Optimization of Design to Enhance Flux and Performance of Gravity Driven Membrane Filters for Household Water Treatment: A field Study in Kenya

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Introduction

Gravity driven membrane filtration
Gravity driven membrane (GDM) filtration is an effective, low cost means of treating raw water to remove pathogens. The necessary pressure for filtration is generated by the head difference between the feed water reservoir and permeate outlet. In this low-pressure system, flux through the ultrafiltration membrane stabilizes after 6 to 15 days and remains relatively constant without the need for backflushing, cross-flow or chemical cleaning, which are usually required for conventional membrane systems. Since the system is low maintenance and requires no energy, it is ideal for use in developing countries.

Figure: Prototype I of household gravity driven membrane filter.

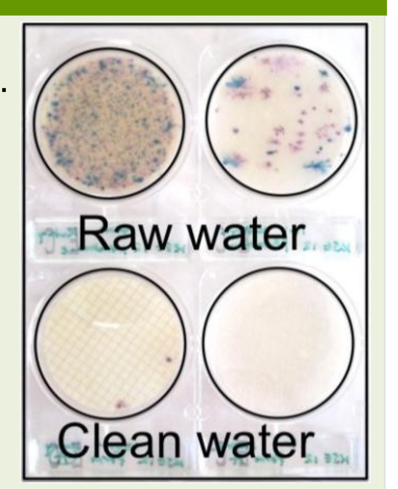
Field trials in Kenya
A first generation of household GDM filters has been under field trial in Kenya since May 2011.

Filter optimization
After one year of testing in the field and continuous tests in the laboratory, it is clear that the current filter prototype is functional; however, the design is not optimized to maximize technical performance (i.e. high flux), health security, and social acceptance.

Health Security: Microbial Water Quality

In the field and in the lab, 100 ml water samples were collected and analyzed using Nissui Compact Dry EC Plates to determine concentrations of *E.coli* and total coliforms.

When ultrafiltration (UF) membranes are operated properly, they act as an impermeable barrier for bacteria and larger organisms. In the field, raw water sources showed significant faecal contamination and GDM filters were successful at removing at least 97.5-100% of *E.coli*. Of the permeate samples, 33 contained no detectable *E. coli* and only 3 samples contained more than one colony forming unit (CFU). However, factors like household hygiene, filter misuse, and high presence of nutrients in the filtered water lead to post-filtration contamination and growth in the clean tank, tap, tubing, or even inside of the membrane.



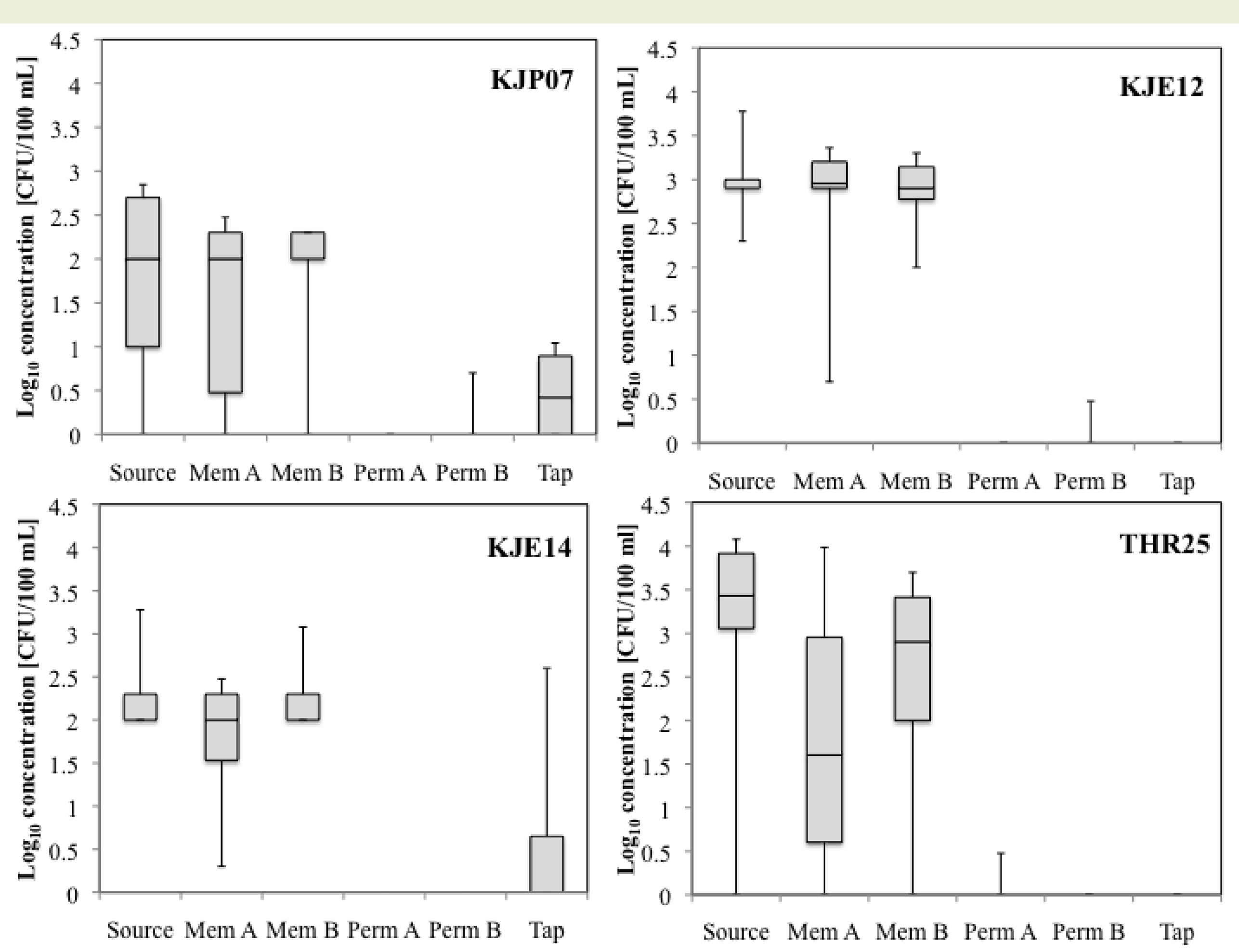


Figure (above): Examples of EC compact dry plates from membrane tank (raw water) and permeate (clean water) samples. Blue colonies are the number of *E.coli* and the sum of the blue and red colonies is the total coliform count.

Figure (left): *E.coli* levels at different points in the filter. Results are from experiments run with two different membrane module configurations run in parallel. System A used the current membrane module schematic and System B was a submerged membrane configuration. Mem A and Perm A refer to the membrane tank and permeate. KJP07, KJE12, KJE14 and THR25 are names of four different filters.

Technical Performance

Flux is dependent on…

Air
In the current prototype, trapped air in the membrane module, and exposure of the fouling layer to air reduce flux. In order to address these problems, a submerged membrane system was evaluated. In this design, the membrane would remain submerged in the standing water of the system and the permeate outlet would be located above the membrane module to eliminate the likelihood of trapped air.

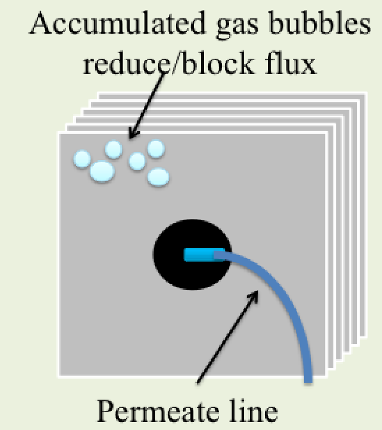


Figure: Schematic of trapped air in membrane modules.

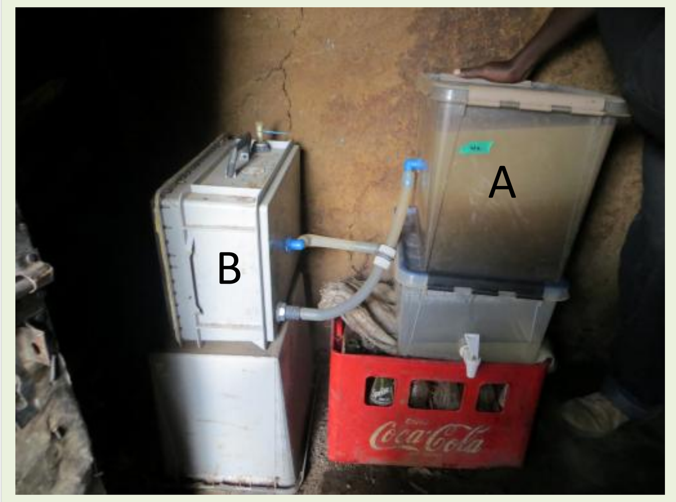


Figure: Assembled experimentation filter. Part A is the current prototype where the membrane is regularly exposed to air. Part B is a air and water tight tank where the membrane is continuously submerged in water. Both membrane tanks share the same raw water and clean water tanks.

Low membrane area loss
In the current prototype, when the water level in the membrane tank drops below the level of the top of the membrane, then parts of the membrane are no longer in use for filtration. This is not an optimal or cost-effective use of the membranes since they are the core and most expensive parts of the system. A submerged system could eliminate this problem and is likely to allow for higher hydrostatic heads, which should also increase the flux of the system.

Source water
Raw water source strongly effects the ultimate flux values. Surface water, such as pond and river water, contain high amounts of organic and inorganic matter and yield lower fluxes than rain or tap water.

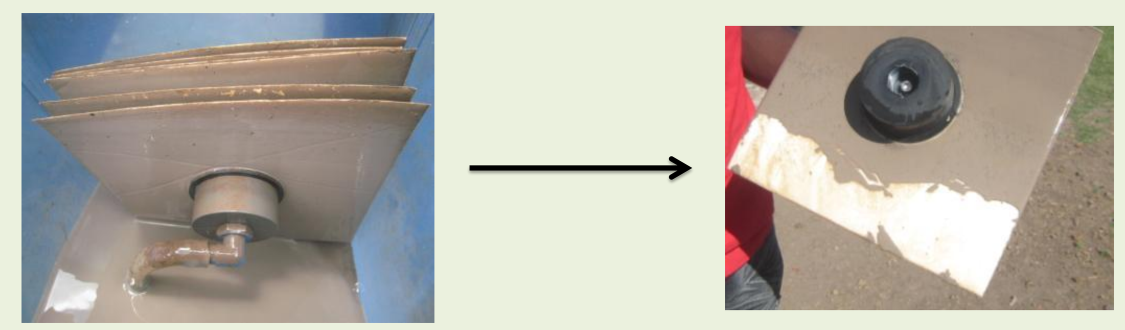
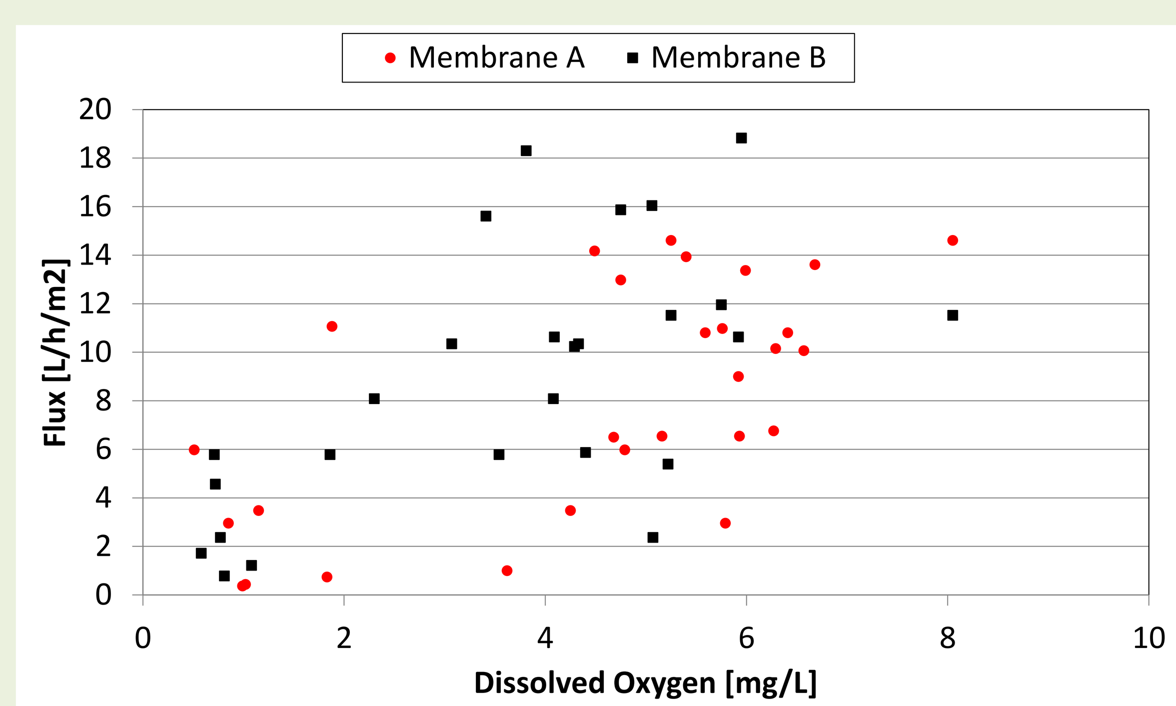


Figure: Sloughing (detachment) of biofilm from membrane.

Sloughing of the biofilm
Intermittent filter operation leads to an increase in stable flux due to sloughing, or detachment, of the biofilm layer, especially during standstill periods. In certain source waters like pond water, sloughing of the biofilm occurs more readily in the half of the membrane continuously submerged in water. Thus a membrane always submerged in water should have more sloughing events with more increases in flux.

Dissolved oxygen
Dissolved oxygen (DO) limiting conditions (<2 mg/L) decrease flux. DO concentrations depend strongly on source water composition. For example, when pond water is filtered, there is a higher chance of DO limiting conditions than in river water, rainwater or tap water sources.



The DO in Membrane Tank A was higher 88% of the time than in B. The difference was on average 1.18 mg/L, but was greater than 2 mg/L in 31% of samples. However, when raw water sources with a high risk of low DO conditions were used, the concentration difference between membrane tanks was smaller and both tanks were at risk of becoming anaerobic.

Figure: Correlation between dissolved oxygen and flux in the two different membrane module configurations. Membrane A is the current system and Membrane B is a submerged membrane system.

Social Acceptance: Taste & Odor

For a drinking water treatment filter, taste of the clean water is an important factor. If the amount of dissolved oxygen (DO) in the membrane tank steadily decreases, the system runs the risk of becoming anoxic or anaerobic and can produce reduced compounds with negative effects on the taste and smell of the permeate. A submerged membrane configuration has a higher risk of low DO conditions.

Sulfides
Hydrogen sulfide, which can cause distinct taste and odor problems in water, was measured as an indicator for anaerobic conditions in water.

Overall, there were no or very low levels of sulfides found in both permeates and the tap of all household filters tested - even in households were DO levels were as low as 0.5 mg/L. The highest concentration was found in one of the tap samples at 22 µg/L, which is still below the human detection limit stated by WHO (50 µg/L for hydrogen sulfide and 200 µg/L for sulfides).

The only case where there were higher values of sulfides present in the permeate was when anaerobic wastewater was used in the lab filter. In this scenario, there were already sulfides and odor problems present in the raw water, so even though the raw water was filtered and clean, the permeates still contained high sulfide concentrations (101 and 114 µg/L in Permeate A and B, respectively). Therefore, if source water is anaerobic and already contains sulfides, the filter does not improve the taste or odor.

Table: Sulfide values found in tap and permeate samples.

Sulfide concentration	Permeate A	Permeate B	Tap
Min [µg/L]	0	0	0
Mean [µg/L]	5.75	5.88	4.05
Max [µg/L]	16	19	22
Samples below detection limit [%]	43.75	56.25	60

Taste test
The filter is unlikely to be able to remove certain chemical compounds that are already present in source waters, however, the filter should not make taste and odor of filtered water less desirable than before, otherwise, consumers could revert to using unsafe sources.

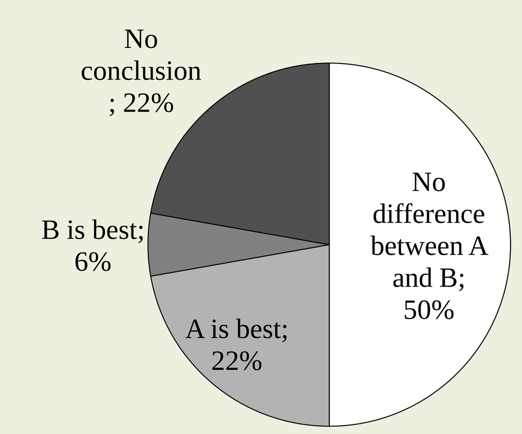


Figure: Comparison of Permeate A and B in taste tests.

A series of taste tests showed that households were not able to detect any negative changes in taste of water filtered through a submerged membrane configuration compared to the current membrane configuration even when anoxic conditions were found in the membrane tanks.

Conclusions and Outlook

Field studies show that a submerged membrane configuration will not cause taste and odor problems in the permeate even when poor quality surface water is used. In order to determine whether such a configuration has an overall performance advantage, more systematic lab testing needs to be performed.

At Eawag, the GDM team is continually researching biological and physical parameters that effect gravity driven membrane filtration. The GDM team is working on developing a 2nd generation GDM filter prototype focusing on filter design and performance, health security, user acceptance and economic strategies.

Acknowledgements

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