Concept Note

An innovation in Biosand filter design enabling further optimisation

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Disclaimer

There have been a lot of very cleaver people involved in the evolution of the biosand filter. If I manage to contribute anything positive to the well established design of the BSF it will be because I stand “*like dwarfs on the shoulders of giants, so that we can see more than they, and things at a greater distance, not by virtue of any sharpness of sight on our part, or any physical distinction, but because we are carried high and raised up by their giant size.*”

Bernard de Chartres (d. 1124)

1 Innovation

In 1809 the genius Humphry Davy built the first light bulb. Thomas Edison improved the invention and in the last 200 years the design has not stood still and has fathered the halogen lamp, the neon light, the arc lamp, the fluorescent tube, the sodium lamp and the LED. In the history of innovation there are few inventions which have stopped evolving. Indeed it seems that people continuously try to improve on mainly the <u>really important</u> ones.

In the main, inventions have two aspects; some basic requirements and some things which over time get optimised as people look at the problem again in increasingly creative ways. For the light bulb the basic requirements were something like

1) convert electrical energy into light at sensible voltages & powers
2) not be dangerous (heat / flames / explosive gases and the like)
3) be robust enough for practical use
4) produce enough light for practical use

The “optimisations” that have kept us busy for 200 years have been things like

4) Maximise the amount of light per joule consumed
5) Minimise the amount of heat per joule consumed
6) Maximise robustness
7) Minimise price
8) Maximise flexibility for different colours
9) Maximise the flexibility for different shapes
10) Maximise potential for miniaturisation (and maxiturisation if that's a word)
11) Maximise the total light available at the total wattage
12) Minimise complexity

The BSF like most other inventions has been contributed to by a long list of geniuses and contributed to in small and big ways by professors, practitioners living in the bush and students in various universities around the world. I guess that's because it's really important and has been earmarked as “the” most practical applicable technology to deliver safe water to the poor in developing countries.

2 Design Brief (for approval and correction by the experts):

I propose a list of design criteria that I think are sensible for judging bio-sand filter designs. They are listed as "Requirements" (aspects that must or must not be true), "Optimisations" (aspects that have either no achievable minimum or no achievable maximum).

<u>Requirements:</u>

1. Must keep the schmutzdecke in oxygenated water at all times[1] (otherwise the aquatic 'B' in BSF is missing)
2. Must allow the same statistical likelihood of "attachment" as the required filtering efficiency by requiring the water to travel:
    a) sufficient distance (at both the macro and micro levels)
    b) through void spaces of appropriate effective narrowness
    c) at appropriate velocity through void spaces (not rate!)
3. Must have an outlet convenient for filling containers with water to be consumed
4. Deliver safe water in sufficient quantity for the users to drink directly (drinking is the priority)

<u>Optimisations:</u>

5. Minimise empty weight (for easy & cheap transportation)
6. Minimise component costs per filter (key if the customer is paying)
7. Minimise tooling costs per filter (though customer may not pay for tooling)
8. Minimise manufacturing complexity
9. Minimise carbon footprint (carbon released in order to render the raw materials)
10. Minimise the flow velocity through voids (reducing shear forces acting on detritus)
11. Maximise residence times of the water in the filter body (time kills).
12. Maximise the area & effectiveness of the schmutzdecke (this is where it mostly happens)
13. Minimise potential for post-filter water recontamination (the design has only a small influence on this but it's worth putting in)
14. Maximise the total throughput (a lot of clean water is clearly better than a bit)

Many of the "optimisations" have so far been considered <u>partially</u> contradictory (e.g. if everything else stays the same 11. and 14. are contradictory **but** they can <u>both</u> be improved by changing a third parameter; cross sectional area)

None of these optimisations are logically contradictory (even both 10. and 14. are not logically contradictory, they can both be maximised using cross sectional area and increasing the distance travelled)

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1 although keeping it wet for longer than 48 hours is pointless since the bacterial predators die off without renewed influx of food (contaminated water) anyway

3 Desert Rose Consultancy's design objectives:

This attempt to input into the ongoing improvement of the performance (in the way it's actually used) of the biosand filter comes following observations about it's use in Ethiopia. It also follows CAWST's latest modification in 2010 of their popular design the MK9 to the latest MK10. What is clear is that CAWST and their partner organisations (Samaritan's Purse etc) have been very diligent and successful in optimising the design as far as possible. It now rests at a point where any optimisations in one parameter will have detrimental effects on one or more other important parameters.

Desert Rose Consulting believe that they have developed an innovation which changes the playing field and opens up a new round of optimisations that will be done under slightly different limitations than the MK10 is currently constrained by.

3.1 Some specific idealised design objectives for this innovation:

- **Have a design with no gravel or small stones and replace the space with just water:** For non-cement designs gravel has to be sourced & crushed, graded and cleaned and has a cost. The gravel serves only one helpful function; stopping the finer material from falling through and clogging the exit. However is it also contributes weight (in gravel itself and in the extra wall required). It also reduces the residence time since without it the water would travel through this portion of the filter at a much slower rate if it was empty space. Or put another way, without it the total water residing in the filter would be that much the greater assuming just water was in it's place.
- **Maximise the schmutzdecke area without necessarily increasing the sand cross sectional area:** Campoz (2002) has shown by his detailed modelling of SSFs that "*the largest headloss occurs in the top 2cm of sand*" (see particularly pp 312-315). This is particularly true of filters that have a developed schmutzdecke (the mode in which Biosand filters are supposed to work). The idea that the top few mm is responsible for almost all the head-loss is clear when one considers that the process of "harrowing" (Lukacs 2001) without disturbing the top few cm of sand restores the filter flow when it has dropped below acceptable limits.
  With the current design, the area of schmutzdecke can only be increased by increasing the cross sectional area of the sand too. In an ideal world, it'd be nice to have a large schmutzdecke area to reduce the headloss, but since the sand doesn't contribute much to the headloss it's un-necessary to increase that area too; it just adds weight.
- **Reduce the volume of cement:** Being self evident, this objective needs little justification. Cement is heavy and expensive. Transporting it has a cost. Transporting a heavy biosand filter has cost and inconvenience. In an ideal world the design would of course be lighter.
- **Have a residence ratio significantly better than 100%**: Acknowledging research done by Elliot et. Al (2008), CAWST adjusted the ratio of the "fill volume" to the "void space" to be 1:1 (CAWST 2008a). However, the figures presented (ibid.) clearly show that in actual fact, much more significant improvements are <u>only</u> really seen if you filter much less than 100% of the void space. The best improvements are attained when filtering between 75% and 50% of the void space. One of the reasons for this is clearly outlined in CAWSTS training literature which states "*Water that has spent the pause period in close association with the biologically active layer contains some contaminants which were not consumed by the micro organisms. These are initially swept through the pore openings which have been partially opened up during the pause period*" (CAWST 2006). This explains why a filtering ratio of 100% is not as good as 75%. It also upholds a filter ratio of <100% as a legitimate and important goal for improved water quality.
- **Increase the daily delivery under recommended operating conditions:** In the CAWST version 10 the maximum fill was reduced to just 12L. The void retention of the filter was also increased to 12L. In addition, many sources (including CAWST 2008b) allude to an optimal pause period as being somewhere in the range 6-12 hours. This means that the family would have access to 36L of water per day (assuming we agree it's inconvenient to get up in the middle of the night to refill the filter). WHO standards for basic drinking & cooking water requirements for even medium term allocation (which they say can only be sustained for a few months) is 7 litres/capita/day (WHO 2005). Consequently it is clear that under recommended operating conditions the CAWST v10 biosand filter cannot provide this basic recommended amount for more than 5 people.

- If it is true that:
  a) the use of the biosand filter is intended to be a longer term

solution that people are 'delighted' with (as opposed to a temporary measure that people can 'live with'

b) a typical african family is larger than 5 people
c) a biosand filter is often sold as being able to sustain the water use for several families

then it is clearly necessary that for a customer to be able to use the biosand filter under the recommended conditions for optimal pathogen removal, the daily delivery needs to be increased as a matter of priority.

If this is not done then we can expect the customer to make decisions based on minimising the negative effects of having no water (which they clearly perceive) over and above the positive effects of water with low microbial quality (which they cannot perceive). This is backed up by Dolan et. al (2009 pp19-20) who state "*Our responses to incentives are shaped by predictable mental shortcuts such as strongly avoiding losses*"

4 The DRC Reversed flow biosand filter

The specific innovation from DRC which has not been documented before is causing the water to flow upwards at the point it leaves the sand. Since the flows are low and sand is denser than water the sand will not follow. This is done with an up-flow section in the centre of a cylindrical filter.

Since the upward flow area is beneath the level of the sand surface it enables a larger schmutzdecke without the expense of the weight and volume of extra sand. The cross sectional area of the sand is actually the same as the CAWST v10 but the schmutzdecke is twice the area.

This has some interesting knock-on benefits:

- The fill volume has been increased without increasing head
- By “folding” the length that the water travels through the sand the filter can be shorter
- The shorter design saves cement (see comparison in section 5)

A starting point (from which further optimisations can be done if desired) is sketched below.

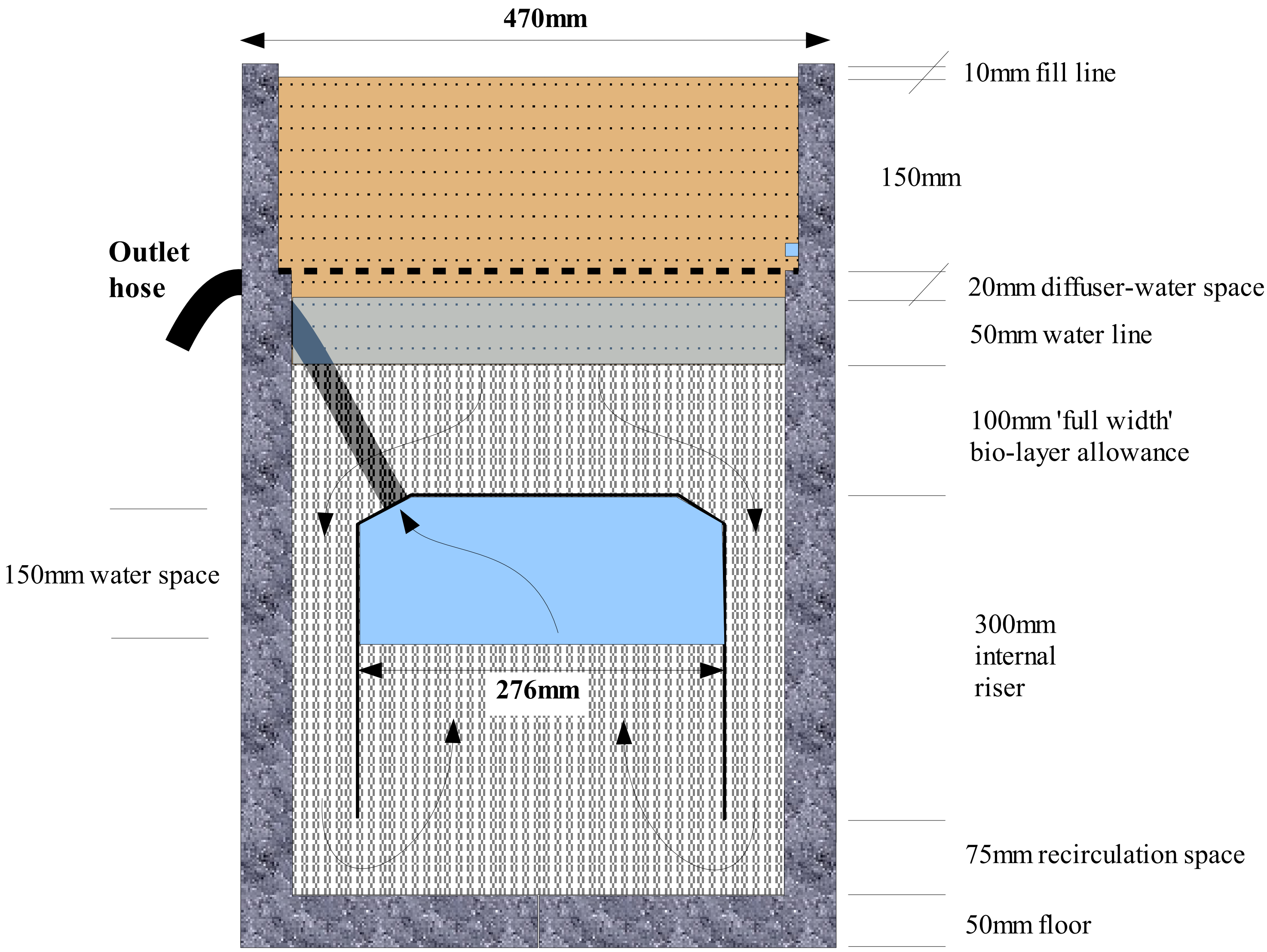

Illustration 1: DRC Reversed Flow biosand filter MK1

5 Comparison with the CAWST version 10

Parameter	CAWST MK10	DRC MK1	Notes
Volume of cement required	71.6 litres	44.8 litres	Uses 63 % of the cement and so is significantly lighter and cheaper
Surface area of schmutzdecke	571 sq cm	1176 sq cm	The filtering area is 106 % larger so the filtering rate can be expected to be much faster
Height of filter	96 cm	75 cm	The filter has the same 55cm sand path and yet because the path doubles back it is 78 % of the height
Outer circumference of filter	144 cm	146 cm	Although the diameter is larger than the width of the MK10, the filter circumference is only 2 % larger. The area gains come from effeciencies of being round as well as some savings on wall width
Head of raw water above the fill line	17 cm	17 cm	Although the head height is the same the fill volume is 67 % larger and for simplicity has been designed to take exactly one full 20L jerrican.
Fill water volume as a percentage of what can be held internally in the void space	100 %	81 %	This means that the most dangerous water (the 19 % nearest the surface of the sand) is retained for 2 rest periods for extra safety.

Table 1: Comparison of this innovation with the CAWST v10

6 Further optimisations possible:

6.1 Optimising Flow with Head

If the objective is to increase the volume of water that the filter filters in one use then the filter can be made taller while still keeping the weight of cement used below the CAWST v10.. The extra height should then split between.
a) greater raw water head height
b) greater internal storage
This extra head, if unchecked, will naturally lead to an increased flow which will be detrimental to filter performance. The extra head can be lost again by somehow restricting the flow of water through another part of the filter. This can be done best by moving the internal riser downwards to create a 'bottle-neck' at the point in the sand where the flow passes between the floor and the riser. If balanced to reduce all of the extra head the operating conditions will be returned to those which existed previously (i.e. exactly the same net head and no extra flow).

It should be noted that the flowrate of this filter may naturally be less than 0.4 m3.m2/hour (with the attendant improvement in water quality) because of the reduced ratio of sand cross sectional area to that of the schmutzdecke develops a higher headloss. If the headloss developed by the sand is considered too great (or the flow is too slow) then the head can be restored back to the normal level as described above by increasing head without checking it by a bottle-neck.

6.2 Optimising Filtrate quality by increasing Residence Time

If water quality (not quantity) is the key optimisation objective then there are a few options that are still available while still keeping the weight of cement used below the CAWST v10. The first is to increase the residence time further. This can either be done to the detriment of the size of the filter (make the sand section taller), or to the detriment of fill volume (move the schmutzdecke further up the design).

6.3 Optimising Filtrate quality by reducing flow.

An alternative strategy for increasing filtrate quality would be to simply restrict the flow using the strategy outlined in 6.1 above. Since the recommendation for best quality is to let it sit for between 6-12 hours then it matters little if a small percentage of this time (e.g. up to 30% ?) is used in running the water through the filter. Operating under this ideal regime the user will not get any extra water whether it runs through in 20 minutes or 2 hours.

6.4 Optimising Riser shape.

Strictly speaking the riser shape above the water line can be conical with the point as the place where the water exits into the outlet tube and the conjunction of the clear water and the surface of the sand being its base. This would further optimise the space of sand immediately below the schmutzdecke where the water is flowing slowest. To start to taper the profile before the water line restricts the final surface area of sand. If this is being done in conjunction with 6.1 or 6.3 above then they are mutually complementary optimisations.

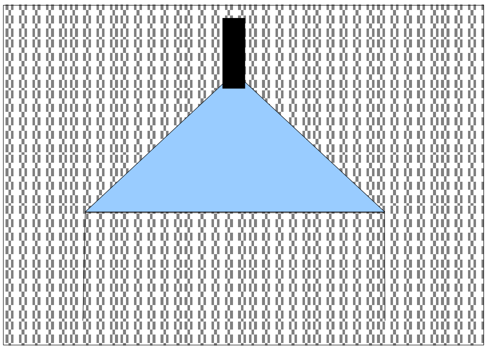

Illustration 2: Conical water space in Riser tube

7 Material

1. Cement is expensive (well it is in Ethiopia anyway. A curious combination of government policy, a booming building economy, high import taxes, immature manufacturing base, high fuel costs, and an enormous country with a sparse road network have made it so. It may be a feature of Ethiopia only but a recent development here has been the Oxfam funded manufacture of HDPE Sanplat slabs for use on top of latrines. These are currently being manufactured outside Addis Ababa by Roto PLC. It's clear that HDPE is being considered a serious alternative to Cement <u>even when they are required in volume for volume quantities</u>!)
2. Cement is heavy. As a technology that is largely targeted at the rural poor with little access to mechanised transport it delivers a solution that (certainly in Ethiopia) requires 4 strong men to carry one BSF (up some of the steepest most beautiful countryside in Africa). It's heavier than wood, plastic. For the required wall thickness it's also heavier than metals (aluminium, anodised steel, mild steel).
3. Cement is not too kind on the environment either. 0.22kg of carbon is released into the atmosphere per kg of cement[2]. This compares with 0.05kg for High Density Polyethylene (HDPE)[3] and 1.4kg for steel[4]. Wood would be actually reduce CO2 in the short term and be carbon neutral in the long term (as the wood ultimately decays).
4. Conventional cement is primarily good in compression (hence buildings) which is not really what the BSF calls for. All other things being equal what the problem really calls for is something that scores highly on tensile strength and low on weight.

Neither of these reasons are enough by themselves to even consider an alternative material but they add up. All we can say is that any innovations that make the cement lighter while keeping or enhancing its tensile strength would be welcome.

Some of the techniques listed below are worth considering but require more dedicated research to make sure they are tough enough, simple enough to make, economically viable etc.

1) Fibre reinforced cement:
The author has tried this with some success on the first attempt. Second hand jute sacking was soaked in cement and wrapped it round a former. The result is a tough structure that resembles the structure of Plaster of Paris typically applied to broken legs. It is rigid and has good tensile strength because of the fibres. It's lighter than cement because the fibres account for a good proportion of the volume. Concerns are whether it's too flexible and will over time crack the cement. If made reasonably thick then it doesn't flex enough to crack the cement.

2) Wooden Barrels:
The Celts were making barrels 2000 years ago. If they could be made at that level of technology then it's likely to be possible to make them with modern machinery (circular saw and a plane) if the design is kept simple (having straight sides).

3) Blow Moulded Plastic:
Under certain project conditions this might deliver the cheapest solution to the customer. For example if an NGO were willing to pay the moulding costs (in the order of $10,000) then it would obviate the manufacturer having to get this back from the customer. With some kind of contract to protect customers from unfair profits (in lieu of the paid for mould) this could be a winner on a per country basis.

4) Rotation moulded plastic:
Rotation moulded designs tend to be cheaper to set up (the moulds are cheaper to create) but the plastic is much more expensive than blow moulded designs. Roto PLC in Ethiopia are the forefront company in this respect and their products are widely known and distributed in Ethiopia. This might be an excellent route for prototyping a blow-moulded design and once the design had been proved and used in some trials with good results the project could revert to (3) above.

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2 Annual Review of Energy and the Environment Vol. 26: 303-329 (Volume publication date November 2001) Abstract: http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.26.1.303?journalCode=energy.2

3 http://www.cpm.chalmers.se/CPMDatabase/Scripts/sheet.asp?ActId=CPMXFRTOOL1998-06-11861

4 http://www.environmentalleader.com/2009/01/21/co2-cuts-in-us-steel-industry-surpass-kyoto-protocol/

5) Tin barrel reinforced with a steel strip along all joints for good sealing and strength. The construction would be very weak when empty but the sand and the tin would work together to make a very strong structure when full; the tin would be under tension from the internal pressure of the sand.

6) A design that can be simply constructed using simple combination of plastic barrels currently available in Ethiopia:
Depending on what was available this may or may not be appropriate. Needs more work in a later version of this note.

8 References

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