An Introduction To Slow Sand Filtration

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Issue 1 December 2005

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1. Types Of Sand Filter

The use of sand and gravel as filter media for water supplies can me split into three basic filter types: *slow sand filters*, *rapid filters* and *roughing filters*.

Apart from desalination and reverse osmosis, slow sand filters are perhaps the most effective single treatment for purifying drinking water supplies. They are use on a large scale as part of the water supply for large cities, as part of systems for small villages and on a much smaller scale they can be adapted for use in individual households.

Rapid sand filters are normally require a subsequent chlorination process and are thus of less use for small village supplies unless the raw (untreated) water supply is of a reliably high quality.

Roughing filters are used to reduce the turbidity of water supplied and often used as a pre-treatment before slow sand filtration.

The important features of these three filter types are detailed below and summarised in table 1.1.

1.1.Slow Sand Filters

Slow sand filters use sand with effective sizes of 0.15 - 0.35 mm (see section 3) to remove a large percentage of coliforms, cryptospridum and Giardia cysts. They operate most effectively at a flow rate of 0.1 – 0.3 m/h (or $m^3/h/m^2$), which equates to 100 – 300 l/h per m^2 of filter area.

These filters use physical processes such as sedimentation, adsorption and straining to remove fine particles as well as microbiological processes to remove organic material and bacteria. Because of the slow filter rates the raw water sits above the sand for several hours before passing through it, various oxidation reactions break down organic material during this time. Algae, that grows on the sand surface, consumes this oxidised organic material and releases oxygen back into the water.

Roughing filters and sedimentation are often used as pre-treatments to reduce the turbidity of the raw water and therefore reduce the rate at which the slow sand filter becomes clogged. Some aeration, to increase the oxygen content of the raw water, is also desirable.

Post-filtration chlorination or UV-purification can also be used; however, with a filter that is functioning well such treatments are not strictly necessary.

The flow of raw water through the filter should be continuous, however small scale filters, for use in individual households, have been designed to work intermittently (i.e. a few hours a day). These have been widely used in several countries around the world (see section 8).

1.2.Rapid Sand Filters

These filters use coarser sand than slow sand filters and the effective size of the filter media is usually greater than 0.55 mm. The flow rates are normally between 4 and 21 m/h equating to 400 to 2100 l/h per m^2 of filter.

These filters do not remove disease causing entities as efficiently as slow sand filters and usually need a post filtration chlorination process.

Flocculation and coagulation are sometimes used as pre-treatments.

1.3.Roughing Filters

These filters are used to remove suspended solids by passing the water through material that is much coarser than that used in slow sand filtration or rapid sand filters. The filter material is usually graded so that the water passes through coarse (25 mm), medium and then fine (5 mm) sand. Flow rates are often in the region of 0.3 – 0.6 m/h (i.e. 300 – 600 l/h per m^2 of filter surface area).

	Rapid Sand Filtration	**Slow Sand Filtration**
Improvement of water quality	With pre-treated water, filtrate quality is possible that has 1 NTU turbidity, 90 % removal of coliforms, 50-90 % removal of cryptosporidium and Giardia cysts, 10 % removal of colour, 5 % removal of total organic content.	With raw water a filtrate quality is possible that has less than 1 NTU turbidity, 95 % removal of coliforms, 99 % removal of cryptosporidium and Giardia cysts, 75 % removal of colour, 10 % removal of total organic content.
Flow Rate	4-21 m/h	0.1 – 0.3 m/h
Filtration Medium	Graded sand and sometimes additional coarse layers. Effective size > 0.55 mm and uniformity coefficient < 1.5.	Effective size between 0.15 – 0.35 mm, uniformity coefficient between 1.5 – 3, preferably < 2.
Cleaning Required	Backwashing needed frequently	Top 1 cm of sand removed every few months.
Pre-Treatment	Usually necessary including coagulation and flocculation followed by sedimentation.	Plain sedimentation and roughing filters may be used to reduce the turbidity to below 20 NTU and preferabley below 5 NTU. Flocculation should not be used.
Post-Treatment	Chlorination is usually required.	Chlorination to be on the safe side.
Filtering Mechanism	Sedimentation, adsorption , straining, chemical and microbiological processes.	Sedimentation, adsorption , straining, chemical and microbiological processes.
Main Filtering Mechanism	Physical especially adsorption.	Microbacterial.
Principal Advantages	Substantially reduces pathogenic bacteria, viruses and cysts, to produce a potable water without further treatment. No machinery required.	Relatively small and compact.
Principle Disadvantages	Can only effectively treat low turbidity water.	Cannot produce a potable water without further treatment. Backwashing water required to clean filter – this usually unvolves pumps.

Table 1.1: A comparison of slow sand filters and rapid sand filters.

1.4.The Basic Design Of Slow Sand Filters

Figure 1.1. show the basic design principles used in a slow sand filter.

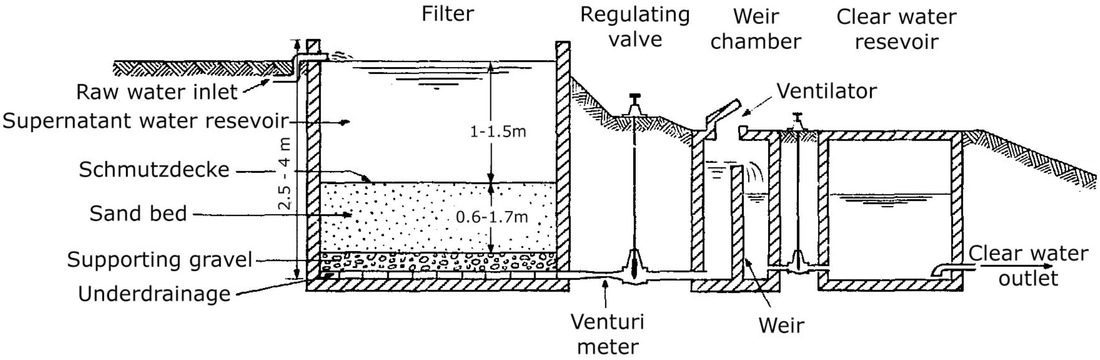

Figure 1.1: The basic design of a slow sand filter.

There are several important elements that should be observed when constructing slow sand filters:

- The raw water supply feeding the filter should be able to maintain a constant head of water above the filter bed, thus there will be a constant pressure pushing water through the filter[1]. The raw water source must therefore be able to supply a flow rate greater than the flow rate through the filter
- The filter bed (normally sand) should be at least 0.6 m deep and should contain sand of an appropriate size and size distribution.
- The under drainage system must support the filter bed while providing the minimum resistance to flow.
- The resistance of the filter bed will increase during use as the pores between sand grains become blocked by the material being removed from the raw water. The flow rate through the bed should be controlled by a regulating value placed in a pipe after the filter. The amount of head above the filter should not be used to regulate flow.
- A weir should be placed in the system between the filter and the storage tank. The weir insures that if the raw water supply fails the filter bed can not run dry. As the filter is used the resistance of the sand bed surface increase due to clogging, the weir insures that it is impossible for the top of the sand bed to run dry even if water can drain out of the bottom of the bed faster than it can pass through the surface.

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[1] Note that the entire filter unit runs full and is therefore under pressure.

2. Filtration Mechanism In Slow Sand Filters

Several mechanisms for the removal of turbidity, bacteria, viruses and organic matter operate in slow sand filters. These can be broken down into two broad groups: *physical and mechanical;* and *biological*. Slow sand filters differ from rapid sand filters and roughing filters in the biological processes predominate.

2.1.Physical And Mechanical Processes

Straining is perhaps the most obvious process whereby particles can be removed from water flowing through a sand bed; that is, particles that are too large to fit through the pores between sand grains become lodged and are therefore removed from the water.

However, rapid sand filters have been shown to trap particles that are far smaller than the pores. For example, sand grains with diameters of 0.5 – 1.0 mm will have pores which are approximately 0.1 mm in diameter but can remove particles with sizes of 0.01 mm and bacteria with sizes of 0.001 mm. Since these observations have been made using rapid sand filters the removal mechanism is physical rather than biological.

There are two important factors that must occur when particles are physically removed from water. Firstly a particle must move into contact with a sand grain (*transport*) and secondly the particle must become attached to it (*attachment*).

2.1.1.Transport

Because of the slow flow rates many of the larger solid particles will settle out in the head of water above the sand bed. The processes that occur within the sand bed can be summarised as followed:

- *Interception* – the water flows so that particles move close enough to a sand grain to become attached.
- *Diffusion* – random Brownian motion brings particles close to grains.
- *Sedimentation* – gravitational forces move particles downwards onto the top surfaces of grains.
- *Hydrodynamic* – particles in a velocity gradient (i.e. where water is flowing around a grain) often develop a rotation which provides lateral forces that move particles out of the water stream and into contact with sand grains.

2.1.2.Attachment

These processes involve electrostatic and molecular (Van der Waals) forces that are similar to those that occur in coagulation. These attractions are sensitive to the surface charges on the sand grains and therefore the pH of the raw water. For example virus removal occurs more readily in low pH environments and for normal sand, *E. Coli* removal is most efficient in water with a of pH5.

2.2.Biological Action

Slow sand filters have small flow rates hence most solid particles are removed in the top 0.5 to 2 cm of sand. This top layer of sand develops into a biologically active area known as the *schmutzdecke* (which translates roughly from German as ‘dirty layer’). While most of the biological activity occurs in this region some activity continues down to a depth of about 0.5 m, although faster flow rates will carry organic food, that sustains bacteria, even deeper into the sand bed.

The Schmutzdecke is perhaps the single most important feature of the slow sand filter and is a sticky reddish brown layer consisting of decomposing organic matter, iron, manganese and silica. It acts as a fine filter to remove fine colloidal particles from the raw water and is also the initial layer of bioactivity.

The schmutzdecke takes a while to form and ripen, this may take 2 – 3 weeks depending on the temperature and the biological content (bacteria and organic material) of the raw water. Once functioning the schmutzdecke should remain undisturbed until the filter has to be cleaned – probably 2 – 20 weeks. After cleaning, where the top 1 cm of sand is removed, the schmutzdecke will take a few days to re-ripen.

The schmutzdecke is effective against intestinal bacteria because the temperature is lower than body temperature and there is little appropriate food. Also there are predatory organisms present at the top of the filter bed.

The effectiveness of the schmutzdecke relies on there being adequate food (organic material in the raw water), a high enough oxygen content and a sufficient water temperature. The following points should be observed when operating a slow sand filter:

- The sand must be kept wet to keep the essential micro-organisms alive in the biological zone.
- The biological zone needs food, therefore raw water should be continually fed in and the filter should be run continuously.
- The biological zone needs adequate oxygen for the metabolism of biodegradable components and the consumption of photogenes. If the oxygen content of the filter drops too far anaerobic decomposition occurs producing hydrogen sulphide, ammonia and other products that affect the taste and odour of the water.

The oxygen content of the filter should be above 3 mg/l to ensure anaerobic conditions are avoided within the filter. To maintain the oxygen level in the filter:

- Ensure there is a continual flow of water through the filter.
- Provide an aeration treatment before, or as, the raw water enters the filter.
- Do not have an excessive head of water above the sand bed.

The biological layer becomes less effective at lower temperatures. When the air temperature drops to below 2°C for any prolonged period the filter should be covered to prevent heat loss or chlorination should be used on the filtered water as a safeguard.

2.3.Algae

During use a layer of algae will build up on the surface of the sand bed. The nature of this algae will depend on the raw water being filtered, the flow rate, the temperature and the amount of sun light that the surface of the filter receives. Some algae types form an impenetrable layer on top of the filter and may reduce the running time before cleaning is required. Other algae types are more fibrous and will take longer to block the filter. The rate of algae growth can be controlled to some extent by altering the amount of time for which the filter is covered and therefore shaded from the sun.

The algae play an important role in consuming CO_2, nitrates and phosphates while liberating oxygen. If the temperature drops for a prolonged period the algae will die off releasing CO_2 and consuming O_2.

3. Sand

3.1.Characterising Sand Samples

A sample of sand taken form a source will not consist of uniformly sized grains but contain a range of grain sizes. Two quantities are therefore needed to characterise a sand sample:

- *Effective particle size* – this is the particle diameter such that 10 % (by weight) of the grains in the sample are smaller than it and 90 % of grains are larger than it. The effective particle size is therefore also referred to as D_{10}.
- *Uniformity coefficient* – this is a method of expressing the sizes difference between the largest and smallest grains in the sample (also known as the particle size distribution). The uniformity coefficient is defined as the ratio D_{60}/D_{10}. Like D_{10}, D_{60} is the particle size whereby 60 % of the samples grains are smaller and 40 % are larger.

The easiest way to determine D_{60} and D_{10} is to pass a dry sand sample through a stack of decreasing sieve sizes as described below.

3.2.Sieve analysis

For this test you will need a set of analysis sieves that are designed to stack together in a tower and scales (preferably digital) that are accurate in the desired range. The size of the sample used will depend upon the weighing range of the scales, for a 200 g sample of sand the scales should be able to weigh between 200 and 0.1 g. In the worst case scenario, if accurate scales can not be found, you can measure volumes and assume that the different sizes of sand all have the same density and packing efficiency.

If you are planning to use sand from a source such as a river sand bank you should wash the sample by agitating it in running water to remove excessively fine grains and organic material. Dry the sand thoroughly before testing. With such sources you will have to wash the sand before using it in a filter anyway.

The analysis proceeds as follows:

1. Stack the sieves with the coarsest at the top and the finest at the bottom.
2. Mix the dry sand well and measure out approximately 200 g into the top sieve.
3. Put the lid on the top sieve and shake the whole stack. You should continue shaking for 10 minutes.
4. Weigh the sand retained in each sieve as accurately as possible. Do this cumulatively so that you weigh the sand retained by the coarsest sieve, then add the sand retained by next sieve and note the combined weight, do this until you have added the sand that passed through all of the sieves and noted the weight.
5. Work out the cumulative weight percent of sand retained by each sieve and then subtract this number from 100 to calculate the cumulative weight percent that passed through each sieve.

An example of sieve analysis results are given in table 3.1.

Sieve Size	Cumulative Wt. Retained (g)	Cumulative Wt.% Retained	Cumulative Wt.% Passed
10.00	0.0	0.0	100.0
6.30	39.2	19.6	80.4
5.00	48.6	24.3	75.7
3.35	74.1	37.1	62.9
2.00	92.4	46.2	55.8
1.18	110.2	55.1	44.9
0.60	126.9	63.5	36.5
0.425	142.3	71.2	28.8
0.15	196.0	98.0	2.0
<0.15	200.0	100.0	0.0

Table 3.1: Example of sieve analysis.

When the sieve size is plotted against the cumulative weight percent passed a size distribution curve is obtained. Using a normal x-axis a characteristic s-curve is formed (figure 3.1). If a logarithmic x-axis is used a curve that approximates a straight line will probably result (figure 3.2)[2]. Values for D_{10} and D_{60} can easily be read from these graphs.

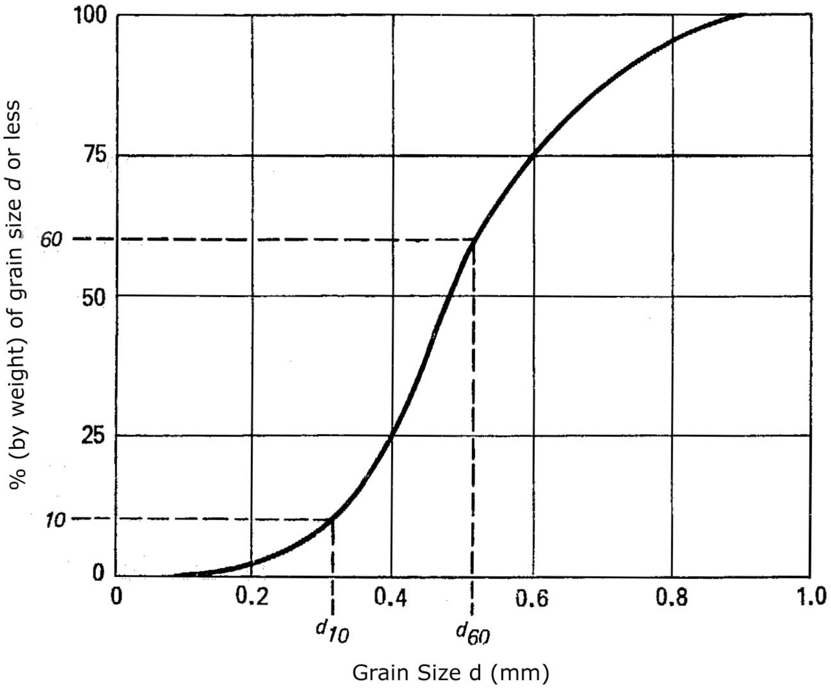

Figure 3.1: Sieve analysis results plotted on a normal x-axis. Note that D_{10} and D_{60} can now easily be read from the graph.

If you are getting a large percentage of sand that will not pass through the coarsest sieve you can improvise a larger sieve using a mosquito net and measure the sieves aperture size using a magnifying glass.

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[2] Such graphs can easily be plotted using a spread sheet or logarithmic graph paper.

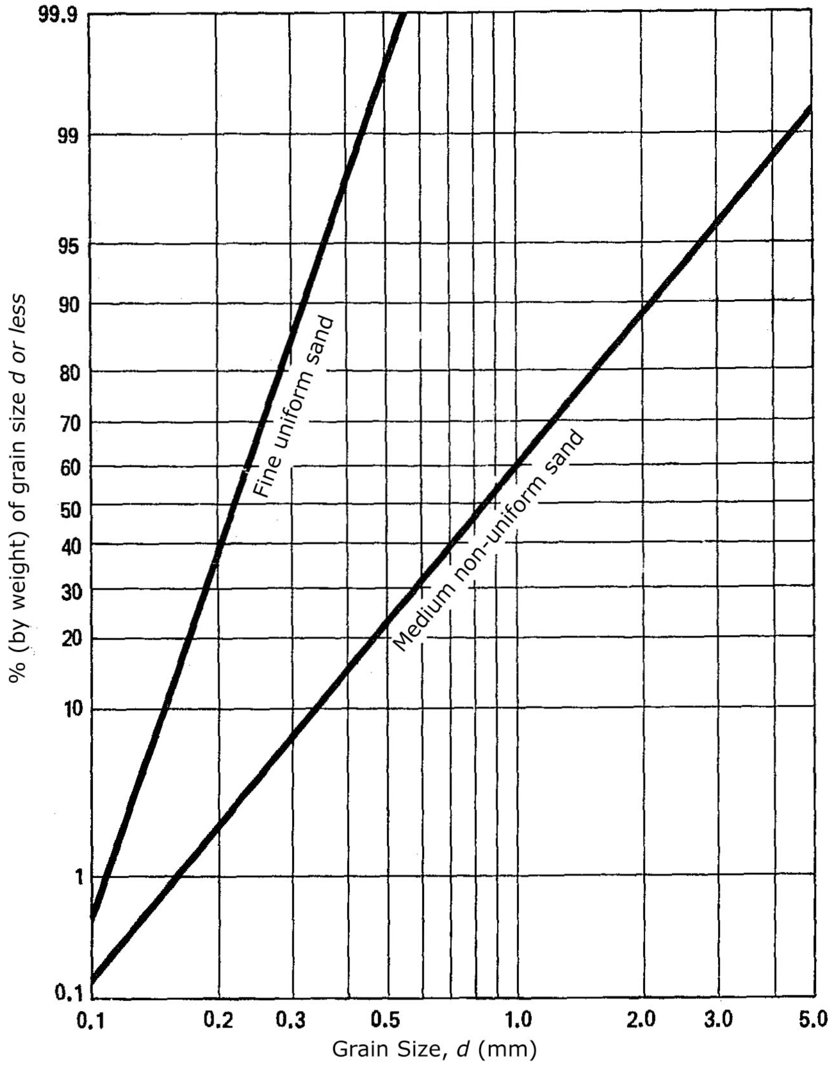

Figure 3.2: Sieve analysis results plotted on a logarithmic x-axis. The graph illustrates two sand samples one with fine grains within a narrow size range and the other with a greater distribution of sizes.

3.3.Sand Requirements

A 1 m^3 sample of sand with a small grain size has a larger total surface area than a 1 m^3 sample of sand with lager grains. A small grain size therefore provides a large surface area onto which sedimentation and adsorption can occur as the raw water passes through the filter. During use the sand grains become coated with a film of bioactive material that removes bacteria and other organic material from the water, so that the finest possible sand would appear to be preferable. However, the finer the sand grains are the smaller the pores between grain and a filter using excessively small grains will soon clog and require cleaning.

The surface area of a sand sample can be calculated from:

$$A = (6/d)(1-P)$$

where A is the gross surface area, d is the grain diameter and P is the total porosity.

For 1 m^3 of sand with an average diameter of 0.25 mm and a porosity of 38% the gross surface area is 15 000 m^2. After making allowances for the portion of the grain's surface facing upwards there is about 1000 m^2 of sand surface below each m^2 of sand filter for sedimentation and adsorption to occur.

Sands with a wide size distribution pack more efficiently than those with a narrow distribution, since the smaller grains can fit into the pores left between the larger grains. However, a sand bed with a small pore volume will reduce the maximum flow rate through the filter and clog quickly. Therefore there as well as an optimum effective size, there is also an optimum uniformity coefficient.

Sand used in slow sand filters should have an effective size of 0.15 – 0.35 mm and a uniformity coefficient of 1.5 – 3, however < 2 is desirable. Preferably the sand should have rounded, rather than jagged, grains and be free from clay. Hence, sand from streams and rivers is normally better suited to slow sand filters than sand from pits.

RedR recommends that you should look for a sand supply locally and wash it to remove fines and organic matter. The maximum grain size should be 3mm and the minimum grain size should be 0.1mm. Coarse grains can be removed by sieving through an appropriate mesh. They add that in practise most sand will work, however fine sand may cause excessive head loss and coarse sand may not produce water of an acceptable quality.

Tests (at a constant flow rate of 0.1 m/h) have shown that the removal of bacteria, turbidity and colour are not very sensitive to sand size up to sizes of about 0.45 mm, although smaller sizes are slightly more effective. Since coarser sands have a smaller surface area than fine sands, if there is no fine sand available the depth of the filter bed should be increased to compensate.

3.4. Washing Sand

If the sand is taken from a natural source it should be washed before it is placed in the filter. Figure 3.3 shows a barrel and pipe arrangement that can be used for sand washing.

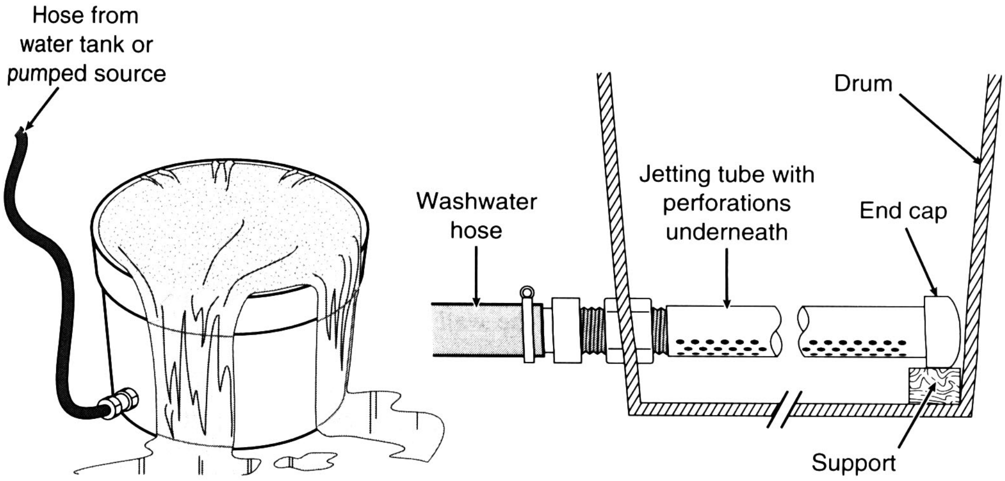

Figure 3.3: Washing the filter sand.

4. Hydraulics Of Filtration

The flow rate through a slow sand filter bed is very small and laminar flow can therefore be assumed. The head loss or resistance due to the filter can be calculated from:

$$H = \frac{V_f}{k} h$$

where h is the thickness of the filter bed, V_f is the filtration rate (the volume passing per hour divided by the surface area) and k is the coefficient of permeability. This coefficient has dimensions of velocity and is usually expressed in m/h. The value of k is best determined experimentally however a value can be estimated from:

$$k = 150\ (0.72 + 0.028\mathrm{T}) \frac{p^3}{(1-p)^2} \varphi^2 d_s^2 \qquad (m/h)$$

where: T = the temperature in °C,
p = porosity (volume of pores / the total volume of the filter medium),
φ = shape factor (sometimes referred to as sphericity),
d_s = specific diameter of sand grains in millimetres.

Grains of sand will rarely have round grains and the shape factor φ is the ratio surface area of a sphere to the surface area of an average grain of the filter sand having the same volume. The shape factors for various grain shapes are shown below:

	Spherical	Nearly spherical	Rounded	Worn	Angular	Broken
φ	1.00	0.95	0.9	0.85	0.75	0.65

The specific diameter d_s is a means of describing a grain size for a sample of naturally occurring sand that has a range of grain sizes. It is defined as the grain size of a grain from an imaginary sample of sand where all the grains have the same size, such that the whole sample has the same gross surface area as an equal weight of the naturally occurring sand.

As described in section 3 the coefficient of uniformity (U) is defined as D_{10}/D_{60} and if the size distribution produces a reasonably straight line when plotted on a log x-axis (as in figure 3.2) the ratio ψ (d_s / D_{10}) can easily be calculated from:

$$d_s = D_{10}\ (1 + \log U) = \psi D_{10}$$

When the sand's particle size distribution does not produce a good straight line when plotted on a log x-axis the values from the following table can be used:

U	1.0	2.0	3.0	4.0	5.0
ψ	1.0	1.6	1.93	2.11	2.21

The particle size distributions for most sands will be derived from sieve analysis where the sieves will have square holes. Since the grains of sand are most probably not completely spherical, the volume of a grain of sand that can just pass through a certain sized hole will be greater or smaller than a completely spherical grain that passes through the same hole, depending on the grain shape. For example an elliptical grain that can just pass through a certain square hole will have a larger volume than a spherical particle that can just pass through same hole. Thus:

$$D_{10} = x\, s_{10}$$

where s_{10} is the size of a square hole that would pass 10% of the filtration sand and x has a value of 1.05 for rounded grains, 1.2 for quite elongated grains and about 1.10 for the elliptical grains normally encountered in filter sands. By substituting this equation into the previous one we can derive a new equation for k:

$$k = 150\ (0.72 + 0.028\mathrm{T}) \frac{p^3}{(1-p)^2} \varphi^2 \psi^2 (1.10 s_{10})^2 \qquad (m/h)$$

Thus:

$$k = 180\ (0.72 + 0.028\mathrm{T}) \frac{p^3}{(1-p)^2} \varphi^2 \psi^2 s_{10}^2 \qquad (m/h)$$

Assuming a sand with nearly spherical grains (φ^2 = 0.9) and a coefficient of uniformity a little less than 2 (ψ^2 = 2.5), a temperature of 10°C and a porosity of 0.38, the formula above gives, for effective sizes s_{10} of 0.15 mm and 0.35 mm, coefficients of permeability of about 1.1 m/h and 6.0 m/h respectively. The latter value is so large that even with thick beds (1.2 m) and high filtration rates (0.5 m/h) the initial resistance is equivalent to a loss of head of less than 0.1 m. On the other hand the smaller sand with a permeability of 1.1 m/h produces an initial resistance of over 0.5 m with the same bed thickness and filtration rates. Thus to keep the resistance to below 0.1 m or less the bed thickness must be limited to 0.5 m and the filtration rate kept to about 0.2 m/h. Note that the only head available to push water through the filter is the head of water sitting above the sand bed.

As the filter bed is used it will become clogged and the schmutzdecke and algae will developed. Thus, the initial value of head loss estimated above will increase. In practice you will probably have to run a test filter for several months before you can be confident about how much headloss will occur with a certain depth of a particular sand.

5. Basic Designs

5.1.The Stages In A Slow Sand Filtration System

There are several important stages in a slow sand filtration system:

- Pre-treatment – one or more of the following:
    - sedimentation tank
    - roughing filter
    - aeration
- The sand bed
- Under drainage, protected by a gravel pack
- A flow-regulating valve
- Weir
- Chlorination (if applicable)
- Storage Tank

5.2.Some Design Notes

5.2.1.Pre-treatment

Slow sand filters operate most effectively when the raw water has a turbidity of less than 20 NTU. If turbidity exceeds this the filter may become blocked after only a few weeks of operation. Thus a sedimentation tank or a roughing filter should be used to pre-treat the raw water.

The raw water should also be well oxygenated so that the conditions within the sand filter will not become anaerobic. Note that the water can be aerated as it enters the sedimentation tank or the sand filter. Also note that although the flow rate through the filter can be controlled by varying the head of water sitting on top of the sand bed, it is far preferable to include a valve to regulate the flow (and always maintain a constant head).

5.2.2.The sand Bed

The sand should meet the requirements laid out in section 3. The sand bed should initially be about 1.2 m deep; although this will reduce each time the filter is cleaned. The head of water above the sand should be about 1 - 1.5 m.

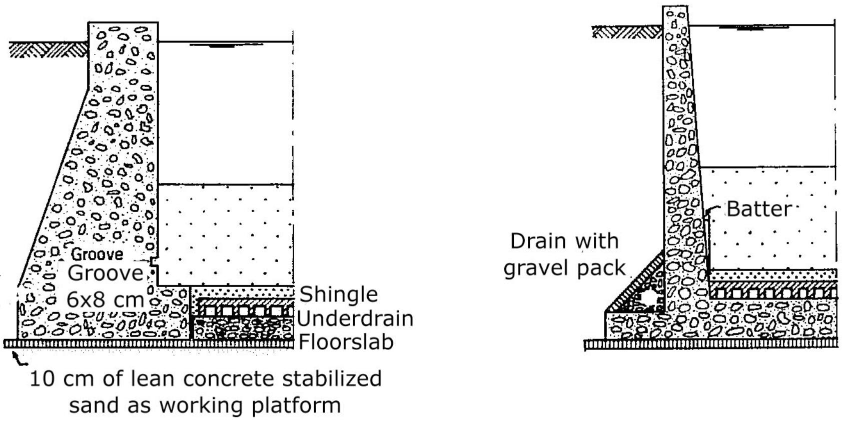

Figure 5-1: Methods of stopping water bypassing the filter.

The filter box must be deep enough to contain the under drainage and gravel pack, the filter bed and the head of water above the filter bed. In total this will be about 3.5 m.

For small filters some device should be used to prevent water running straight down the filter's walls without passing through the filter bed. Methods include notches or batters in the walls and keeping the under drainage some distance from the base of the walls (figure 5.1).

5.2.3.Under Drainage And Gravel Pack

The filtered water passes through a gravel pack to prevent any of the sand from the filter reaching the drain. The gravel pack must consist of several layers of gravel with successively increasing particle size, normally four layers will be sufficient. If available *geotextiles* can be used instead of gravel layers.

The coarsest layer of gravel should have an effective diameter of at least twice the size of the openings into the drainage system; the gaps between bricks or slots cut into piping. There are various methods of calculating the sizes needed for the other layers but these require each gravel sample to be graded separately. For example one method is to ensure that the D_{15} size of one layer is 9 times the D_{15} size of the adjacent layer; if the ratio is greater than 9 then migration may occur.

However, with a filter sand that has a effective diameter of about 0.15 mm the four layers should be graded as follows: 0.7 – 0.14 mm, 2 –4 mm, 6 – 12 mm and 18 – 36 mm.

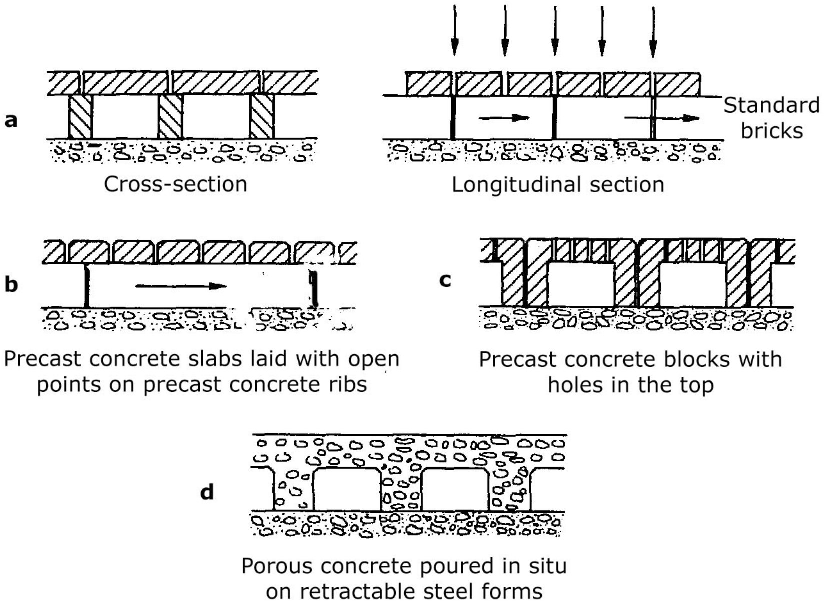

Figure 5.2: Designs for under drainage.

Figures 5.2 and 5.3 show various designs for under drainage. Remember that the whole drainage system should slope towards the outlet pipe.

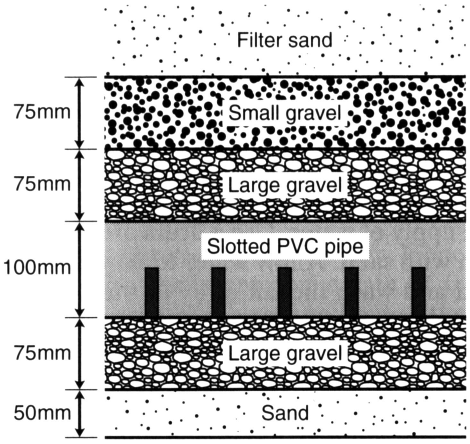

Figure 5.3: Using a slotted pipe as under drainage.

5.2.4.Flow-Regulating And Other Valves

The rate of flow through the filter should be controlled by a value and not the amount of head above the filter. As the flow rate reduces during filter use the valve can be opened to maintain the supply, once the filter is cleaned the flow can be reduced so that the water has the correct residence time inside the filter. Remember that the optimum flow rate is about 0.1 – 0.3 m/h (or m^3/h per m^2 of filter surface area).

Several other valves should be added to help during maintenance (see figure 5.4).

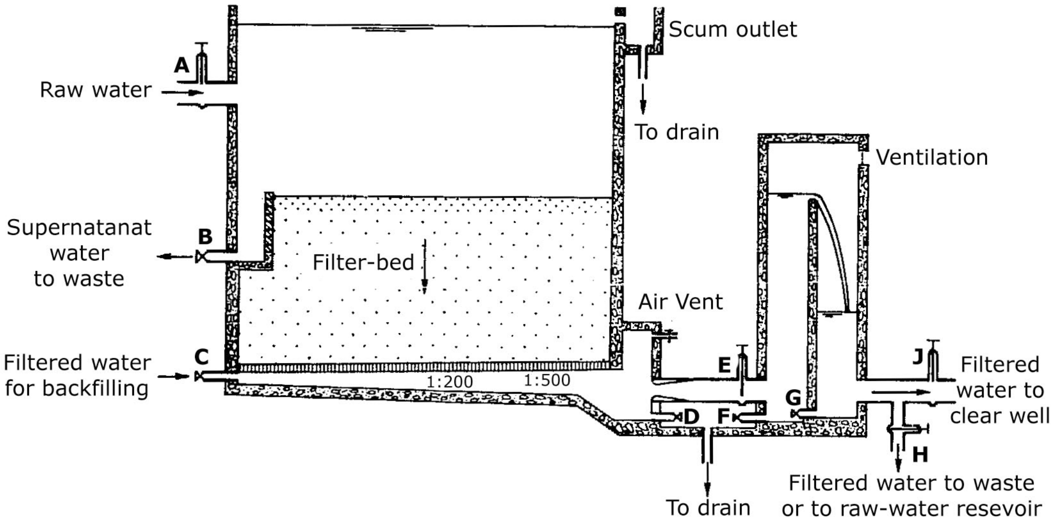

Figure 5.4: Valves to be included in a slow sand filter. Value A is to cut the raw water supply to the filter. Valve B is to run the head of raw water away from the filter before cleaning (not that it is recessed below the initial sand level). Valve C is for initial filling and re-filling after cleaning (the filter is filled from the bottom so that air bubbles are forced upwards). Valves D, F and G drain the filter bed and both sides of the weir. Valve E is the flow-regulating valve. Valves J and H control the outlet of water from the weir.

5.2.5.The Weir

A weir is included on the design to prevent the filter bed from ever running dry.

5.2.6.Chlorination

The water obtained from the filter can be chlorinated as a safety measure, although the filtered water should be quite safe.

5.2.7.The Storage Tank

This should be sized in the normal way. However, care should be taken to prevent over sizing, so that any organisms remaining in the water as not given enough time to multiply.

5.3.Filter Sizing

The amount of water needed for a community is calculated in the normal way, taking account for population growth. Assuming that the desired flow rate of 0.1 – 0.3 m^3/h (100 – 300 l) per m^2 of filter surface is achieved, it is a simple matter to calculate the area of filter needed. Note, that for any particular sand and raw water supply a test filter should be used to find the range of possible flow rates throughout the cleaning cycle of the filter. If possible this test should be conduced for an entire year.

Example

For a village with a population of 1000 and a yearly growth rate of 2.5%, the total population in 10 years can be calculated to be 1280 people. The sand filter is therefore designed for this amount of people. Allowing 40 l per person per day the total daily requirement will be 51200 l or approximately 52 m^3.

If we continuously feed the filter into a storage tank, so that the hours of peak demand can be catered for, the hourly output need is 2.17 m^3/h (52/24)[3]. We then assume that we can obtain a flow rate of 0.1 $m^3/h/m^2$ by adjusting the output valve, therefore the area of the sand filter will be approximately 22 m^2 (2.17/0.1).

Two filters should be build so that while one is being cleaned the water supply can be maintained. During maintenance the filter that is still operating can be run at 0.2 $m^3/h/m^2$; this is still within the recommended limit (0.1 – 0.3 $m^3/h/m^2$). Therefore each filter will have an area of 11m^2, for a circular construction this equates to a diameter of 3.75 m.

In this example the raw water source must be able to reliably supply the hourly demand of 2.17 m^3/h. However, slow sand filters are normally used to clean surface water supplies, for example rivers and lakes, and the reliability of the raw water supply should not be an issue.

5.4.Examples Of Basic Designs

Figures 5.5, 5.6 and 5.7 show some designs for sand filters that are suitable for small communities.

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[3] This equates to 2170 l/h or 0.6 l/sec.

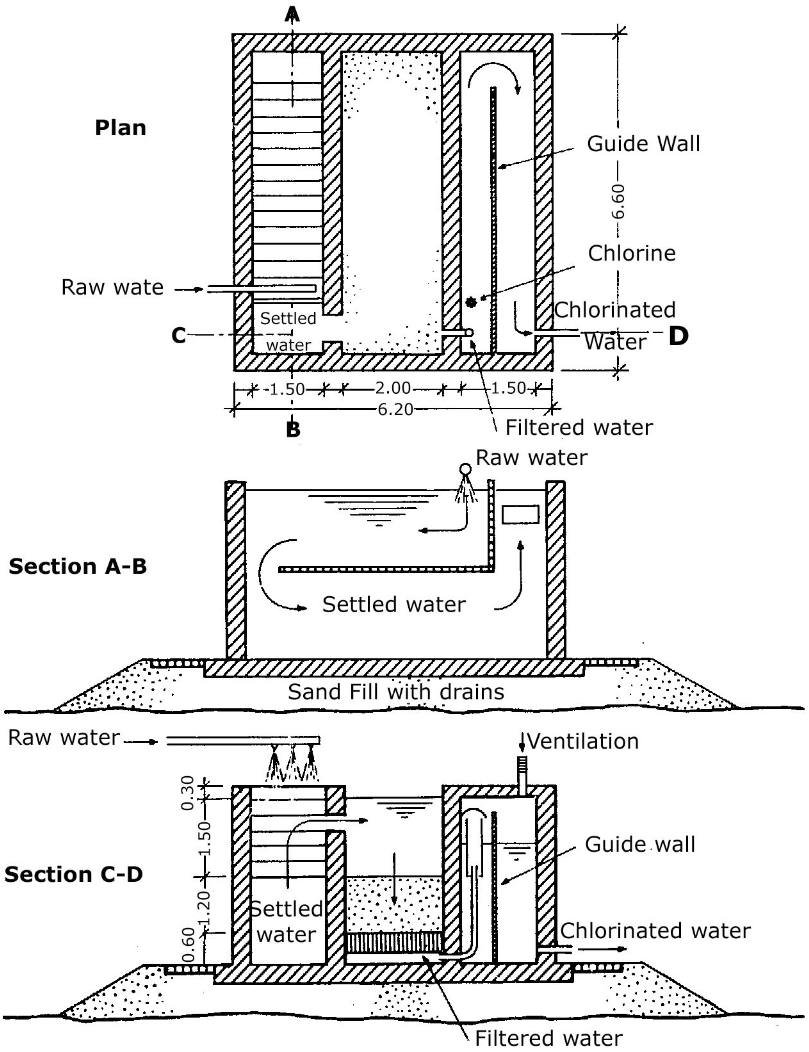

Figure 5.5: This design contains aeration, sedimentation sand filter and weir, all in the same construction. Taken from Slow Sand Filtration by Huisman and Wood.

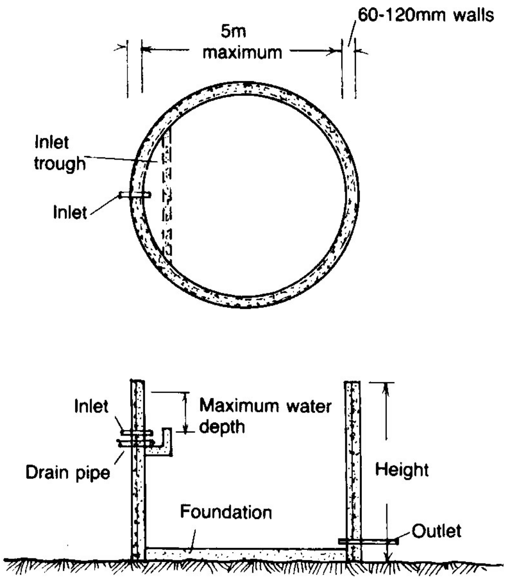

Figure 5.6: Filters that have a loading of less than 6 m^3/hr can be built using a circular, ferrocement construction. Taken from www.lifewater.org.

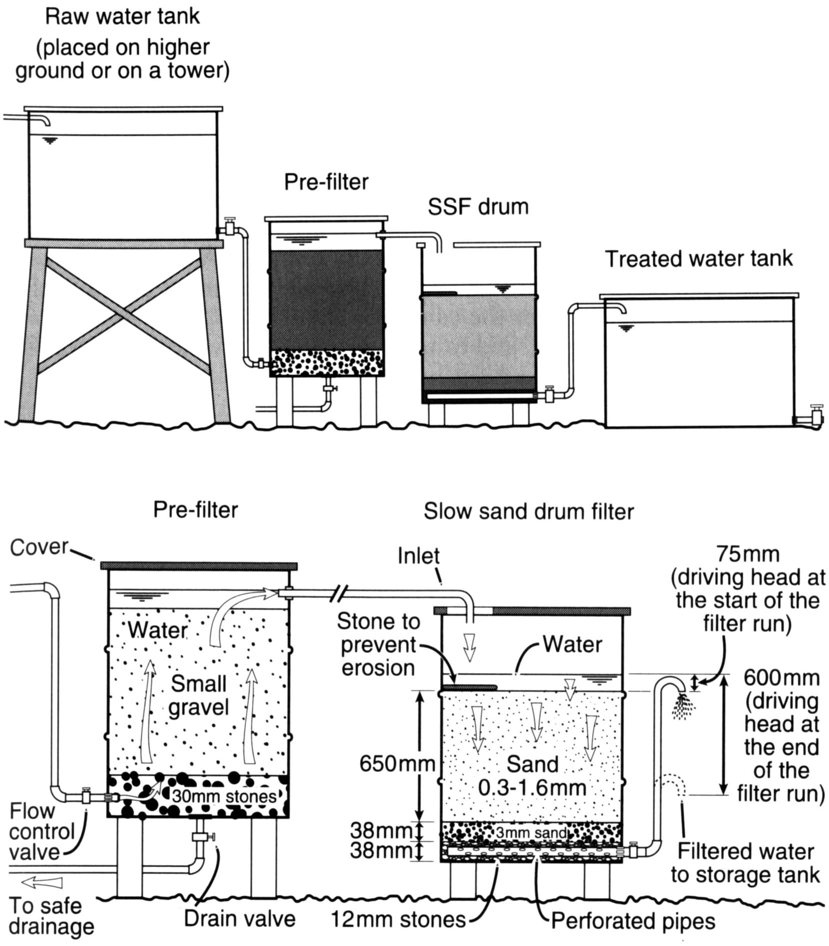

Figure 5.7: A sand filtration unit constructed from oil barrels. Taken from Engineering In Emergencies Second Edition, by Davis and Lambert.

6. Operation And Maintenance

6.1.Commissioning A New Filter

When the filter is first filled water should enter from the bottom (through valve C in figure 5.4.) so that any air bubbles will be forced up and out through the top of the sand bed. Once the water is 0.1 m above the sand bed the inlet valve (valve A) can be opened; the flow rate should be very small to start with so that the top of the sand bed is not disturbed. When the water reaches the working level the drain valve (valve D) can be opened so that the filter starts to operate.

The filter should be run to waste for a few weeks while the schmutzdecke forms. During this ripening process the filtration rate should be gradually increased until the normal operating flow rate is reached (probably 0.1 $m^3/h/m^2$).

The filtered water should be tested to check that it is clean. Once it is of an acceptable quality the flow rate regulating valve (valve E) can be opened so that water passes over the weir and into the storage tank.

As the filter operates it will become clogged and thus the filtration rate will reduce. To counter this the flow rate regulating valve (valve E) should be regularly adjusted.

6.2. Filter Cleaning

After a few months valve E will need to be fully open to maintain the flow rate and at this point the filter will need cleaning. The inlet valve (valve A) should be closed and the head of raw water allowed to run through the filter (or valve B can be opened). When there is only a little water left above the sand bed, value D should be opened and the remaining head should be run to waste until the water level in the filter is 0.1 - 0.2 m below the surface of the sand bed.

Once exposed, the top 1 or 2 cm of sand should be removed. The filter is then backfilled until the water is about 0.1 m above the sand. Re-ripening should only take a few days.

After about 20 to 30 cleanings the depth of the sand bed will have been reduced to between 0.5 and 0.8 m. At this point new sand must be added to the filter so that the sand bed is restored to its original depth. The remaining sand should be removed and the new sand placed at the bottom of the filter, the old sand is then replaced so that it forms the upper half of the sand bed.

7. Roughing Filters

Roughing filters can be used as a pre-treatment for slow sand filters. They should be used if the raw water has a particularly high turbidity. Although roughing filters are similar to slow sand filters they use a filter medium with a larger particle size and consequently run at a higher filtration rate; also, physical rather than biological mechanisms predominate. The filters are more efficient if the three layers are housed in separate containers; however, this method of construction is more difficult to implement.

Roughing filters operate at a flow rate that is 10 to 15 times greater than the flow rate through a slow sand filter. Therefore, the when used in conjunction the surface area of the roughing filter will be 10 to 15 times smaller than the surface area of the slow sand filter.

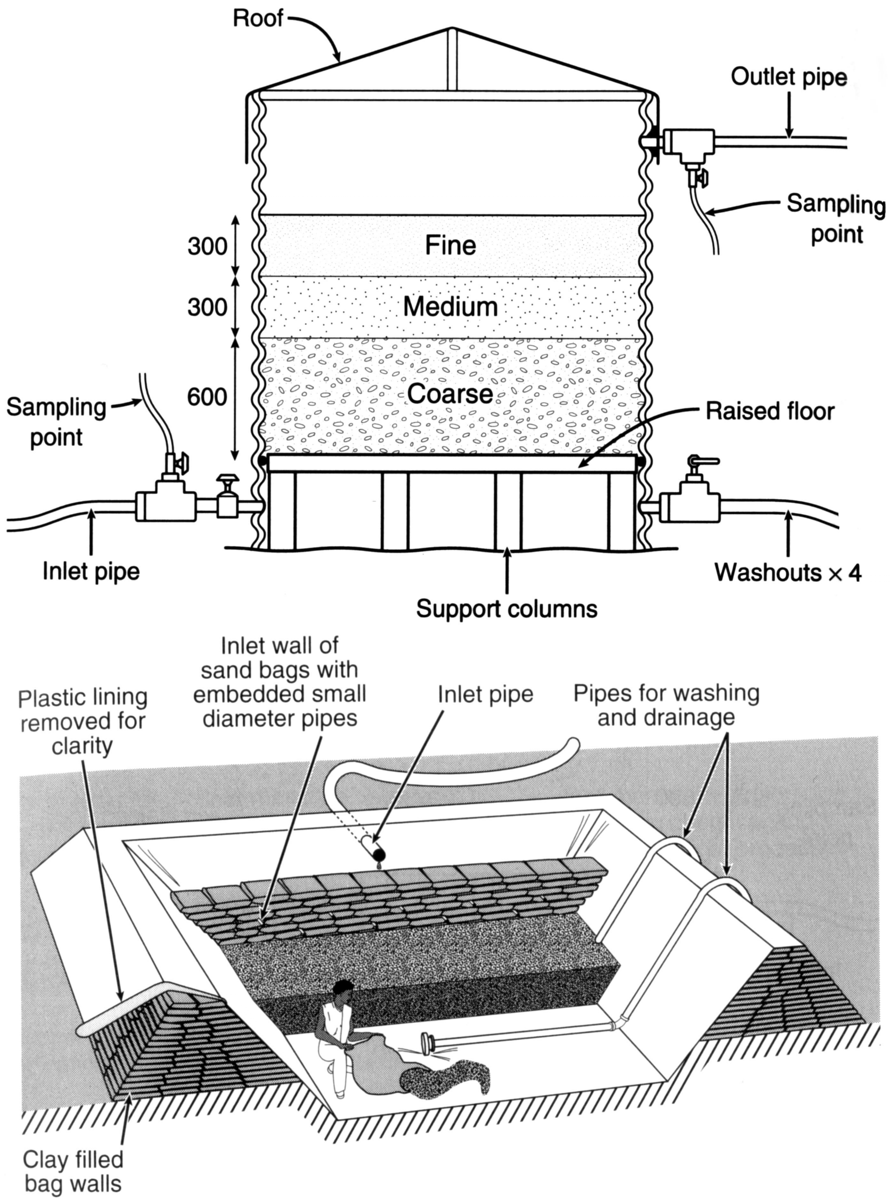

Figure 7.1 and 7.2: Vertical and horizontal roughing filter designs. Not that the verticle filter shown is an up-flow filter.

Vertical and horizontal roughing filter designs have be used successfully (figures 7.1 and 7.2). Both designed employ three layers of the filter medium with successively smaller particle sizes.

Vertical filters can be either down-flow, where the raw water enters at the top and filters down, or up-flow where the water enters at the bottom and filters up. For up-flow filters there must be enough head available to force the water up through the filter bed. Both up-flow and down-flow filters are cleaned by passing water through the filter in the direction opposite to the operating flow.

Roughing filters should not be used as a single treatment because they can not effectively remove bacteria, viruses or cysts; post treatment such as slow sand filtration or chlorination is always required.

8. Household Sand Filtration

The concepts behind slow sand filters have been adapted to produce a small scale bio-sand filter suitable for use on a household scale. These small filters differ from community scale slow sand filters in that they operate intermittently (not continuously) they also use considerably higher flow rates. Like larger slow sand filters, household filters remove bacteria via bacteriological mechanisms and the presence of a schmutzdecke.

Flow rates through a bio-sand filter are typically 0.6 m/h and the sand used should have particles with diameters between 0.45 and 1.19 mm.

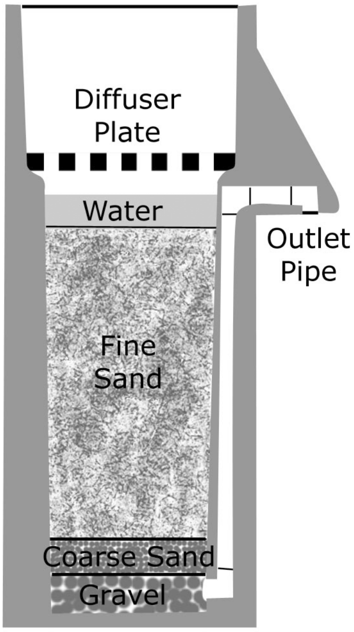

Figure 8.1: The CAWST household bio-sand filter. The filter area is 0.09 m^2 and the whole unit is 0.9 m high. Details on how to make this filter and the filter mould can be found at www.biosandfilter.org.

Figure 8.1 shows a common design for household filters. Such filters are made by pouring concrete into a mould, thus the filters can be easily produced on a large scale. Other designs using plastic containers and oil drums have also been tried. There are several important design features:

- Water is poured into the top of the filter from a bucket so that a diffuser plate is needed to prevent the schmutzdecke, at the top of the sand bed, from being disturbed. If the diffuser plate does not full fill this task the filter will not operate properly.
- The height of the outlet pipe is such that a 5 cm layer of water is always present above the sand bed. The depth of 5 cm has been shown to be the best balance between protecting the sand bed from drying out and being damaged by incoming water, and allowing oxygen to diffuse through to the schmutzdecke.
- There are no valves or taps.
- The sides slope to prevent water flowing down the sides of the sand bed without being filtered.

The effectiveness of this type of filter has been widely studied by the Department of Civil and Environmental Engineering at MIT[4]. The effectiveness of the household filter has been shown to vary greatly depending on how well they are build and maintained. The consistency of the raw water supply also effects the filter's performance, particularly if the water is taken from a piped supply that is intermittently chlorinated; in which case that schmutzdecke is killed off by the chlorine.

The household filters should be commissioned and maintained in a similar manner to slow sand filters.

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[4] May thesis on this subject can be found at http://web.mit.edu/watsan/.

Appendix A1. Micro-Organisms That Cause Waterborne Disease

The term “bacteria” refers to the group of prokaryotes of the Bacteria Kingdom. Prokaryotes, by definition, are living, single-celled organisms containing very few cellular structures. Bacteria range from 0.1 to 50 µm in diameter. Bacteria that cause waterborne sicknesses include *Salmonella, V. cholerae, and Shigella*. Sicknesses caused by these organisms include salmonella, cholera and soft tissue infections .

Viruses are not considered living organisms. They are genetic elements that can replicate independently of a cell’s chromosome, but not independently of the cell itself. Viruses are typically much smaller than cells, ranging from 0.02 to 0.3 µm (Madigan et al., 2000). Viruses known to cause waterborne sicknesses include hepatitis, enteroviruses, adenoviruses and rotoviruses. Sicknesses caused by these organisms include gastroenteritis and Hepatitis A and E.

Protozoa are eukaryotic organisms. Like bacteria, protozoa are single-celled organisms. Protozoa lack the chlorophyll of algae, and are larger than viruses and bacteria. Some types of protozoa are large enough to be seen with the naked eye. *Paramecium* cells, for example, are 60 µm in length. Protozoa can cause dysentery and suppression of the immune system.

Helminths are worms (parasitic and non-parasitic). Three main types of helminths cause disease in humans: tapeworms, roundworms and flukes. Guinea worm (a type of roundworm) is found in Asia and Africa and causes a disease called Dracunculiasis. Dracunculiasis is not life-threatening, but it results in painful skin ulcers. Unlike other diseases caused by helminths, dracunculiasis is only transmitted through contaminated water. Table 1.1, from the World Health Organization shows waterborne pathogens and their significance in water supplies. Infectious dose information (as determined by the World Health Organization) for helminthes, as well as bacteria, viruses and protozoa, is also available in table A1.1

Pathogen	Health significance	Persistence in water supplies[a]	Resistance to chlorine[b]	Relative infective dose[c]	Important animal source
Bacteria					
Campylobacter jejuni, C. coli	High	Moderate	Low	Moderate	Yes
Pathogenic					
Escherichia coli - Pathogenic *Escherichia coli* - Toxigenic	High	Moderate	Low	High	Yes
Salmonella typhi	High	Moderate	Low	High[d]	No
Other *salmonellae*	High	Long	Low	High	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	High	Short	Low	High	No
Yersinia enterocolitica	High	Long	Low	High(?)	Yes
Pseudomonas aeruginosa[e]	Moderate	May multiply	Moderate	High(?)	No
Burkholderia pseudomallei					
Mycobacteria					
Legionella					
Viruses					
Adenoviruses	High	?	Moderate	Low	No
Enteroviruses	High	Long	Moderate	Low	No
Hepatitis A	High	?	Moderate	Low	No
Hepatitis E	High	?	?	Low	No
Norwalk virus	High	?	?	Low	No
Rotavirus	High	?	?	Moderate	No(?)
Small round viruses	Moderate	?	?	Low(?)	No
Protozoa					
Entamoeba histolytica	High	Moderate	High	Low	No
Giardia intestinalis	High	Moderate	High	Low	Yes
Cryptosporidium parvum	High	Long	High	Low	Yes
Acanthamoeba					
Toxoplasma					
Cyclospora					
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	Low	Yes

Table A1.1: Waterborne Pathogens and Their Significance in Water Supplies.

? not known or uncertain.

a Detection period for infective stage in water at 20°C: short, up to 1 week; moderate, 1 week to 1 month; long, over 1 month

[b] When the ineffective stage is freely suspended in water treated at conventional doses and contact times. Resistance moderate, agent may not be completely destroyed.

[c] Dose required to cause infection in 50% of health adult volunteers; may be as little as one ineffective unit for some viruses.

[d] From experiments with human volunteers

[e] Main route of infections is by skin contact, but can infect immunosuppresed or cancer patients orally.

Taken from Household Scale Slow Sand Filtration In The Dominican Republic, By Kori S. Donison (see Appendix A3).

Appendix A2.RedR Operational Experience

The following data and comments have been obtained from operational experience of slow sand filters for refugee water supplies.

- A sand filter package can be erected by unskilled personnel and be running within 3-4 weeks. The critical time factor is the supply and preparation of sand - to speed up the process, sand preparation can be started even before the tanks are designed and ordered.

- Turbidities of water entering the SSF should be less than 20 NTU. Turbidities of up to 200 NTU can be tolerated for only a few days. If the turbidity of the incoming water is above 20 NTU, take measures to reduce turbidity level (roughing filters or coagulation).

- Storing raw water in tanks before filtering gives a significant reduction in turbidity and pathogen counts due to sedimentation and die-off.

- A properly operated slow sand filter gives safe, potable water but chlorination following SSF is recommended as a safety precaution.

- Recontamination of the treated water from the SSF can occur if any of the tanks or containers used to hold this water (including domestic containers) are not kept clean. Periodic chlorination of tanks used to store treated water may be needed.

- The filter run time (time between cleaning) varies widely, depending on the raw water turbidity (which varies according to the seasons) and filtration rate. Typical filter run times are between 2 and 20 weeks.

- Algae in the filter tank water above the sand does not necessarily adversely affect the operation of the filter.

- A tank must be drained completely when the flow is stopped for more than a day, otherwise anaerobic conditions in the filter sand are encouraged. This can give a lasting bad taste to the water even after resumption of flow. Avoid lengthy stoppages and draining of the filter if at all possible.

- One day operator and one night operator are required to operate each filter package.

- Operators must be trained to maintain a constant flow rate.

Taken from Engineering In Emergencies.

Appendix A3. Further Reading & Links

Slow Sand Filtration, by L. Huisman and W.E. Wood. WHO 1974. Available at www.catas1.org.

Managing Water In The Home: Accelerating Health Gains From Improved Water Supply, by M. Sobsey. WHO 2002. Available at www.catas1.org.

WHO Guidelines for Drinking-water Quality. 3rd edition. Available at http://www.who.int/water_sanitation_health/dwq/gdwq3/en/.

Engineering In Emergencies, Second Edition, by J Davis and R Lambert. Published by ITDG in association with RedR.

Safe Household Drinking Water Via Biosand Filtration Pilot Project Evaluation And Feasibility Study Of A Biosand Pitcher Filter by Melanie I. Pincus. Available at http://web.mit.edu/watsan/.

Household Scale Slow Sand Filtration In The Dominican Republic, By Kori S. Donison. Available at http://web.mit.edu/watsan/.

http://web.mit.edu/watsan/
www.biosandfilter.org
www.lifewater.org
http://www.who.int/water_sanitation_health/dwq/gdwq3/en/
www.catas1.org