Guidelines

Preparation of Media for the BioSand Water Filter

Four Layer System

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The purpose of preparing and publishing these guidelines on the internet is to provide a readily available technical reference to all those involved in BioSand Water Filter manufacture, funding, use, evaluation or support.

Introduction

The four layer system was developed for use by organizations that produce many hundreds, thousands or more household Biosand Water Filters in a central manufacturing facility per year. (There are actually several such facilities around the world.) The four layer system can be implemented using simple manual techniques or using highly mechanized large volume manufacturing facilities. The three layer system remains ideal for the small producers. (See Guidelines for Preparation of Media for the BioSand Water Filter Three Layer System.)

The four layer system requires a thorough understanding of the filtering procedure and how the filter media affects the quality of the treated water. The apparent simplicity of the three layer system is lost; however, the subjectivity associated with 'washing' media is eliminated. Quality control is greatly improved.

Following is a description of the four layer system and how it may be implemented.   Only essential concepts are presented. Ultimately, local manufacturers must develop their own techniques and procedures while adhering to the fundamentals expressed in these guidelines.

Detailed instruction and demonstration of filter media selection and preparation is provided in workshops focussed specifically on filter media production.

Description of the Four Layer System

The four layer system requires the preparation of four types of media; the underdrain layer, separation layer and two filtering layers.

Consider the following sketch of a cross-section of a filter bed in a BioSand Water Filter that uses the four layer system.
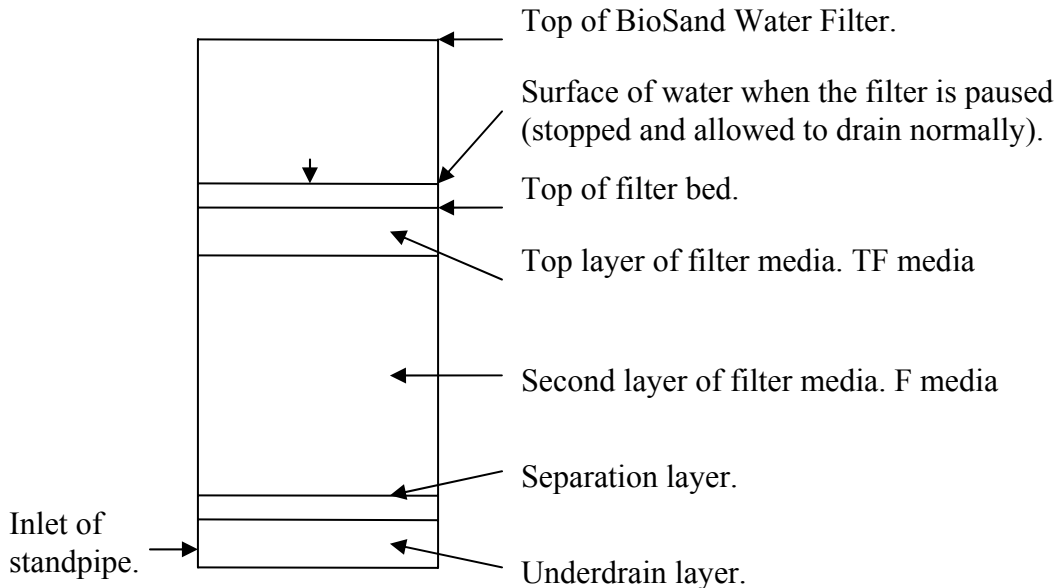
Top of BioSand Water Filter.

Surface of water when the filter is paused (stopped and allowed to drain normally).

Top of filter bed.

Top layer of filter media. TF media

Second layer of filter media. F media

Separation layer.

Inlet of standpipe.

Underdrain layer.

Figure 1. Cross-section of the filter bed of a typical BioSand Water Filter using the four layer media system.

A description of each of the various layers follows:

1. Underdrain layer: Allows vertical drainage through two filtering layers and allows filtered water unrestricted access to filter standpipe. The thickness of the underdrain layer must be sufficient to cover the inlet to the filter standpipe (located at the inside bottom of the filter body) with 2 cm of underdrain material. The underdrain layer is composed of particles ranging in size from 6.25mm to 12.5mm (1/4 to 1/2 inch) in diameter. The total depth of the underdrain may be 8 cm or more. The thickness of the underdrain layer is the same throughout the layer.
2. Separation layer: Prevents filter media from entering the underdrain layer and the standpipe.   The separation layer should be 3 cm in thickness. The separation layer is composed of particles ranging in size from 3.125 mm to 6.25 mm (1/8 to 1/4 inch) in diameter. The thickness of the separation layer is the same throughout the layer.
3. Top layer of filter media (TF): Responsible for removal of most particles and micro organisms. Together with the second layer of filter media controls the flow of water through the filter bed. The particles in the top layer of filtering media range in diameter from 1/2 to 1/4 the diameter of particles in the second layer of filter media. The thickness of the top layer should be between 4 and 6 cm and uniform depth throughout.
4. Second layer of filter media (F): Responsible for complete deactivation of viruses. Together with the top layer of filter media controls the flow of water through the filter bed.   The flow rate through the BioSand Water Filter must not exceed 600 liters per

square meter of media surface (at the top of the filter media bed). The largest particles in the second layer of filter media must be less than 3.125 mm (approximately 1/8 inch). The second layer may include the <u>same particles that constitute the top filtering layer</u>, if both F and TF media were produced from the same samples of crushed rock (See Figure 2.). The combined thickness of the second layer of filter media and the top layer of filter media should be no less than 40 cm. The thickness of the second layer of filter media is the same throughout.

Media Installation Instructions

All four layers of filter must be correctly installed in order to determine how the relative depths of the top and second layers affect the flow rate through the filter. The underdrain and separating layer are always the same depth.

Media installation proceeds as follows:
1. The first step is to determine the maximum depth of the media in the filter. If the filter walls are made of plastic and are transparent it is possible to make all depth measurements from outside the filter. If the filter body is not transparent, (concrete), then it is necessary to fill the filter to the point where water is just starting to drip from the standpipe. At this time the depth of water in the filter is equal to the depth of the media plus the paused water depth. A piece of wood that is 1 or 2 cm in diameter and 10 cm longer than the depth of the filter may be used to measure media depth. The wood is placed on the bottom of the empty filter and held vertical. A second similar but shorter piece of wood is placed across the top of the filter and the vertical piece is marked with a pencil immediately above the horizontal piece. The distance from the bottom of the vertical piece of wood to that mark will be equal to the depth of the inside of the filter plus the thickness of the horizontal piece of wood.
2. Using a measuring cup or similar container add underdrain media such that it covers the inlet to the standpipe with 2 cm of material. (Cups should be filled and levelled.) The top of the underdrain layer must be perfectly level. Typically, your hand is used to level the top of the layer. If your arm is too short a piece of wood can also be used. It is normal for the water to become quite turbid and it will not be possible to see the media through it. The measuring stick is now very useful. The depth of media required to cover the inlet to the standpipe is noted and a second mark is added to the vertical stick a distance equal to the depth of the underdrain layer below the first mark. The depth of the media can be conveniently measured by placing the horizontal piece of wood across the top of the filter and positioning the vertical piece against it. When the depth is exactly correct the second mark and the top of the horizontal piece will be the same. Record how many cups of underdrain media were required. The number of full and partial cups of media will be used to determine how much underdrain media will be supplied with the filter.
3. Put the diffuser basin into position and add water until there is approximately 10 cm standing above the underdrain material. (The diffuser basin is used to prevent the water from disturbing the media when poured into the filter.) Remove diffuser basin.

4. Prepare to add the separating media. Add a second mark to the vertical piece of wood 3 cm below the first mark. Using the measuring cup carefully add 3 cm of separating media. Again, the top of the separating layer must be perfectly level. Record how many cups of separating media were required.
5. Put the diffuser basin into position and add another 10 cm or so of water. Remove diffuser basin. There should never be more than 20 cm or so of water in the filter when media is being added.
6. Select thicknesses for the top and second media layers while considering the guidelines for the depth of water above the filter media when the flow from the filter has stopped, the paused water depth.
7. Place marks on the vertical piece of wood equal to the thicknesses of the second layer and top layer.
8. Carefully measure the amount of second filtering media required to bring the filter bed to the mark that indicates the top of the second layer. (Note that media should ALWAYS be added to water and added quickly - almost dropped in. By adding media to water there is no danger of trapping air in the media which can stop the flow of water through a process known as air binding. By adding the media very quickly into no more than 20 cm of water there is no danger the particles will separate with coarse falling into place first followed by the fine particles, a process known as stratifying. The stratifying effect greatly decreases the flow of water through the filter and is avoided using this procedure.) Record the amount of media used to complete the second filtering layer. (Place a bucket under the standpipe to capture any water that may dribble from the standpipe outlet during media installation.)
9. Carefully measure the amount of the top filtering media that must be added. Record this amount.
10. Clean surface of the media by adding sufficient water to fill the portion of the filter interior above the top of the filter media with 20 cm or so of water. Remove the diffuser basin. Using your hand or a brush, vigorously stir up the water above the media surface. Your fingers can penetrate the top of the media by a 1/2 cm but no more. The vigorous agitating action will cause the top of the media layer to be release particulate material that would otherwise plug it off. Once sure that all material is suspended that can be suspended a cup is used to remove as much of the very turbid water from the filter as possible. Wait a few seconds to allow the media to settle before starting this process. Care should be taken not to remove any of the media by allowing the cup to scoop into the media surface. The cleaning action can be repeated as often as required. Level the top of the media as a last step of the cleaning process. The effect of this cleaning is to maximize the flow of water through the filter bed that has just been installed.
11. Measure the flow rate through the filter by replacing the diffuser basin and adding enough water to completely fill the filter. Using a calibrated measuring cup or a plastic container such as an empty water or soda pop bottle, (any of the plastic bottles will work though 500 ml and 1 litre bottles work the best), measure how long it takes to fill this bottle with filtered water, which will still look very turbid. (Note that after three or more 20 litre buckets of water are added to the filter the water will flow very clear.) Calculate the actual flow rate through the filter by dividing the volume filtered measured in litres by the time required to produce the volume in minutes. Compare this flow to the

objective flow rate for the filter. The objective flow rate is calculated by multiplying the surface area at the top of the media measured in square meters by 600 litres per hour per square meter. For example if the surface area of the filter, at the top of the media, is 0.1 square meter, the objective flow rate is 0.1 square meters times 600 litres per square meter per hour equals 60 litres per hour or 1 litre per minute.

12. If the flow rate as measured is above or below the objective flow rate the thicknesses of the second and top filtering layers must be adjusted. This is described later.

(Note: With use the media will settle a centimetre or so. Once the actual settlement is known it is advisable to increase the depth of the second layer of filtering media (F media) by the known depth of settling. In effect the filter is overfilled at time of installation in anticipation of the settling that will inevitably occur. Tamping the surface of the filter media after overfilling is not necessary. Overfilling with the TF media, rather than the F media, may result in an unacceptable decrease in flow rate through filter.)

Selection of Crushed Rock for Media Preparation

The preferred source of material with which to produce the filter media is crushed rock from a rock quarry. This material can be expected to be very clean and free from organic and microbial contamination. There is usually an opportunity to acquire large quantities of raw materials exhibiting consistent particle size distribution.

Ideally, the material is very hard, a quartzite or granite.   Very soft material such as crushed limestone can also be used. Mudstones that contain oxidized iron or manganese should be avoided as they will likely contaminate and color the water as it is filtered.   A potential problem with softer rocks, (like limestone and mudstone) is that some particle rubbing and grinding always occurs during handling and transport resulting in the production of unwanted fines,. From a consumer perspective the color of the rock should be as light as possible though any color is actually satisfactory provided the color does not transfer to the water during the filtering process.

Crushed limestone works very well. The limestone is very difficult to dissolve in water and will work fine for the life of the filter. It is occasionally observed that when water filtered through limestone is boiled there is a white deposit on the bottom of the pot. This deposit would occur even if the water was not filtered. The white deposit is usually calcium carbonate. When the water is heated it cannot dissolve as much calcium carbonate and it will precipitate out.

Crushed rock is often available in a size already very close to that needed for the underdrain layer and separation layers and may be purchased directly. Very little waste will result when processed.

Crushed rock for the preparation of the filter media and separation layer is usually the finest material in the quarry. Often it is considered waste material.   The material used for the filtering layer MUST contain particles varying in size from very fine, almost dust size, to larger than 1/8 inch or the opening of the filtering sieve.   Material that is all dust simply won't work as the flow

through it will likely be too low or require considerable preparation to make work. Material that does not contain any fines cannot work either because the flow rate through the media will be too large.

Media delivered to the processing site should be protected from the weather and risk of contamination from weather, animals or humans. This may require a roofed working area and a concrete floor. Drying media outdoors will require a large concrete pad with good exposure to the sun. The entire media processing area should be secured with appropriate fencing or walls that also allow good access for trucks.

Every shipment of unprocessed media should be evaluated, using appropriate particle size evaluation techniques, to insure that the media supplied is similar to previous shipments that were used to establish media preparation procedures and filter bed design. Particle size distributions can very considerably from shipment to shipment. However, it is reasonable to assume that individual shipments are more-or-less homogenous and it is advisable to obtain the largest shipments that can be managed.

If it is determined that the particle size distribution of a shipment is different from previous deliveries, the media preparation procedure and filter bed design may need to be evaluated and changed if necessary.

Media Contamination

Clean (uncontaminated) media is free from toxins and any organic material, living or dead. Media at risk of contamination with toxic substances by virtue of being near industrial activity or affected by waste disposal activities should be completely avoided. Surface accessible deposits of sands and gravels, including gravel pits, beaches and river banks, usually contain significant organic material due to vegetation accumulation and human and animal activities. Only media obtained from rock quarries that produce material from solid rock formations can be expected to be contamination free.

Media contamination occurs due to the presence of individual organic particulate material, (pieces of plants, animals, insects, seeds, etc.), and organic material that was originally dissolved or suspended in water and is now attached to individual rock particles. Organic material is food for micro-organisms, a few of which might be pathogenic (disease causing). Standard practice is to test for the presence of pathogen indicator micro-organisms such as fecal colliform bacteria (found in the intestinal tracts of warm blooded animals and present in the many billions per gram of human feces), Escherichia colliform or e-coli bacteria (dominant colliform bacteria found in intestinal tracts of warm blooded animals) and total colliform bacteria that includes all forms of colliform bacteria including those that naturally live in the soil or associated with other forms of life. If colliform bacteria are present it is normal to find similar numbers of fecal colliform and e-coli bacteria and tens times their number of total colliform bacteria. These colliform bacteria are NOT usually pathogenic themselves. (There are notable exceptions such as the 0157 strain of e-coli, which is very dangerous.) Rather, their presence is used as an indicator of the possible presence of other, serious pathogenic organisms, resulting from direct contamination by human

feces or animals that could carry the same pathogens (parasites such as Giardia and Cryptosporidia).

It is possible to evaluate media contamination by taking a gram of filter media (straight from the quarry or after the media preparation process), washing it in one litre of sterilized water (boiled and cooled river water) and having it tested for the presence of any one or more of the indicator organisms. The testing should be performed by a reputable local laboratory. Laboratory instructions must be carefully followed. If any of the indicator organisms are present the media is at risk of being contaminated and must be further evaluated with respect to the possible cause of the contamination (lack of protection at the quarry, handling, etc.). Other sources of crushed rock may need to be found.

It may be possible to wash the organic particulate material from the rock media; but it is not possible to remove the organic material attached to the rock particles themselves. Micro-organisms will continue to grow on the particles as long as there is food (organic material) available. When all of the food is consumed the micro-organism will disappear and the media is 'clean'.

It is possible to disinfect the media by heating it or soaking it in disinfectants such as chlorine bleach. The rock particles will still have 'disinfected' organic material attached. The disinfected media is quickly contaminated once the media is installed in a filter and water containing living micro-organisms is poured through it. The media will appear contaminated, based on bacteria tests on the treated water, until all of the attached organic material has been consumed by the micro-organisms and they no longer exist within the filtering, separation or underdrain media itself. It is common to observe more bacteria in the filtered water than in the unfiltered water. The media will appear contaminated for a period of several months.

Sieve and Screen Selection

Selecting sieve sizes of 12.5 mm (1/2 inch), 6.25 mm (1/4 inch), 3.125 mm (1/8 inch) (or slightly smaller but never smaller than the holes in typical mosquito netting) and 1.0 mm (1/16 inch) (or smaller) can produce useful results. A table of standard sieve sizes is attached in Appendix A. Sieves are purchased for the purpose of testing particle size distribution, not for large scale production. Material with the same size openings as the sieve material that is used for large scale production is known as screening material.

Test sieves are essential for quality control as it pertains to purchase of raw material used to produce filter media or the production of the media used in each of the various layers. Test sieves can be purchased from a variety of suppliers or can be constructed using comparable screening material (considerably less expensive).

Screening material is also known as woven wire cloth or wire mesh cloth. Many types of screening materials can be purchased with a variety of physical characteristics from numerous manufacturers around the world. (Usually a simple internet search using combinations of the

search words such as "woven wire mesh cloth screening suppliers" will provide adequate information.) The web site www.wire-cloth.com is particularly useful.

Once a supplier is identified sufficient material should be purchased to construct a set of small production screens with which to evaluate media produced for performance in an actual BSF and to develop media production procedures. To be useful the small production screens should be approximately 60 cm long, 45 cm wide and about 10 cm deep.   Larger screens are heavy and awkward to use. Appendix B shows a table of specifications for typical wire mesh cloth.

Screening Machines

There are many commercial screening machines that can be useful and cost effective when producing large quantities of material. 'Home made' designs can work as well.   (A simple internet search is useful for identifying the various designs, scales, costs and availability of screening machines around the world.) Once selection of screens is completed large quantities of screening material can be purchased being careful to ensure that it has the correct openings and that it can be used with the intended screening machine.

Media Preparation

The parameters available to control flow rate through the filter are screen sizes used to produce the top and second layer of filtering media, thickness of top and second layers and the washing of the filtering media (top two layers are either washed or not washed). The underdrain and separation layers are the same size and always washed thoroughly.

The material used for the underdrain and separation layers is usually screened first and then washed until the wash water runs clear.   It is very important to wash these layers thoroughly as they 'clean or rinse' very slowly, shedding particulates over a long period of time in normal filter use in contrast to the filtering layers which 'clean' very quickly even if not washed at all. Soaking dry media in water or simply wetting it twenty-fours prior to washing will improve and greatly speed up the washing process. Washing media with cement mixers or other types of rotating drums may be practical.   Commercial media washing machinery is available. Wash water may be captured, allowed to clarify and reused in the washing process.

Note that washing cannot be performed half-way when using the four layer system. The four layer system allows filter media to be either washed or unwashed unlike the three layer system that requires a very controlled approach to media washing.

See Figure 2, which shows a flow chart describing media preparation – assuming that EACH of the four media layers can be produced from ONE source of crushed rock. Often, this is not the case and at least two supplies (from the same rock quarrying, crushing and screening operation) are used. The combinations that may be found include:
1. One supply for the 12.5 mm material and another for three other media layers.
2. One supply for the 12.5 mm material and the 6.25 mm material and another for the two filtering layers.

The sieving process for each of these combinations is obvious.

Considering the fact that most of the filter bed is composed of the second filtering layer it may be advantageous to consider either of these two options rather than a single crushed rock source even though it may appear, at first glance, that both would produce more waste materials.

The media preparation procedures described allows production of the underdrain and separation layers and two types of media for each of the filtering layers.   The two types of media for the top filtering layer are named TF_1 and TF_2.   The two types of media for the second filtering layer are named fine media types F_1 and F_2.   Because F_2 is washed it does not contain the very smallest fine particles that remain in F_1.   Use of F_1 will result in higher flows than the use of F_2. Similarly, because TF_2 is washed it does not contain the very smallest fine particles that remain in TF_2. Use of TF_1 will result in higher flows than the use of TF_2.

Production of media used for filtering layers must consider the moisture content of the raw material before processing. If crushed rock, that is to be used to prepare either the top or second layers, is received dry, it should be not be allowed to become wet as this will make sieving very difficult.   Unprocessed dry material can be sieved immediately into media used for the second filtering layer. The top filtering layer can be produced at the same time.   Observe that the top filtering layer contains all of the fine particles contained in the second filtering layer.

Note that while washing may NOT be essential for media used in the filtering layers, **media used for the separation and underdrain layers is ALWAYS washed.**

If the material is received damp it usually must be dried before sieving. If it is later determined that the media will be washed then it might be advisable to consider washing all of the unprocessed raw material prior to drying. Drying media continues to be a particularly challenging issue though opportunistic use of solar energy; that is, clean sheltered concrete or asphalt drying areas exposed to the sun appears to be a first choice.

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                              ┌─────────────────┐
                              │  Crushed Rock   │
                              │     (Wet)       │
                              └─────────────────┘
                                      │
                                  ◇ Dry Rock ◇
                                      │
                              ┌─────────────────┐
                              │  Crushed Rock   │
                              │     (Dry)       │
                              └─────────────────┘
                                      │
     ┌──────────────┐                 ▼
     │  Disposal    │◀───────  ◖ 1/2" Sieve ◗
     └──────────────┘                 │
            ┌────────────────────────┤
            │                  ◖ 1/4" Sieve ◗
            │          ┌─────────────┤
            │          │       ◖ 1/8" Sieve ◗
            │          │       ◖ or smaller. ◗
      ◇ Wash ◇    ◇ Wash ◇            │
            │          │       ◖ 1/16" Sieve ◗
      ◇ Dry ◇     ◇ Dry ◇      ◖ or smaller.  ◗
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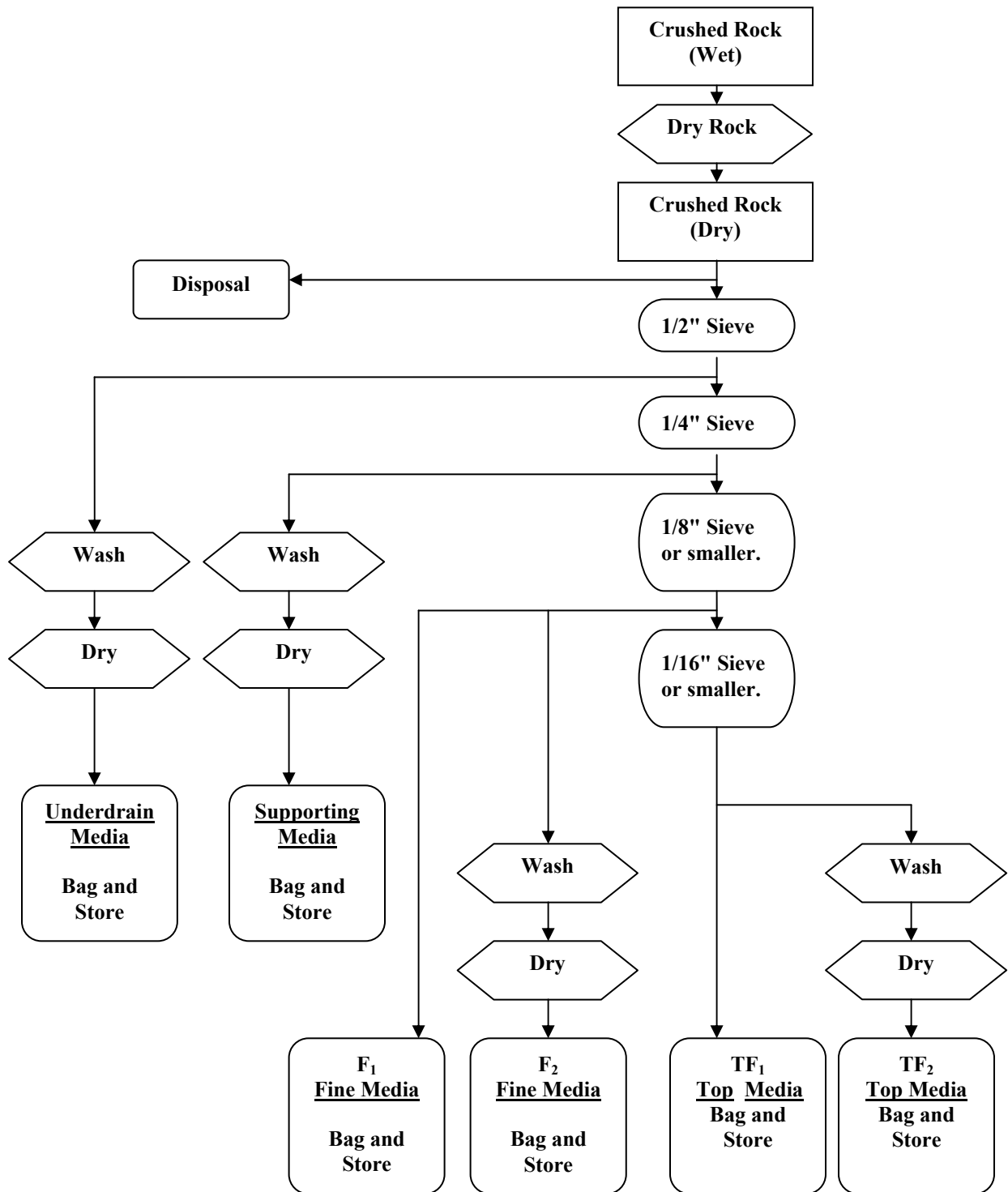
Figure 2. Media preparation flow chart when one crushed rock supply is used to produce media used in the four layer system.

Underdrain Media

Bag and Store

Supporting Media

Bag and Store

F_1
Fine Media

Bag and Store

F_2
Fine Media

Bag and Store

TF_1
Top Media
Bag and Store

TF_2
Top Media
Bag and Store

If it is important to increase the flow rate through either the top or second filtering layers they can be washed. Note that washing is NOT always essential for media used in the filtering layers. (The media used for the separation and underdrain layers is ALWAYS washed.) Crushed rock rarely contains substantial quantities of fine silt or clay that interfere with installation. If the media does contain large quantities of silt and clay it must be washed thoroughly before use.

Every shipment of unprocessed media should be evaluated, using appropriate particle size evaluation techniques, to insure that the media supplied is similar to previous shipments that were used to establish media preparation procedures and filter bed design. Particle size distributions can very considerably from shipment to shipment. However, it is reasonable to assume that individual shipments are more-or-less homogenous and it is advisable to obtain the largest shipments that can be managed.

If it is determined that the particle size distribution of a shipment is different from previous deliveries, the media preparation procedure and filter bed design may need to be evaluated and changed if necessary.

Media Bed Design

General

Note that flow rate through a BioSand Water Filter is determined when the depth of water in the filter is at the very top of the filter, nearly overflowing. This depth is maintained throughout the entire flow test.

Understanding that the particle sizes in F_1 are less than F_2 and that the particle sizes in TF_1 are less than TF_2, possible variations in media bed include:

1. Underdrain - Support - F_1 - TF_1.   lowest flow rate
2. Underdrain - Support - F_2 - TF_1.
3. Underdrain - Support - F_1 - TF_2.
4. Underdrain - Support - F_2 - TF_2.   highest flow rate

Once it is confirmed that appropriate filter media can be produced there are two techniques for arriving at the final filter bed design.

Confirmation of Media Utility

The ability of water to flow through the F and TF materials alone must be evaluated to determine the amount of each material that is used in the filter to achieve the desired flow rate of 600 lph/m^2. A full scale filter is installed using appropriate depths of underdrain and separating media and completed using either the F or TF media (similar to a three layer system). The flow rate through the completed filters is measured as described earlier. It is important that the flow rate through the filter installed using the F media is greater than 600 lph/m^2 and the flow rate through the filter installed using the TF media is less than 600 lph/m^2.

If both the F and TF media produce a flow less than 600 lph/m^2 the F media is too fine and coarser material will need to be produced. A sieve with openings larger than 1/16" will be required. (Appendices A and B provide information on sieve selection.)   The flow rate through the new F and TF materials will need to be evaluated again.   The flow rate through the new TF material will increase but it should still be less than 600 lph/m^2. If the flow rate for the newly produced F is still less than 600 lph/m^2 and the amount of F material produced is becoming very small, it is probable that it is not possible to produce the F media from the raw material being used. If the material was not washed before sieving it may be worth trying to use washed and dried material. If the washed and dried material doesn't provide adequate media an alternate source of raw material that contains coarser material must be located.

Similarly, if both the F and TF material produce a flow greater than 600 lph/m^2 the TF material is too coarse and a finer material will need to be produced. A sieve with openings smaller than 1/16" will be required. The flow rate through the new F and TF materials will need to be evaluated again. The flow rate through the new F material will decrease but it should still be more than 600 lph/m^2. If the flow rate for the newly produced TF is still larger than 600 lph/m^2 and the amount of TF material produced is becoming very small, it is probable that it is not possible to produce the TF media from the raw material being used. If the material was washed and dried before sieving it may be worth trying to use unwashed material. If unwashed material doesn't provide adequate media an alternate source of raw material that contains finer material must be located.

In order to minimize volume of waste of crushed rock the proportion of the quantity of F and TF materials that one would like to produce is similar to that actually being used in the filter. This objective is rarely achieved. Usually, there is a more of one size than can be used. This material should not be wasted as it still has value for other purposes.

In some circumstances the F and TF materials cannot be produced from two different supplies of material source. This is not necessarily a disadvantage and may result in less wastage. The media preparation flow chart shown in Figure 2 does not apply.

Technique #1 – Filter Media Design – 'Trial and Error Technique'

This technique is very simple and effective but depends on the designer's 'intuitive' understanding of how media preparation will affect the flow through the BSF.

The easiest process for determining the depths of the top and second filtering layers is to start with a filter charged with the F media to within 5 cm of maximum depth (plus the separation and underdrain layers). Remember that the top of the filter bed (that includes the underdrain, separating layer, F layer and the TF layer) should allow for a minimum paused water depth of approximately 5 cm. The top 5 cm is filled with the unwashed TF material. The resulting flow rate is measured. If the flow rate is still too large, more of the F media needs to be replaced.

If the flow rate is <u>too low</u>, it is necessary to replace the unwashed TF media with washed TF media. (It is very important that the top filtering layer be at least 4 cm thickness to facilitate cleaning.) If the flow rate is still too low when using washed TF, it may be necessary to use a coarser sieve for production of the F and TF media or consider other strategies to produce the media as described in the previous section.

If it appears that the TF layer exceeds 6 cm thickness the process of media preparation may be too labour intensive and a finer sieve should be used to produce the F and TF filtering material or other strategies considered to produce the media as described in the previous section.

(Note: The thicknesses of the F and TF layers can vary outside the limits suggested. The combined thickness of the F and TF layers must always be the same.)

Once procedures are established to produce the filtering layers it is reasonable to expect them to remain constant – provided the raw material remains the same. The procedures used to prepare the media should be documented in a straightforward way, easily understood by all individuals responsible for implementing the procedure.

Periodically, the flow rate should be checked to insure it is below the maximum yet not so low as to adversely affect filter acceptance. (Lower flow rates are OK but may not be acceptable to the intended consumer.)

<u>Technique #2 – Filter Media Design – 'Analytical Technique'</u>

The analytical technique will provide a very good estimate of the depths of the F and TF layers if it is followed very accurately. The only way to be sure that the depths are correct is to install the media in a BSF and measure the flows. The final depths of F and TF can be adjusted accordingly.

The procedure used is as follows:

Consider Figure 3 which shows a labelled sketch of a cross-section of a typical BioSand Water Filter.

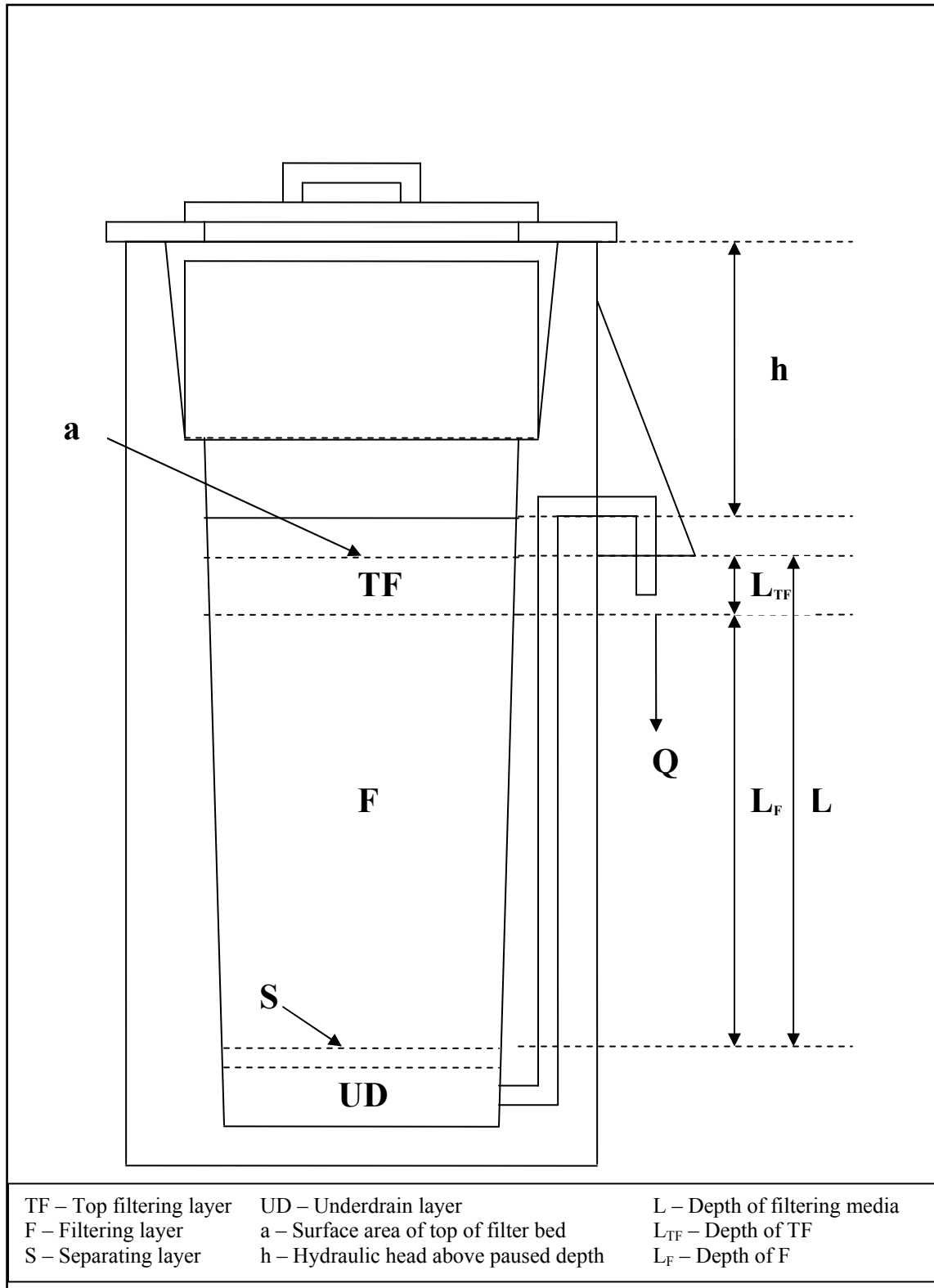|		
TF – Top filtering layer	UD – Underdrain layer	L – Depth of filtering media
F – Filtering layer	a – Surface area of top of filter bed	L_{TF} – Depth of TF
S – Separating layer	h – Hydraulic head above paused depth	L_F – Depth of F

Figure 3. Definition diagram for hydraulic analysis of BSF.

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The following equations describe the hydraulics of flow through the BSF.

(1) $\quad Q = aK_e \dfrac{h}{L}$

(2) $\quad Q_{TF} = aK_{TF} \dfrac{h_{LTF}}{L_{TF}}$

(3) $\quad Q_F = aK_F \dfrac{h_{LF}}{L_F}$

(4) $\quad Q = Q_F = Q_{TF}$

(5) $\quad h = h_F + h_{TF}$

(6) $\quad L = L_F + L_{TF}$

Equations (1) to (6) may be solved to develop Equation (7)

(7) $\quad L_{TF} = L \dfrac{\left(1/K_e - 1/K_F\right)}{\left(1/K_{TF} - 1/K_F\right)}$

Where:

Q	Flow through BSF
a	Surface area of top of media.
K_e	Hydraulic conductivity considering both F and TF.
K_F	Hydraulic conductivity of F layer.
K_{TF}	Hydraulic conductivity of TF layer.
h	Hydraulic head across F and TF (distance from top of paused depth to top of filter.
L	Depth of both F and TF.
L_F	Depth of F layer.
L_{TF}	Depth of TF layer.

The thicknesses of the F and TF layers are then determined using the following procedure:

1. Determine K_e using Equation (1) by rearranging it as shown below:

   $$K_e = \frac{QL}{ah}$$

   Q = intended flow rate through filter m^3/h (known).

   L = depth of filtering media m (known).

a = intended surface are of top of filter bed (known).

h = hydraulic head equal to the distance between the top of the filter to the top of the paused water m (known).

2. Determine K_F by installing a BSF with correct depths of underdrain and separating media and using only the F media to the full depth L. The filter is then filled with water to the top and the flow rate Q_F is measured using a calibrated container and a stop watch. Determine K_F using Equation (2) by rearranging it as shown below:

$$K_F = \frac{Q_F L}{ah}$$

3. Determine K_{TF} by installing a BSF with correct depths of underdrain and separating media and using only the TF media to the full depth L. The filter is then filled with water to the top and the flow rate Q_{TF} is measured using a calibrated container and a stop watch. Determine K_{TF} using Equation (3) by rearranging it as shown below:

$$K_{TF} = \frac{Q_{TF} L}{ah}$$

4. L_{TF} is calculated using Equation (7).

5. L_F is calculated using Equation (6).

The analytical technique is also useful for determining the utility of different sieved products for use in a BSF. It is possible to determine the K_F and K_{TF} using a small filter or equivalent and using these values to determine the design of the filtering bed whatever materials that can be found..

Bagging and Storage of Prepared Media

Prepared filter media (all four layers) should be bagged in clean, water-proof sacks. Labelling should be waterproof. The media for each layer should be bagged separately. Each bag should contain slightly more media than is necessary since supplying less media than required can present serious problems at time of filter installation. Some settling of the filtering media will likely occur after it has been installed for some time and the extra media can be used to bring the filtering layer to the desired depth. The bags of prepared media should be protected from weather and contamination.

Quality Control Considerations

Periodically, it is useful to evaluate the unprocessed crush rock to determine if its characteristics (particle sizes) are changing. This is best achieved with a set of small sieves. The percentage of material captured on these sieves relative to total sample will remain constant if the particle size variation in the bulk sample is constant. If the particle sizes are thought to have changed significantly then it may be important to evaluate the entire media production process. Often problems of this nature become known from the people who are installing the filters in the field. They may complain of the filter production being too high or too low and these MAY suggest that the processed material is changing due to changes in the characteristics in the unprocessed crushed rock OR media production is not being performed carefully enough.

Water Supply, Clarifying and Reuse

Media preparation requires the use of significant quantities of water. Ideally, media cleaning should occur near an abundant supply of water clean enough for media preparation. The water may be slightly turbid and be considered unsafe for human consumption but it should NOT contain pathogens that can penetrate the skin (e.g. Schistosomiasis). Wash water produced during media preparation is contaminated with excess sediment and should not be disposed of without allowing most of the particles to settle. It is definitely preferable to clarify the wash water (even using small amounts of coagulant such as alum) and reuse the clarified water. Media preparation operations that clarify and reuse their wastewater may be located quite far from the raw water supply.

Actual Installation Considerations

Should the raw material supply used for producing the top and second filtering layers vary with time (this is quite probable) it may be impractical to try to alter the media production procedures to keep up with the variations in the characteristics of the resulting filtering media. Rather, it may be practical to install the filter bed using a standard procedure, which would result in flow rates near the maximum allowable. If after installation the flow rate is too low some of the top layer (1 cm or less) can be removed to achieve desirable flow rate. If the flow rate is too large the top filtering layer can be increased to reduce the flow rate to maximum allowed. The effect of removing or adding filter media is to increase or decrease the depth of the layer of water on top of the filter bed when flow is stopped. This is acceptable provided the variation of water depth is within 1 cm or so of the objective 5 cm.

Four media systems developed using one type of material may be quite different from other four media systems developed using other types of material. Crushed granite, gneiss, quartzite, limestone, dolomite, sandstone, etc. can be expected to require quite different preparation procedures. As a rule the more similar the shape of the crushed particles (closely examined using a magnifying glass) the similar the preparation procedure will be. Development of media preparation procedures using a completely unique material will be greatly facilitated by starting with any known procedure that is working successfully and modifying it as required.

Final Comments

It is clear that developing and implementing the four layer system appears to be an onerous task that must be undertaken in a professional manner. The purpose is to provide very good QA/QC that is practical to use. This is especially important where media preparation is concerned and essential when thousands of BSF's are being produced. The three layer system has been demonstrated to do this as well but not without considerable effort. Once the necessary manufacturing procedures have been put into place the four layer system can be expected to require significantly less work to produce quality filter media with a minimum of effort and expense.

APPENDIX A

Standard Sieve Sizes

Mesh Size (microns)	TYLER	ASTM-E11	BS-410	DIN-4188
µm	Mesh	No.	Mesh	mm
5	2500		2500	0.005
10	1250		1250	0.010
15	800		800	0.015
20	625		625	0.020
22				0.022
25	500		500	0.025
28				0.028
32				0.032
36				0.036
38	400	400	400	
40				0.040
45	325	325	350	0.045
50				0.050
53	270	270	300	
56				0.056
63	250	230	240	0.063
71				0.071
75	200	200	200	
80				0.080
90	170	170	170	0.090
100				0.100
106	150	140	150	
112				0.112
125	115	120	120	0.125
140				0.140
150	100	100	100	
160				0.160
180	80	80	85	0.180
200				0.200
212	65	70	72	
250	60	60	60	0.250
280				0.280

315				0.315
355	42	45	44	0.355
400				0.400
425	35	40	36	
450				0.450
500	32	35	30	0.500
560				0.560
600	28	30	25	
630				0.630
710	24	25	22	0.710
800				0.800
850	20	20	18	
900				0.900
1000	16	18	16	1.0
1120				1.12
1180	14	16	14	
1250				1.25
1400	12	14	12	1.4
1600				1.6
1700	10	12	10	
1800				1.8
2000	9	10	8	2.0
2240				2.24
2360	8	8	7	
2500				2.5
2800	7	7	6	2.8
3150				3.15
3350	6	6	5	
3550				3.55
4000	5	5	4	4.0
4500				4.5
4750	4	4	3.5	

APPENDIX B. Specifications for a typical wire-mesh cloth.

Mesh Per Lin. In.	Wire Dia., In.	Width Open., In.	Open Area, %	12"x 12" Sheets Each	36" & 48" Wide Continuous Lengths		
					3-12 sq. ft.	15-36 sq. ft.	39-60 sq. ft.
1" *	0.120	0.880	77.4	$ 16.92	$16.92	$13.84	$11.62
1" *	0.080	0.920	84.6	10.84	10.84	9.17	6.78
3/4" *	0.120	0.630	70.5	21.47	21.47	17.56	14.74
3/4" *	0.080	0.670	79.8	12.54	12.54	10.62	8.56
2 x 2	0.120	0.380	57.8	33.00	33.00	26.40	22.18
2 x 2	0.105	0.395	62.4	23.46	23.46	16.12	13.15
2 x 2	0.080	0.420	70.6	14.80	14.80	11.84	9.94
2 x 2	0.063	0.437	76.4	8.83	8.83	7.15	5.70
2 x 2	0.047	0.453	82.1	6.91	6.91	5.75	4.68
3 x 3	0.080	0.253	57.6	19.56	19.56	15.64	13.13
3 x 3	0.063	0.270	65.6	13.04	13.04	10.43	8.76
3 x 3	0.047	0.286	73.6	8.34	8.83	7.06	5.35
4 x 4	0.080	0.170	46.2	29.95	29.95	23.96	20.13
4 x 4	0.063	0.187	56.0	17.98	17.88	14.30	12.10
4 x 4	0.047	0.203	65.9	10.18	10.18	8.14	6.60
5 x 5	0.047	0.153	58.5	12.60	12.60	10.08	8.47
5 x 5	0.041	0.159	63.2	10.01	10.01	8.02	6.73
6 x 6	0.063	0.104	38.9	26.72	26.72	21.86	18.36
6 x 6	0.047	0.120	51.8	15.16	15.16	12.12	10.19
6 x 6	0.035	.0132	62.7	9.35	9.35	7.48	5.98
8 x 8	0.063	0.062	24.6	54.91	55.47	45.38	33.60
8 x 8	0.047	0.078	38.9	20.12	20.12	16.46	13.82
8 x 8	0.035	0.090	51.8	10.54	10.54	8.43	7.08
8 x 8	0.032	0.093	55.4	11.60	11.60	9.67	7.87
8 x 8	0.028	0.097	60.2	7.46	7.46	5.96	4.99
10 x 10	0.047	0.053	28.1	31.38	31.38	25.10	21.08
10 x 10	0.035	0.065	42.3	14.14	14.14	11.31	9.50
10 x 10	0.032	0.068	46.2	14.49	14.49	12.07	8.80
10 x 10	0.025	0.075	56.3	7.18	7.18	5.74	4.82
12 x 12	0.041	0.042	25.4	37.33	37.33	32.66	25.97
12 x 12	0.035	0.048	33.2	20.30	20.30	16.24	13.64
12 x 12	0.032	0.051	37.5	15.68	15.68	12.54	10.54
12 x 12	0.028	0.055	43.6	12.08	12.08	9.76	8.12
12 x 12	0.023	0.060	51.8	7.46	7.46	5.96	4.99

14 x 14	0.032	0.039	29.8	20.85	20.85	17.63	12.21
14 x 14	0.025	0.046	41.5	11.06	11.06	8.84	7.44
14 x 14	0.023	0.048	45.2	13.15	13.15	11.12	7.70
14 x 14	0.020	0.051	51.0	8.67	15.75	6.93	5.60
16 x 16	0.028	0.035	30.5	19.13	19.13	16.40	13.17
16 x 16	0.023	0.040	39.9	14.02	14.02	11.87	9.58
16 x 16	0.018	0.045	50.7	7.70	7.70	6.16	5.20
18 x 18	0.020	0.036	41.1	17.98	17.98	14.98	12.18
18 x 18	0.017	0.039	48.3	7.15	7.15	5.72	4.60
20 x20	0.023	0.027	29.2	15.68	15.68	12.54	10.54
20 x 20	0.020	0.030	36.0	13.40	13.40	11.35	9.17
20 x 20	0.018	0.032	41.0	6.33	6.33	5.27	4.60
20 x 20	0.017	0.033	43.6	7.81	7.81	6.51	5.28
20 x 20	0.016	0.034	46.2	8.94	8.94	7.15	5.60
24 x 24	0.014	0.028	44.2	8.94	8.94	7.15	5.70
28 x 28	0.010	0.026	51.8	4.95	4.95	4.12	3.60
30 x 30	0.013	0.020	37.1	6.28	6.28	5.23	4.55
30 x 30	0.012	0.021	40.8	7.43	7.43	5.94	4.80
35 x 35	0.012	0.017	33.8	6.28	6.28	5.23	4.55
35 x 35	0.010	0.019	42.4	7.16	6.37	5.46	3.83
40 x 40	0.0135	0.012	21.2	16.72	16.72	14.34	11.50
40 x 40	0.011	0.014	31.4	7.81	7.81	6.51	5.28
40 x 40	.010	0.015	36.0	7.43	7.43	5.94	4.80
40 x 40	0.0095	0.016	38.4	7.19	7.19	5.99	4.88
50 x 50	0.009	0.011	30.3	8.54	8.54	6.82	5.70
60 x 60	0.0075	0.009	30.5	7.40	7.40	5.92	4.97
70 x 70	0.0065	0.008	29.8	6.52	6.52	5.34	4.48
80 x 80	0.0070	0.006	19.4	8.10	8.10	6.75	5.88
80 x 80	0.0055	0.007	31.4	7.24	7.24	5.79	4.86
90 x 90	0.0055	0.006	25.4	9.15	9.15	7.95	6.26
100 x 100	0.0045	0.006	30.3	7.30	7.30	5.83	4.60
120 x 120	0.0040	0.0043	26.6	12.76	12.76	10.63	8.65
120 x 120	0.0037	0.005	30.7	7.40	7.40	5.92	4.97
150 x 150	0.0026	0.0041	37.4	10.45	10.45	8.36	6.70
165 x 165	0.0019	0.0041	44.0	10.35	10.35	8.87	8.65
200 x 200	0.0021	0.0029	33.6	11.42	11.42	9.13	7.68
200 x 200	0.0016	0.0035	46.0	17.82	17.82	15.07	12.18
230 x 230	0.0014	0.0028	46.0	20.36	20.36	17.23	13.91
250 x 250	0.0016	0.0024	36.0	21.94	21.94	18.28	14.87
270 x 270	0.0014	0.0022	38.0	22.56	22.56	19.09	15.42
325 x 325	0.0014	0.0017	30.0	22.70	22.70	18.15	15.30
325 x 325	0.0011	0.0020	42.0	30.66	30.66	26.28	21.09
400 x 400	0.0010	0.0015	36.0	49.95	49.95	42.81	34.37

| 500 x 500 | 0.0010 | 0.0011 | 25.0 | 132.83 | 132.83 | 110.69 | 90.02 |
| 635 x 635 | 0.0009 | 0.0006 | 14.5 | 615.61 | 615.61 | 533.53 | 426.12 |