Centre for Affordable
Water and Sanitation Technology

Design Rational for the CAWST Biosand Filter

CAWST Learning Exchange

June 2012

OUTLINE

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2. Slow Sand Filter (SSF) Technology
   - BSF versus SSF
3. Why is the BSF designed as it is?
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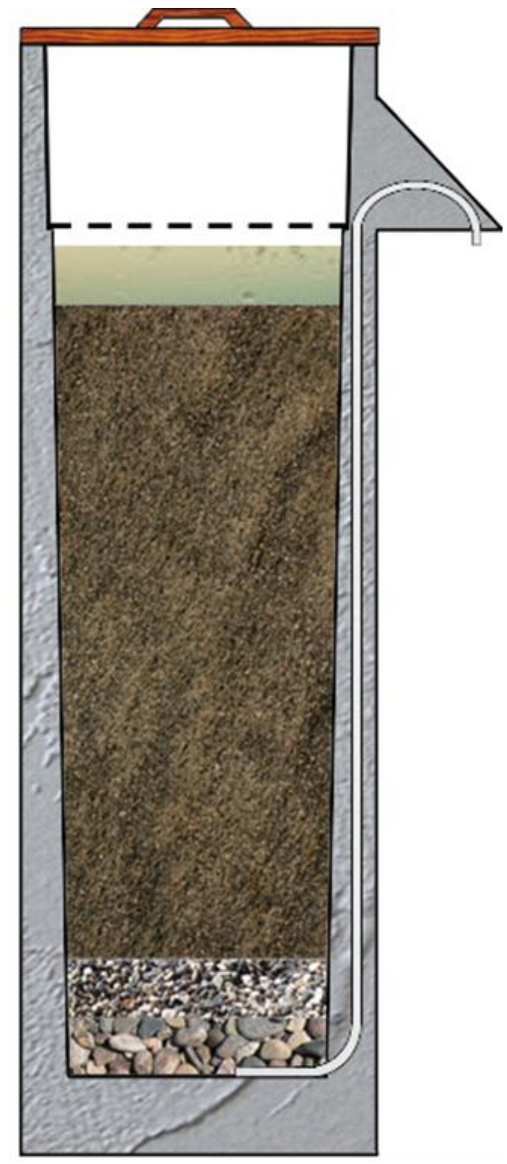
   - Lid
4. Why was the version 10 created?
   - What's the difference between Version 10.0 versus 10.1?



What is Needed? [of a HWT device]

- Highly effective against all categories of microbial pathogens
- High capacity (daily and long-term production)
- Easy to deploy, learn, use, maintain
- Operates in high and variable turbidity
- Affordable (up front and long term)
- Portable, robust design
- Improves water aesthetics
- Attractive, aspirational
- Protects against recontamination
- Reduces arsenic and fluoride
- Reduces other chemical contaminants

From: Thomas Clasen, London School of Hygiene and Tropical Medicine;
Household Water Treatment: Evidence of Effectiveness and Issues in Scaling Up

Slow Sand Filter Technology

The Biosand Filter (BSF) is an adaptation of Slow Sand Filter (SSF) Technology:

- SSF is a 150 year old technology used in many major cities such as London and Amsterdam as a step in their municipal water treatment process
- In 1991 Dr. David Manz developed a slow sand filter to be operated intermittently, thus making it more suitable for household applications . This was achieved in the design by making the highest point of the outflow tubing 5 cm above the sand, ensuring that water covers the sand at all times (Clasen, 2009).
- Both the SSF and the BSF are a gravity-driven sand filters with similar filtration sand supported by coarse sand and gravel.

Differences between municipal (SSF) and household (BSF) design

Biosand Filter (BSF) technology is very similar to that of Slow Sand Filter (SSF) but differs in some important ways:

1. The SSF is sized for municipal requirements while the BSF is sized for household water treatment needs.
2. Water flows continuously through SSF but intermittently through the BSF.

   [The BSF is sometimes called an Intermittent Slow Sand Filter (ISSF)]
3. The flow of water through the SSF is normally controlled with a flow-control device at the outlet. The BSF operates without flow-control – this is because the flow rate of the BSF is the most important measure of the filtration sand quality.

Differences between municipal (SSF) and household (BSF) design

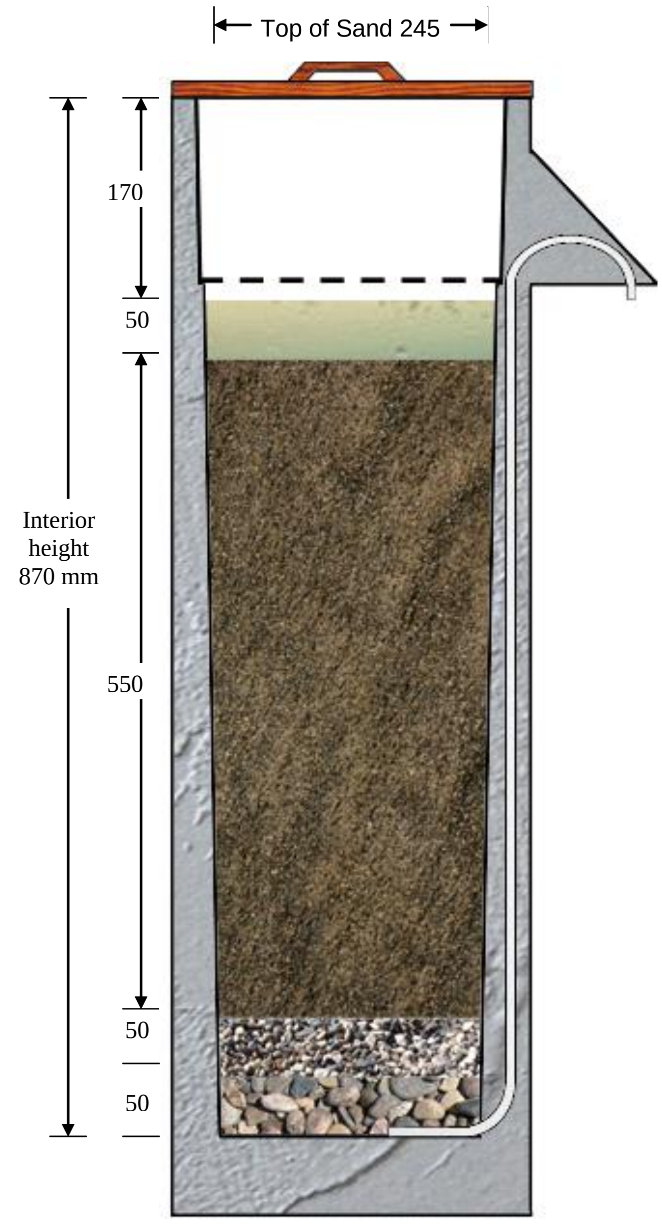
4. The method of cleaning the filter bed varies:
   - Cleaning the SSF means removing ~1 cm of the filtration sand every 6 weeks or so. The SSF starts with 1 – 1.5 m of filtration sand and replaces all that was removed when the bed depth reaches approximately 0.5 m.
   - The BSF is small enough to 'clean in place' - a technique that restores the flow rate without the need to remove the sand.
   - The sand bed depth of the CAWST biosand filter is 0.55 m.

BSF Design – Shape and Materials

The biosand filter body (or housing) has been made from various materials; concrete, plastic and metal, and in at least two shapes; square and round.

- The exterior of the CAWST biosand filter is concrete.
  - The concrete walls can be painted and even tiled for greater attractiveness but unpainted walls allow more evaporation and cooling of water [painting three sides and leaving the back wall unpainted improves attractiveness while still allowing cooling]
- Plastic body filters can be as effective as concrete body filters if rigid plastic is used for the walls and the outlet tubing does not rise up through the sand.
- The shape (round vs. square) of the filter body does not affect the filter performance

[the filtration sand is the engine of the filter not the filter body]

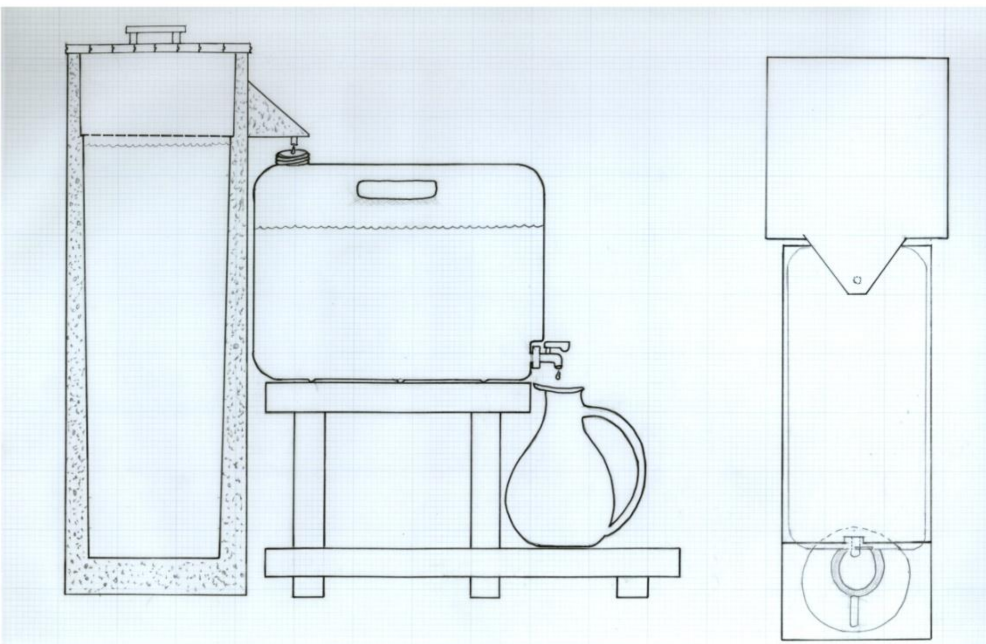


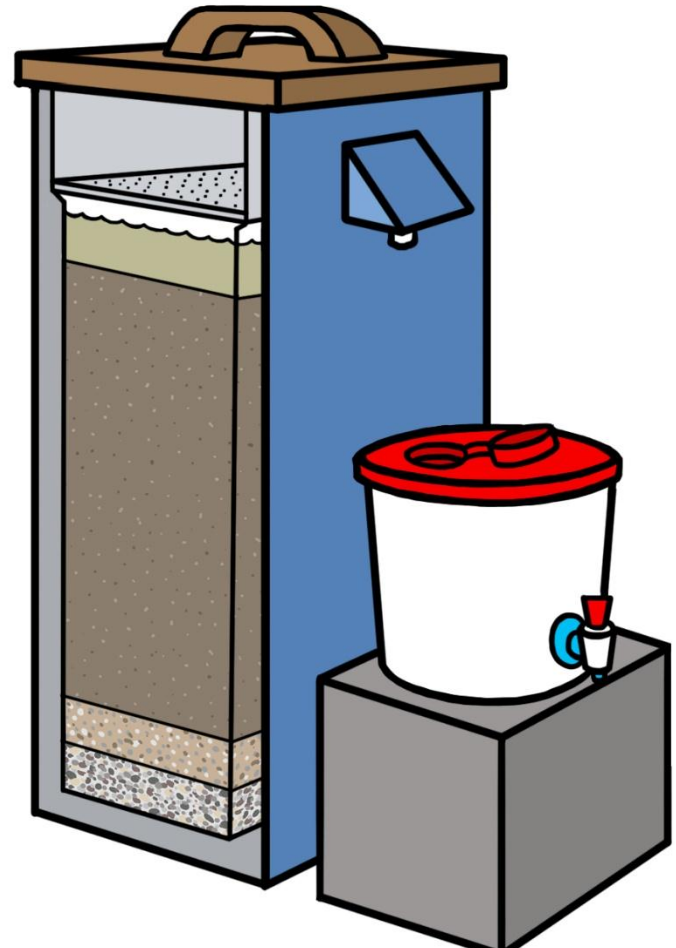
BSF Design – Size

- Exterior size of filter is 30.5 x 30.5 x 94cm (12 x 12 x 37 inches)
  - Footprint is 1 square foot of floor space
  - Height to lift the fill bucket is convenient; about the same as counter height in a kitchen

'Side-wall' or 'slip-stream' effect may occur if the width of the BSF is too small because water may short-circuit down along the walls instead of passing through the sand

BSF Design – Ergonomic considerations





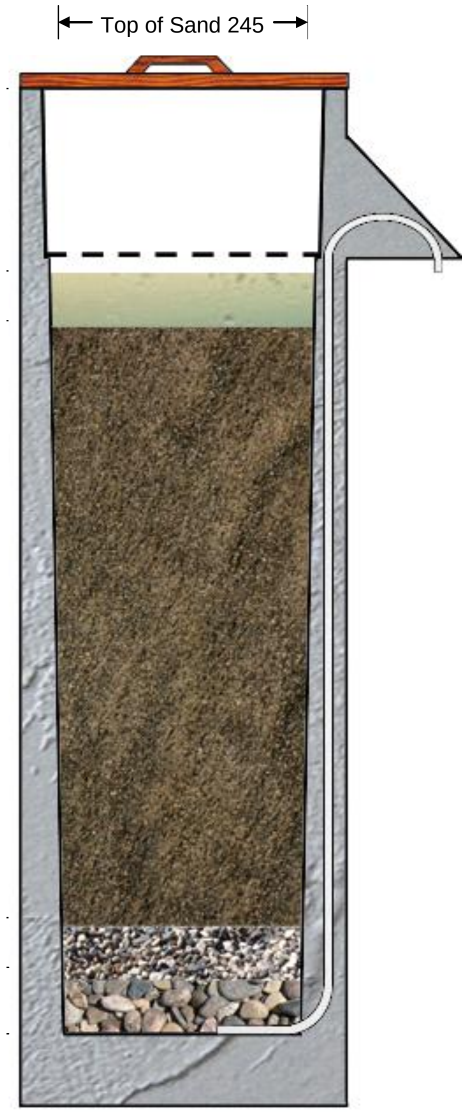
Safe storage is an important step in water treatment – this should be a consideration when BSF projects are implemented.

BSF Design – Wall Thickness

- Wall thickness tapers; from 20mm (¾") [25mm (1") for the v10.1] at the top to 41.5 mm (1 $^{5}/_{8}$") at the base [v10.1 has the same thickness at base of wall]
  - The thickness at the top of the wall is to provide strength [if a mold is inaccurate, a thin wall at the top may result]
  - The taper is needed to extract the inner mold – the amount of taper determines the wall thickness at the base
  - The v10.1 design allowed the wall thickness at top of the walls to be increased where strength is more critical [without changing the taper of the inner mold]
  - The wall thickness of the CAWST design was reduced in order to reduce the weight of the BSF
    - This was the change from version 8 to version 9 [circa 2006]
    - This revision was driven by CAWST clients' survey responses that a lighter BSF body was needed.

BSF Design – Filtration Rate

- A critical dimension is <u>the surface area of the top of the filtration sand</u>:
  - This is **0.06 m²** (0.65ft²) for the CAWST biosand filter.
  - The filtration rate (or hydraulic loading rate) recommended by CAWST is 0.4 $m^3/m^2/hr$ [equates to 0.4 m/hr – a velocity term – distance per unit time]
  - This is measured when the filter is first installed [called the 'clean bed filtration rate']
  - For the surface area of $0.06 m^2$ this **filtration rate** of 0.4 m/hr equates to a recommended **flow rate** of 0.4 L/min [a volume per unit time term]
  - Different sized BSF (with different surface areas) will have different target flow rates but should always have the same target filtration rate.



BSF Design – Quantity of Water

- Quantity of filtered water from BSF is +/- 60 litres per day [evaluation in Uganda (2009) found average of 200 L/day when each BSF was shared by 5 families - avg. 32 people - however this reduced removal effectiveness]
  - BSF is filled with 5 or 6 batches of water per day using a bucket/ jerry can to get 10 - 12 litres per fill.
  - For a household of six people this is 10 litres per day per person
  - A person requires 2 – 5½ litres water per day for drinking plus additional volume for cooking and hygiene
  - Most BSF users feel that the quantity of water from the BSF is sufficient for one family [avg. 94% gave this response in 7 BSF project evaluations in 6 countries]

BSF Design – Weight and Portability

- The BSF concrete filter body is heavy – about 80-90 kg (175 - 200 lb.)
- This weight roughly doubles once the filter is installed with sand, gravel and water meaning even the plastic body filters are very heavy once they are installed.
- The BSF is <u>not</u> portable
  - Sand compaction occurs if the BSF is moved to another location after it has been installed. This can reduce the flow rate to unacceptable level. Cleaning the filter will not restore the flow rate; the filter must be reinstalled.
  - The positive is that the BSF can't be stolen or swept away in a flood.
- Transient populations are not a good target group for the biosand filter.

Sand depth and reservoir volume

Depth of filtration sand is based on 2 criteria:

1. Minimum 50 cm to provide surface area for adsorption of contaminants
   - viruses are removed deep in the sand bed as well as in the biolayer [50 cm is the normal minimum sand bed depth of SSF]
2. Sufficient sand volume so that the pore volume of the sand is more than or equal to the volume of the reservoir (the maximum fill volume)
   - For the CAWST version 10 this is a depth of 55 cm
   - This amount of sand can 'hold' 12 litres of water in the pore spaces. [pore volume is approx. 40% of the total sand volume]

The reservoir of the version 10 BSF is designed so that it can accept a maximum of 12 litres of water in one fill –the same amount that the filtration sand can hold [this was the reason for the version 10 design; reservoir volume ≤ pore volume and lower hydrostatic head]

Filtration Sand

"The heart of BSF design lies in the careful and appropriate selection of the filter media."

Michael Kubare and Johannes Haarhoff
Department of Civil Engineering Science,
University of Johannesburg,
IWA Publishing 2010 Journal of Water Supply: Research and Technology—AQUA | 59.1 | 2010

[Filtration sand covered in separate presentation by Sandy]

Separating layer of coarse sand

The separating layer separates the filtration sand from the under-drain layer.

- This is essential to prevent the filtration sand from moving down into the outlet tubing and plugging it off [you’ll need to reinstall the BSF if this happens - ouch]
- The size of grains and the depth of the separating layer are both important;

  Grain size is 0.7 mm – 6 mm [~8 times size variation]

  Layer depth is 50 mm. [depth is ~20 times median grain size]

One method for grading of the media support layers is a time-tried rule dating back to the 1930s (Baylis 1935): namely, that the average grain size (d_{50}) of each successive coarser layer must be not more than twice the average grain size of the layer above it.

- Investigate the separating layer grain size if the tubing of filters is plugging frequently [two separating layers instead of one may be needed to better control grain size distribution]

Under-drain layer of gravel

- Provides the ‘plug’ or ‘piston’ flow through the filter so that the water travels equally through the entire filtration sand bed
- Without the under-drain layer there would be ‘convergent ‘ flow with all the water streaming to the ‘pressure sink’ at the tubing inlet
- The under-drain layer is sized to:
  - minimize the pressure loss of the water moving through it
  - support the sand above
  - be too large to enter the inlet of the tubing

    size: 6 – 12 mm (¼” to ½”)

    depth: 50 mm (5 cm or 2”)

The more ‘square’ the graph the closer to 100% ‘plug’ flow

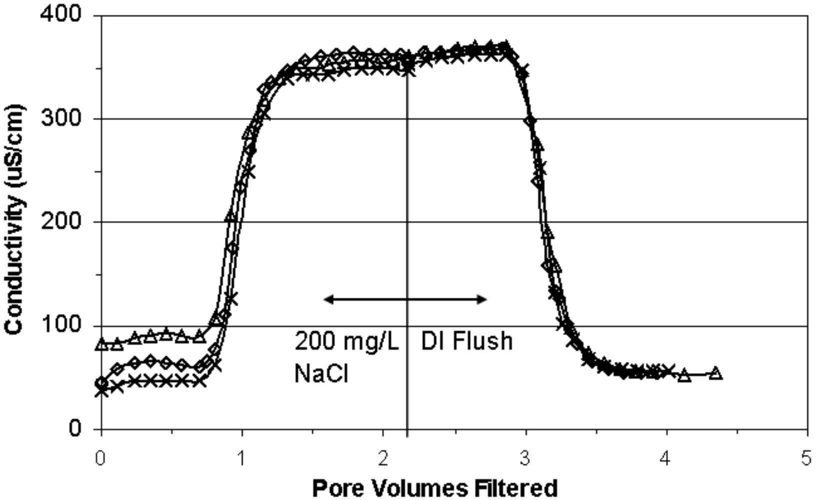


Figure 2: Results of three step-input tracer tests conducted with the plastic BSF.

From: Mark Elliot et al; *Water Research* 2008

Tubing/ outlet piping

The outlet pipe is designed to:

1. extract the water from the bottom of the filter,
2. provide a means to capture the water in a variety of containers (distance of spout from wall),
3. cause the level of the standing water during the pause period to be 5 cm above the top of the sand
   - Early versions used ½” PVC outlet piping which acts like a weir - water level will be left at the highest point of the pipe bottom
   - Thin-wall versions (9 and 10) use ¼” tubing which will siphon – water level during pause period is left at height of spout

Standing water layer

- The biolayer of the biosand filter must be submerged at all times by the standing water layer [technical term is ‘supernatant’]
- In slow sand filters (SSF) the standing water is kept at approx. 1 metre – the continuous flow of water provides the oxygen to the biolayer of the SSF
- In the BSF, the design for the standing water layer depth considers:
  1. The ability of oxygen to reach the biolayer by permeating through the standing water layer during the pause period [there is little real data on oxygen levels in the standing layer and below – this needs more study - but <u>less</u> water depth is better]
  2. The ‘cushion’ that the standing water layer provides helps to diffuse the energy of the water that flows down from the diffuser plate/ basin [the last defense to protect the biolayer from disturbance – the <u>greater</u> the water depth the better]
  3. The amount of water that may evaporate when the filter is not used for an extended period. [a dry filter will kill the organisms in the biolayer – 5 cm could be gone in as little as 3-4 days evaporation – the <u>greater</u> the water depth the better].

Standing water layer: Buzanis, 1996

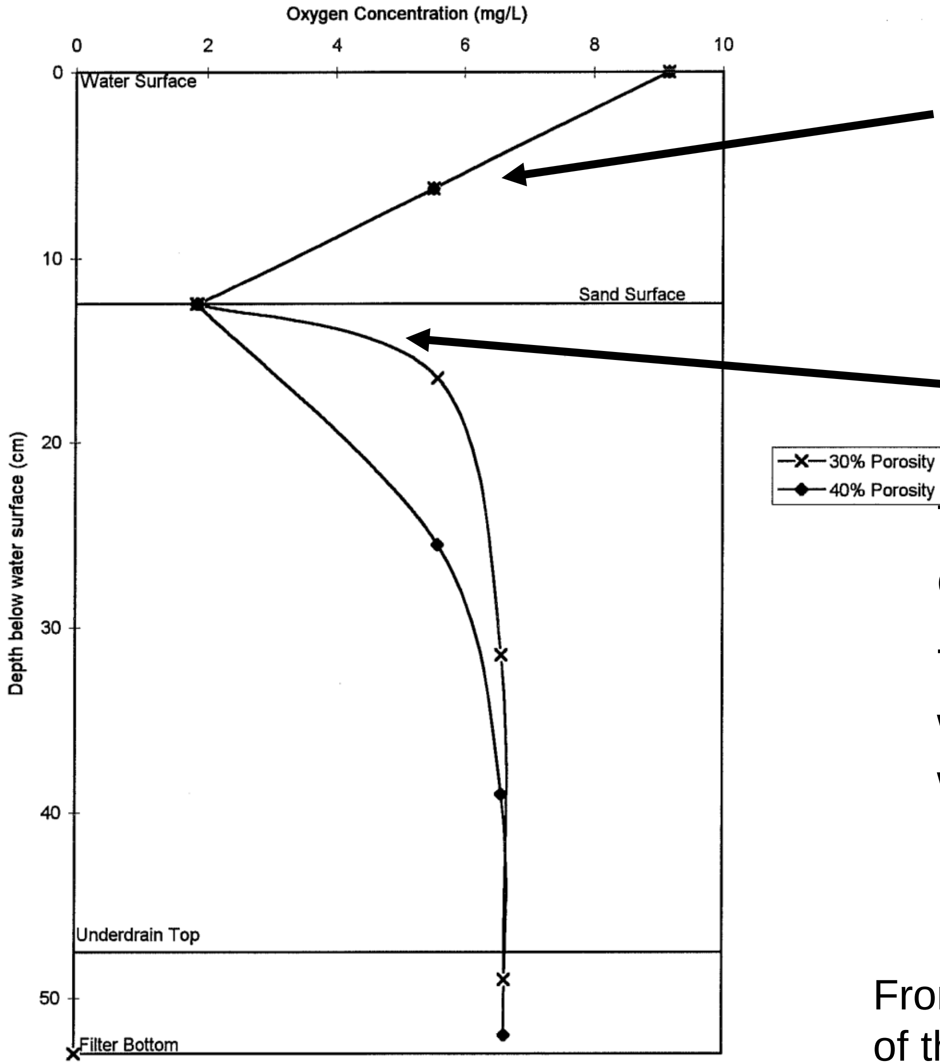


Figure 8.14 Typical Oxygen Concentrations through Filter after Pause Time

- Oxygen concentration drops as the water depth increases

biolayer is consuming oxygen during pause period

The deeper the water, the less the oxygen to the biolayer

This is a concern especially if the water has low oxygen levels to begin with (deep well, stored water)

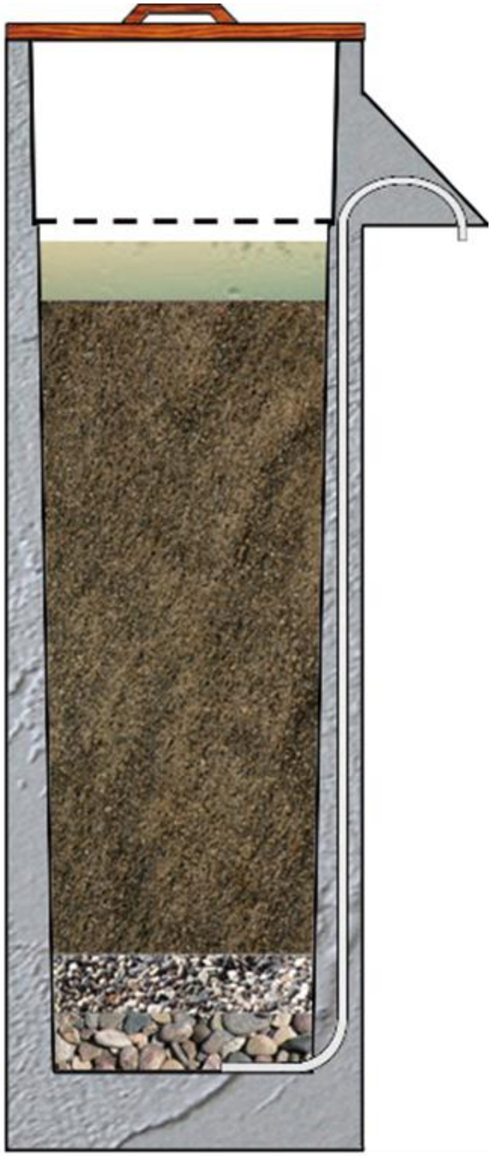
Recommend NOT greater than 5 cm

From Palmateer - It is believed that the height of the standing water may be important in the development of the biofilm; 2-3 cm appears to be an efficient level.

BSF Design - Diffuser

1. The purpose of the diffuser is to diffuse the energy of the water when it is poured into the BSF [diffuser basins are not used in the SSF]
2. Palmateer (1997) found that after they had done testing, the biolayer was disturbed. The heterotrophic bacteria removal was only 83+ %
3. Located 20mm (¾") above the standing water level during the pause period

   [for reference, the location of the diffuser inside the filter corresponds with the bottom of the concrete nose on the outside. Also, the length of spout determines air space below the diffuser to the top of the standing water]
4. The diffuser is typically either a plate or a basin/ box [other designs exist too].
5. David Manz design was 100 holes of 3mm (1/8") diameter in the base of the diffuser.



BSF Design - Lid

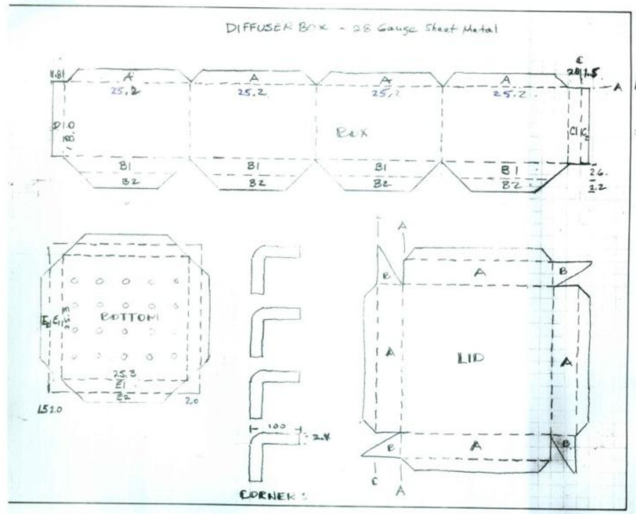
The purposes of the lid are to prevent:

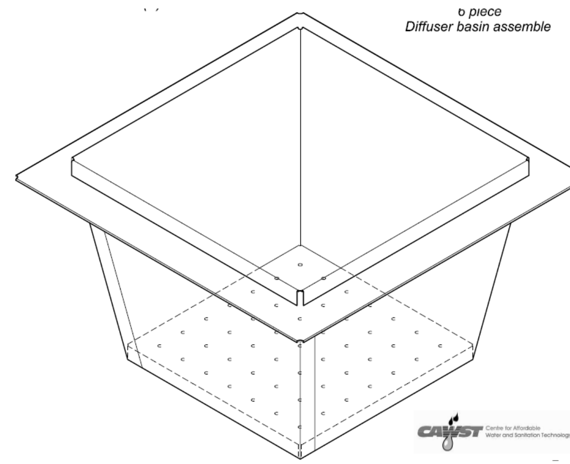
1. insects from breeding inside
2. entry of light causing algae growth
3. dirt, animals & foreign objects from entering

Other advantages of the lid include:

- makes BSF more attractive [cloth is sometimes placed underneath lid]
- provides a level surface at a convenient height [the handle may be place on the side of the lid to provide flat surface]

Diffuser Basins





What's the difference between Version 10.0 versus 10.1?

The version 10.0 is designed for a ledge in the filter to hold a diffuser plate. If an implementing organization decides to go with diffuser basins in all their filters, it then makes sense for them to build any future molds without having the 'ledge' for the diffuser plate - version 10.1 [or 'version 10 without a ledge']:

- This simplifies the mold by eliminating the use of ¼" (12 mm) steel to make the upper part of the inner mold.
- It makes it less expensive to fabricate a steel mold because it is easier to make the mold and uses less material.
- Eliminating the ledge in the filter removes a quality issue because often this ledge (for the diffuser plate to rest on) is not properly formed which is another cause for the sand to be disturbed.