LOW-COST INLET FILTERS FOR RAINWATER TANKS

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ABSTRACT

Inlet filters are a common method for enhancing water quality in rainwater harvesting systems. They range from cheap cloth or gravel filters to complex and expensive multi-stage systems. Field experience has shown, however that filters often suffer from a lack of maintenance so self-cleaning is an advantage. Filters can clean themselves by dividing the water stream into two components; the first and largest is the clean water passed to the tank, the second much smaller component can be used to carry away suspended particulates.

This paper reports the results of a series of laboratory tests on the abilities of very simple filters to remove particulates from roof run-off water. The low-cost (<$5) filters tested were of stretched cloth: two cloth types were used. Self-cleaning and plain (debris-retaining) filter designs were compared. Each filter was tested with a standard (published) contaminant load based on sand and Polyethylene sheet "leaves" under a variety of representative flowrates.

Filter performance indicators are

1. hydraulic efficiency – the fraction of water transmitted
2. cleaning effectiveness – the fraction of particulates removed from the flow.

The initial tests showed that self-cleaning by using a sloping surface works satisfactorily and that simple cloth filters have a comparable performance to sophisticated filters found in German rainwater harvesting systems. However the German test configuration used was found to poorly represent roof run-off water in tropical countries and will be changed for continuing tests to be performed on refinements to the crude filters reported here.

INTRODUCTION

Inlet filters are a common method for enhancing water quality in rainwater harvesting systems. They range from simple cloth or gravel filters to complex multi-stage systems. Low-cost RWH systems require low-cost filters – a cost ceiling of $5 per filter may be required. Field experience has shown that filters often suffer from a lack of maintenance, so self-cleaning is an advantage. Filters clean themselves by dividing the outgoing stream into two components; the first and largest is the clean water passed to the tank, the second much smaller component is used to flush away the majority of suspended solids.

CHARACTERISING INLET WATER FILTERS

The primary measures of any inlet filter are its *hydraulic efficiency* which is a measure of the fraction of the incoming stream that penetrates the filter (and how much is spilled) and its *effectiveness* which is a measure of the fraction of the incoming particulates that are removed by the filter.

Hydraulic efficiency

All water filters will spill (waste) some water. The amount spilled depends on several factors

- The fineness of the filter material which directly affects its permeability (the ease with which water passes through the material) – the finer the material, the less easily water will pass through it
- The slope of the filter – the greater the slope, the faster water will be shed
- The area of the filter – the greater the area, the more opportunity for the inlet water to pass through it
- The rainfall intensity – the heavier the rainfall and hence the greater the flow from the roof, the greater the fraction of water that will be spilled
- The existing dirt load on the filter – filters that are clogged pass water less efficiently than clean filters

Water spilling from a filter becomes unacceptable if it is allowed to become too large a fraction of the incoming stream, however a small amount of spillage can be tolerated provided it is used to keep the filter clean.

Filter effectiveness

The effectiveness of the filter is its ability to remove particulates from the incoming stream. Most filters will remove larger particles such as sticks and leaves; it is the sediment load that poses the challenge to filter designers. The effectiveness can simply be expressed as the fraction of *total* particulates removed by the filter (e.g. net reduction in turbidity) or more usefully as the fraction of *smaller* particles, defined using an exceedance curve, that are removed.

Trade offs

Generally a high hydraulic efficiency and a high effectiveness are the mark of a good filter. These two criteria are, however, often in competition and limited by practicalities.

- A fine filter material will have a good effectiveness, removing large fractions of fine particulates but it will have a poor hydraulic efficiency
- Increasing surface areas can reduce this conflict this to a certain extent, but will ultimately lead to filters becoming unwieldy and requiring large openings in the tank. Large openings can let in excessive light and raise the risk of water contamination by vectors such as rats or lizards.

Design flowrates

A useful limit on design flowrate can be gained by looking at the fraction of rain that falls at high rainfall intensities. Rainfall intensity analysis in the humid tropics, undertaken by experimenters with microwave transmissions (Adimula et al., 1998), have found that a negligible fraction of annual rainfall occurs at intensities exceeding 3mm/min and rainfall intensities of more than 2mm/min account for only 3%-7% of the total rainfall. At these high intensities other parts of a RWH system (such as gutters) should also be at their limit so there is little point in pushing filters to perform beyond 2mm/min, which translates to a flow of 1.7 l/s on a typical 50m^2 roof.

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THE EXPERIMENTS

Past work

Rott and Mayer (2001) developed a system for testing filters as a part of the work surrounding the development of the German rainwater harvesting standard (DIN 1998). In order to make comparison between high-cost and low-cost filter designs, R&M's test procedure was employed in this programme. The equipment they devised consisted of a tank of water to which a known contaminant load could be added. The particulate test load is listed in Table 1

Table 1: Contaminant load used by Rott and Mayer

Contaminant	Concentration (per m^3 of water)
LDPE sheet 15µm 50mm x 50mm	10
Polypropylene balls D = 3.5 mm	100 g
Quartz sand with size range between 0.25-0.5mm	100 g
Quartz sand with size range between 0.71-1.25mm	100 g

The water containing the particulate load was diverted through a series of valves and water calming structures and over the filter. The water penetrating the filter flowed into a holding tank and water not able to flow through the filter was discarded. The filtered water was then measured to obtain a hydraulic efficiency and allowed to pass through standard (ISO 3310/1) sieves to obtain each filter's effectiveness.

Apparatus and method

The experiments reported in this paper used similar equipment but with a few changes:

- Rott and Mayer included techniques to calm the flow before the filter. These were discarded as not representative of typical RWH systems in low-income countries. This change should result in slightly lower measured hydraulic efficiencies due to splashing, but have little effect on filter effectiveness.
- The polypropylene balls were omitted as they cause neither fouling nor are likely to penetrate any of the filters under test. Results should be unaffected.
- Rott and Mayer discarded spilled water to a drain. Operational constraints have not allowed this so spill water has been retained – this allows a check on Hydraulic efficiency.

The filters tested were designed to fit over the access hole in a typical domestic RWH tank and have a round profile with a 500mm diameter. Two designs were tested.

- A simple ring with fabric stretched over it
- A ring with a conical shaped frame using 6 spokes with the central point 150mm above the ring. This design was intended to shed some water and use this to self-clean

The designs are shown below in figure 1.

Figure 1: Filter designs tested

Each design was tested with two fabric types.

- Silk with a weave of 0.25 mm
- Muslin with a weave of 1.0 mm

After the apparatus was set–up and calibrated, each filter was tested using the following procedure

1. The filter was wetted and placed under the feed-tank outlet
2. The flow was set using a gate valve
3. The ball valve to the feed tank was opened

The flow rate from the equipment reduced by 25% to 40% over the course of each test due to falling water levels in the feed tank, the exact amount depending on the flow rate set by the gate valve. So each test was adjusted to obtain the desired average flow rate. After each test the amount of water in both the filtered tank and the spill tank were measured and the filter's hydraulic efficiency thus calculated.

For tests of filter effectiveness, the water in the filtered water tank was drained and the tank rinsed through a set ISO 3310/1 sieves to measure the particulate load the filter had let pass. This was than compared to the particulate load of the feed water to obtain the filter effectiveness. Only one effectiveness test was done on each filter in this first set of experiments.

Figure 2: Filters under test

Results

Initial runs confirmed the expectation that an angled (conical) filter would self-clean, as can be seen in figure 3. Figure 3a shows a flat filter with an accumulation of sediment after a test. Figure 3b shows a conical filter of the same material after an identical test with only a little sediment in the bottom.

Figure 3: Sediment loads on conical and flat filters after testing

a. Flat filter

b. Sloped filter

Results for material removal are shown below in table 2. The results are encouraging with both fabrics showing material removals toward the top end of the ten German filters tested by Rott and Mayer (R&M).

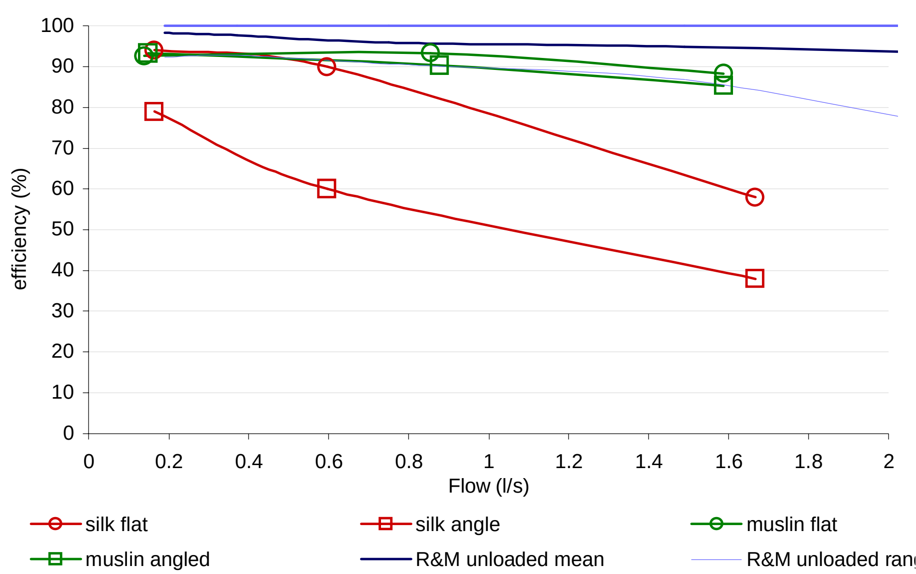
Table 2: Filter effectiveness results

	Reduction (%)					
	R&M Min of 10 filters*	R&M Mean of 10*	R&M Max of 10*	Silk flat filter+	Silk conical filter+	Muslin conical filter+
LDPE flakes	100	100	100	100	100	100
0.25-0.5mm sand	0	54	100	95	100	90
0.71-1.25mm sand	56	91	100	100	100	98

* as reported Rott and Mayer (2001)   + as performed at Warwick University 2005

The results of the hydraulic efficiency tests for two fabrics are shown below in figure 4. They show that while a fine silk filter shows very poor results for hydraulic efficiency, particularly in the conical configuration, the muslin cloth shows more promise with efficiencies for both conical and flat configurations in the same band as the German filters tested by Rott and Mayer.

Figure 4: Hydraulic efficiency of filters



Over the course of the tests several qualitative affects relevant to detailed design were noted.

- Shedding of debris is improved by better material stretching, since the fabric sagged when wet, re-stretching when dry. This is likely due to the material expansion due to the addition of water into its fibres - indicating that such filters should be stretched over the frame when wet.
- Both filters, but particularly conical self-cleaning designs, benefit from improved support as otherwise particulates collect in sagged sections
- Water also runs down the inside of conical filters so there should be detailing around their inside bottom edge to ensure this water falls inside the receiving tank.

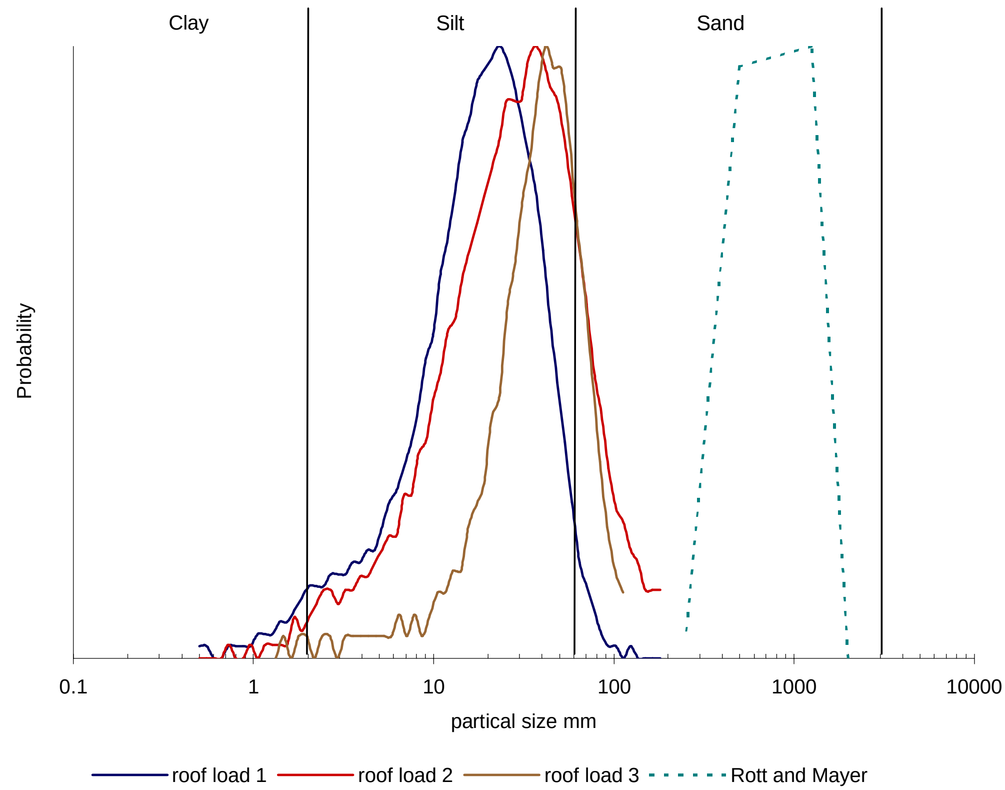
LIMITATIONS OF EXISTING METHODS AND NEXT STEPS

The methods used by Rott and Mayer, and the associated simulated sediment load, work well as a simple and repeatable test to characterise filters used in Europe for secondary water (i.e. water used for toilet flushing and clothes washing), providing a unified standard. Their standard load does not however realistically represent actual sediment loads in roof run-off water in low-income countries. Figure 4 compares the particle size distributions for sediment collected from three rooftops in Uganda, Ethiopia and Sri Lanka with those used by Rott and Mayer. As can be seen, the particles used in their tests are about two orders of magnitude larger than particles typically found on tropical roofs.

If filters for drinking water are to be tested, the indicator should be more realistic (and the test more gruelling). The majority of roof borne sediment is in the silt range and will take time to settle – so ability to remove these very small particles is desirable. The use of silt however requires different experimental techniques to characterise the contaminant load before and after filtering. Simple turbidity provides a quick indication of gross load but more sophisticated laboratory techniques such as laser diffraction are needed to account for particle-size distribution.

The overall level of contaminant load used in the reported tests is also much lower than that typically found in rural roof runoff. To be realistic it should be increased by a factor of 10 or more. With smaller suspended solids, turbidity can be used as the calibrating factor; increasing the sediment load until, say, 50 NTU is reached.

Figure 4: Examples of particle size distributions of roof contaminants



CONCLUSIONS AND NEXT STEPS

From these initial tests it is clear than simple cloth filters can be made with high effectiveness and hydraulic efficiency characteristics. Self cleaning by introducing a sloped side appears to work. These encouraging results coupled with cloth's availability, low-cost and ease of cleaning make cloth filters very attractive for use in low-cost roofwater harvesting systems.

Further work does need to be done to test more fabric types and to establish the different cloth and configuration's performance after a period of continuous loading. All subsequent tests will also be carried out with more realistic (i.e. finer and heavier) sediment loads.

REFERENCES

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