operation by the regular operators for the use of polymers to be justified. If polymers are used, plant owners need to be prepared to change the filter media more frequently and ensure the state of the filter media is checked at least monthly.

Backwash Frequency

The longer deposited material remains in the filter, the more difficult it becomes to remove during backwashing. Experience has shown that running filters for 36 h without backwashing can lead to an irreversible deterioration of the state of the filter media even when the rate of solids loading is low and auxiliary backwash is used (19). Brouckaert (20) found that delaying backwash for 1 day after the end of a filter run resulted in an approximately 10 % decrease in detachment efficiency (% of deposited floc mass detached during backwashing) The same study found that backwash efficiency was more strongly correlated with filter run time than either terminal headloss reached or mass of floc deposited during filtration. The decrease in backwash efficiency was assumed to be due to physico-chemical changes in the floc deposits. Therefore, in the absence of auxiliary wash, filters should be backwashed at least once a day to reduce the potential for mudball formation. This also applies to filters which do not operate continuously. At plants with valveless filters, operators must be trained to record when automatic backwash occurs and to initiate manual backwash in any filter which does not backwash itself at least once a day.

Non-Routine Methods For Mudball Removal

The AWWARF Maintenance and Operations Guidance Manual (1) describes several non-routine methods for breaking up or removing mudballs during backwash. These include raking the surface of the bed, fishing for mudballs with a 1 cm mesh net on a pole, breaking up submerged mudballs with a tool similar to a pitch fork and using a high pressure hose to increase the agitation of the media during backwashing. A device called a hydropneumatic wand which delivers a jet of high pressure water and air is also described.

These procedures are typically carried out weekly to monthly for open gravity filters (1) and less frequently for sealed filters (e.g. pressure and valveless filters) The first 4 methods are difficult to implement in the latter because they generally have to be opened and drained for the operator to have access to the bed. The authors of this paper have used a high pressure air lance to break up mudballs in a valveless filter after it was opened and partially drained. A portable compressor was used. A minimum frequency of 3 months is recommended for this non-routine intervention in sealed filters.

ASSESSING THE EFFECTIVENESS OF BACKWASH

The most accurate assessment of the state of the filter bed may be obtained by extracting core samples from various points in the filter and performing a floc retention analysis. Floc retention analysis involves stripping floc deposits off media samples and measuring the resulting turbidity in 500 mL of water. The results are usually reported as turbidity per 100 g media. 30 – 60 NTU indicates the filter is clean; 60 – 120 NTU indicates a slightly dirty bed; over 120 NTU indicates a dirty bed where the filter washing system and procedures need to be evaluated and over 300 NTU indicates a possible mudball problem. If the backwash is efficient, the floc retention results tend be fairly uniform throughout the bed depth whereas there tends to be a large amount of variability in floc retention at various points in the bed for inefficient backwash (7). Core sampling should be carried out every 3 to 6 months and should be considered part of routine plant performance monitoring whether it is carried out by local personnel or external agencies providing technical support. Detailed procedures for filter media sampling and analysis of retained solids are provided in (1,7). Methods for obtaining more reproducible measurements of retained solids are discussed in (21).

Kawamura (7) recommends that if mudballs are found in the filter then the fraction of the filter volume that they occupy should be determined. This involves excavating a known volume of filter media (representative of the entire media depth) and collecting the mudballs it contains by hand. The volume of mudballs can be measured by placing them in a beaker or graduated cylinder and gently pressing them down to avoid large void spaces. The % volume of the filter occupied by mudballs can then be calculated. Less than 0.1 % indicates a clean bed, 0.1 – 0.5 % indicates the media is in good condition, 0.5 - 1.0 % may be considered fairly clean, 1 – 5 % indicates the filter is in bad condition and if greater than 5 % of the volume is made up of mudballs then the filter media should be replaced.

Observation of the surface of the filter before, during and after backwashing will also provide some clues about the state of the media (1, 7). Lumps and cracks on the surface of the bed prior to backwashing indicate excessive mud accumulation and probable mudballing as do lumps, mudballs, worms and debris on the surface after backwashing Visual inspections should be conducted at least once a month for open gravity filters and at least once every three months for valveless and pressure filters.

Regular monitoring of filter performance (turbidity and headloss development, especially at the beginning of each run) is also recommended to help identify backwashing problems early, especially in the case of sealed package plant filters. However, significant mudballing may occur before filter performance deteriorates (4). Furthermore, record keeping is typically poor in rural plants and local personnel often do not have the skills required to analyse their own data therefore filter monitoring cannot be substituted for periodic direct inspection of filters including pressure and valveless filters.

PREDICTING THE USEFUL LIFE OF FILTERS

In order to predict the useful life of a filter bed (period of operation before the media must be replaced) under suboptimal backwash conditions it is necessary to have: (i) a means of predicting the rate of accumulation of residual sludge (deposits not removed by backwashing) in a filter and (ii) some criteria for determining when the media should be replaced based on the accumulated sludge content. This section discusses a method for estimating the amount of time it will take for the mudball volume fraction to reach 5 %, Kawamura's (7) criteria for filter media replacement.

Rate Of Accumulation Of Residual Sludge

Brouckaert *et al.* (20, 22) measured the amount of residual sludge retained in laboratory filters with upflow water wash only after 1 to 9 consecutive filter runs and found there was a fairly steady increase in retained sludge with increasing number of runs although the rate of increase appeared to decline slightly as the cumulative mass retained increased. Possible explanations include that the finest fraction of the filter media is most prone to mudballing as discussed previously. As these smaller particles become incorporated into mudballs, the shearing forces on the structures formed increase tending to limit their rate of growth. Factors including backwash rate, filter run time and floc characteristics affected the backwash efficiency for individual filter runs. The following model of residual sludge accumulation over multiple filter runs was proposed:

$$\frac{\Delta\left(\sum M_R\right)}{\Delta n} = f\left(p_{f1}, p_{f2}, p_{f3}, \ldots, p_{b1}, p_{b2}, p_{b3}, \ldots, \left(x_i d_i\right)_n\right) \qquad [4]$$

ΣM_R = Cumulative mass of sludge retained, g/m^2 filter area

n = Number of filter runs

p_{f1}, p_{f2}, p_{f3} = Parameters relating to the filter run which affect the strength of deposits e.g. coagulant used, run duration, etc.

p_{b1}, p_{b2}, p_{b3} = Backwash parameters which affect the hydrodynamic detachment forces e.g. backwash rate and temperature, etc.

$(x_i d_i)_n$ = Size distribution of media not incorporated in mudballs after n filter runs

Equation [4] states that increase in residual floc retained after backwash from one filter run to the next will depend on both filtration and backwash conditions and the current state of the filter bed. The filter media size distribution can be determined from core sample analysis as described in (1, 7), This model would be calibrated for any given plant using available operating data.

Calculation Of Mudball Volume

The volume of mudballs in a filter at a given moment in time can be estimated by first calculating the mass of sludge retained in the filter after backwashing and then estimating the volume of mudballs it will produce (20). The cumulative mass of retained solids, ΣM_R can be estimated from the results of floc retention analysis of core samples. Either a composite sample of media representing the entire filter depth can be prepared or else the average result of evenly spaced points throughout the filter depth can be used. However, the amount of material stripped off the filter grains needs to be expressed in terms of g of deposit per unit filter area rather than turbidity. For greatest accuracy, the amount of solids stripped off the filter media should be measured directly by suspended solids analysis (23). The cumulative mass retained in the filter based on a 50 mL sample of media is

$$\sum M_R = \text{mass of deposits recovered from 50 mL media(g)} \times \frac{l_{fx}}{5 \times 10^{-5}} \qquad [5]$$

l_{fx} = Fixed bed height, m

Mudballs typically consist of a mixture of filter grains and floc deposits. If it is assumed that the volume fraction of sand in a mudball is approximately the same as the volume fraction of sand in a clean fixed bed, then the volume of mudballs can be estimated as follows:

$$V_{mb} = \frac{\sum M_R}{1000 \rho_d \varepsilon_0} \qquad [6]$$

V_{mb} = Volume of mudballs per unit filter area, m^3/m^2
ρ_d = Deposit density, kg/m^3
ε_0 = Clean fixed bed porosity

In general, the fixed bed porosity varies between 0.4 and 0.5 depending on the media size and backwash method. Methods for determining fixed bed porosity are described in (1, 16, 17) The density of the mud deposits may be assumed to be $\rho_d = 1030$ kg/m^3 (24). The % volume of mudballs is

$$\% \text{ volume } = \frac{V_{mb}}{l_{fx}} \times 100\% \qquad [7]$$

The rate of increase in mudball volume is

$$\frac{\Delta V_{mb}}{\Delta n} = \left(\frac{1}{1000 \rho_d \varepsilon_0} \right) \frac{\Delta \left(\sum M_R \right)}{\Delta n} \qquad [8]$$

The number of days to reach 5 % mudball volume can than be estimated based on the expected average filter run time. An example of this calculation is presented in (20).

Application To Design And Management Of Rural Filters

More experimental work is required to quantify the effects of media grain size distribution on backwash efficiency and mudball formation. The results of such studies could be helpful in determining the optimum media size distributions for minimising backwash problems while meeting other treatment objectives. However, for managing filters in the field, a conservative estimate of the filter bed life can be attained by assuming a linear increase in residual sludge with time. Ideally, replacement of the filter media should be scheduled based on core sampling of the filter carried out one month after a clean filter has commenced operation. The estimated life of the filter can be subsequently updated based on later media sampling exercises e.g. after 3 to 6 months of operation. The rate of mudballing could be expected to vary with factors including solids and hydraulic loading, coagulant dose, filter run time and water temperature as well as backwash rate if this changes. Operators at all treatment plants should be recoding data on flow rate, water quality, chemical consumption, performance of different treatment units and backwash frequency. This data could be analysed in conjunction with core sampling results to determine which operational practices and conditions are most critical to the long term performance of the filters.

ADVANTAGES OF SLOW SAND FILTERS FOR RURAL TREATMENT PLANTS

Realistically, maintaining rapid filters in good working order will remain a major challenge for small rural treatment plants, even if the recommendations in this paper are adopted. All of the backwashing problems discussed here can be avoided if slow sand filters are installed instead of rapid filters In slow sand filters, floc, micro-organisms and dirt particles are mainly removed in a thin layer known as the *schmudzedecke* which forms at the top of the filter. When the filter clogs up, the *schmutzedecke* layer is simply scraped off. This can be done by operators, community members or casual labourers with minimal training. Filters typically operate for several weeks or months between cleanings, depending on the characteristics of the water being filtered. The sand removed during scraping may be cleaned and replaced or discarded and replaced with fresh sand. Slow sand filters have traditionally been operated without any chemical pre-treatment. However, this option is only suitable for very high quality raw waters because turbidity removal is generally poor when coagulant is not used. In South Africa, a number of small treatment plants use slow sand filtration instead of rapid filtration following conventional coagulation, flocculation and sedimentation.

As a result of its simplicity of operation and design, slow sand filtration is considered an appropriate technology for both developing countries and rural areas of industrialised countries. (7). Slow sand filtration is currently enjoying a resurgence in popularity in the USA partly because it can be effective in removing pathogens including *Giardia* even without the use of coagulants (25). Slow sand filters do have a number of disadvantages including that they require much larger filter areas than rapid filters, cannot handle high solids or algal loads, require 24 – 48 h to clean and take up to a week to ripen after cleaning (7). Furthermore, proper operator training in their use and maintenance is still crucial. Nonetheless, rural municipalities and communities with limited technical resources are more likely to be able to operate slow rather than rapid filters in a sustainable and cost effective manner. Local authorities and consultants in South Africa therefore need to be better informed of the relative advantages and disadvantages of rapid and slow sand filtration in order to select the most suitable technology for their particular situation.

CONCLUSIONS AND RECOMMENDATIONS

- The use of coagulants leads to mudballing in filters without auxiliary backwash systems. Eventually the filter media will have to be replaced or chemically cleaned.
- Fixed grid surface wash system can be as effective as consecutive air and water wash and are recommended for developing countries.
- Annual replacement of the filter media may be a more practical and cost effective option than auxiliary wash in some situations. For dual media filters, only the anthracite layer may need to be replaced on a regular basis.
- The use of coarser media and higher backwash rates, backwashing filters at least once a day and avoiding the use of polymeric coagulants or flocculants can reduce the rate of mudballing in the absence of auxiliary wash.
- Non-routine methods of breaking up or removing mudballs from the bed procedures should ideally be carried out at least monthly if mudballs are observed.
- Visual inspections of the state of the filter bed before, during and after filter backwash should ideally be carried out at least monthly. Core sampling and floc retention analysis should be carried out every three to six months.
- The rate of mudball accumulation can be estimated from the floc retention analysis. The filter media should be replaced once the volume fraction of mudballs in the bed reaches 5 %. The useful life of a filter bed can be estimated by assuming a linear

increase in retained floc over time. The actual rate of mudballing will vary with factors including solids and hydraulic loading, coagulant dose, filter run time and water temperature.

- Slow sand filters are much easier to operate and maintain than rapid filters therefore they are often a better choice for rural treatment plants. Conventional pre-treatment may be required to prevent slow sand filters from clogging too quickly.
- Regardless of the filtration and backwash technology selected, proper operator training is critical.

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