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THE PERFORMANCE OF NATURAL FABRIC PROTECTED HOUSEHOLD SLOW SAND FILTERS (HSSF)

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ABSTRACT

Non-Woven synthetic Fabrics (NWF) are put on the top surface of Slow Sand Filtration (SSF) units with the primary aim of increasing the filter run times and concentration of most of the treatment process in the fabrics layer(s) and hence reducing the frequency of filter cleaning and re-sanding. The aim of this research was to investigate the performance of natural fabrics for protection of a SSF unit, especially the Household Slow Sand Filter (HSSF) which is under development at the University of Dar es Salaam, Tanzania. The natural fabric used was *Luffa cylindrica* commonly known as vegetable or plant sponge. Field tests were conducted at a filtration rate of 0.1 m/h and a number of water quality tests were conducted on the inlet water and the filtrate from the HSSF units.

In the study, it was established that it is possible to use *Luffa cylindrica* to protect the HSSF. It was also found that very low rates of head loss development could be achieved by sewing up and progressive optimization of the thickness of compressed *Luffa cylindrica* fabrics. As a result of this, filter run time extension of up to 1.6 times was attained. It was also established that it is possible to concentrate the majority of the impurities in the *Luffa cylindrica* multi-layers such that routine maintenance involves cleaning of the fabrics only at the end of the filter run. The limitation of fabric fibre strength with time was observed after a few (two or three) filter runs. Therefore, the authors recommend that research in preliminary treatment of the fibres with a suitable chemical should be done to establish the possibility of extending the useful lifetime of these fabrics. It is also recommended that the natural fabric protected HSSF should be operated at filtration rates lower and higher than 0.1 m/h for an extended duration in order to establish their optimal operational filtration rates. Furthermore,

parameters like taste and odour of the filtrate from HSSF units be monitored in future research so as to establish if water becomes tainted by the natural fabrics in the long run.

INTRODUCTION

Slow Sand Filtration (SSF) has been in continuous use in public waterworks since the beginning of the nineteenth century and has proved to be extremely effective under widely differing circumstances [1]. It is simple, inexpensive and reliable when properly applied. To date it is still the chosen method of final water filtration for some of the major cities of the world [2].

In the developing countries, the use of SSF is considered to be particularly suitable for rural water supply schemes in view of its simplicity of operation and maintenance. However, the major part of the direct operational costs for SSF are associated with filter re-sanding. Where very turbid water is directly fed to SSF, very short filter run times can be experienced. These result in a big demand in terms of labour and effort for filter cleaning even if the latter is mechanised [2]. Literature [3], has shown that SSF units can be by-passed by operators in order to avert the heavy cleaning workload.

In a number of developing countries, experiences with SSF constructed in some big integrated rural water supply projects using chemical pre-treatment have revealed the prevalence of the problem of short filter runs of SSF [3]. There are two possible explanations to this problem, one of which could be poor operation of the pre-treatment units (or the plant as a whole) thus leading to floc carryover or break-up. The second reason (which is valid for non-chemical based pre-treatment) may be due to feeding of inlet waters with high contents of impurities directly into the SSFs thus resulting in very rapid clogging of the filter beds.

Recent studies done in the UK with man-made synthetic fabrics have confirmed that if suitable types and thickness of the Non-Woven Synthetic Fabrics (NWF) are placed on the top surface of the sand bed, the operational costs of SSF can be drastically reduced due to the resulting increase in the filter run time and the concentration of the majority of impurities in the NWF layers. The net effect is reduction of the frequency of filter cleaning and routine re-sanding. Optimization of the NWF layers placed on top of SSF was attained by Mbwette, [2]. In the studies carried out in the UK, filter run time extension factors of between 4.9 and 8.4 were attained without allowing significant penetration of impurities onto the sand bed. As regards filtrate water quality, all studies done to date have shown that the use of the man-made fabrics does not bring about any enhanced filtration performance of the SSF [2], [4].

With respect to synthetic fabric biology, apart from the intensive study of the micro-organisms in SSF reported in literature [5], very little new information regarding synthetic fabric biology is known. Information on bio-degradability of NWF is still very scanty although it is known that any fabrics containing organic binders are likely to be very weak within a short period of usage. As regards synthetic fabric cleaning, as long as proper selection of the physical and mechanical properties of the NWF is ensured initially, for small scale SSF pressure hosing with water has been established to be sufficient [2], [6], [7]. This is likely to be a serious operational problem for huge slow sand filters of sizes similar to those used by Thames Water Authority in the UK or other European cities if this type of protection were to be adopted.

The research carried out in the UK has further revealed that the use of a selected mixture of a number of NWF as a surface protection layer on top of SSF bed receiving inlet waters with an excess of floc can drastically improve the operational performance of the filters [2]. The mattings used are made from synthetic fibres currently manufactured in very few developing countries including those of East Africa.
In line with the need to maintain the simplicity of SSF, it was therefore felt necessary to investigate the feasibility of using natural fabrics as an alternative SSF bed protection media in place of NWF especially for small scale HSSF. It was conceived that the high availability of the natural fabrics in most developing countries would improve access of the protected HSSF technology to the wider public. Moreover, available literature does not report much about scientific investigations which have been carried out in protection of SSF beds with natural fabrics apart from the preliminary studies done recently at Imperial College [8]. Documented research during the last decade has largely been in the protection of SSF with Non-Woven synthetic Fabrics.

OBJECTIVES OF THE STUDY

The general objectives of this study was mainly to attempt to off-set operational limitations of SSF handling turbid waters by replacing the proven NWF protection of the sand bed with a natural fabric which is not easily degradable when used as a bathing sponge. The specific objectives of this research were four-fold:

To look at one of the available types of natural fabrics and establish its physical, mechanical and filterability properties with respect to the possibility of utilization in protection of small scale SSF sand beds and in particular HSSFs.

To investigate the possibility of extending the filter run times of HSSF by progressive optimization of the thickness of the natural fabric(s) so that very low rates of head loss increase across the top fabric can be realised.

To concentrate the capture of impurities within the natural fabric layer so that maintenance of the HSSF involves fabric cleaning only at the end of the filter runs.

To compare the operational performance of a natural fabric with selected NWF with respect to sand bed protection in HSSF.

NATURAL FABRICS

Classification

Natural fabrics are those fabrics which consist of non-man made“”fibres.They can be sub-divided into two groups namely, animal fibre and plant fibre fabrics. The animal fibres include wool, hair, alpaca, cashmere. camel, etc. The plant fibres include among others, cotton, jute, coir, abaca, sisal, flax, ramie and *Luffa cylindrica* [9]. Silk fibre which is a solidified viscous fluid excreted from special glands by a number of insects and spiders is usually considered separately. In literature, plant fibres can be conveniently classified according to the plant from which they are extracted as follows [9]:

Leaf (hard) fibres
Bast (soft) fibres

Seed-hair fibres
Miscellaneous fibres

For this research, special consideration of one of the plant fibre fabrics known for its abundance and resistance in water when, used as a body-washing sponge was made in the absence of NWF in Tanzania.
The plant fibre selected for this study i.e. *Luffa cylindrica* (in *Swahili called Dodoki*) falls in the "seed-hair fibres" group.

Properties of Fibres

Chemical composition

Literature [9] has shown that chemical analysis of *Luffa cylindrica* reveales that its main contents are cellulose, moisture, ash, lignin and pectins, and other extractives. In *Luffa cylindrica,* cellulose constitutes over 60% of the fibre material followed by lignin and pectins which together constitute 6-24% of the fibre materials. Moisture constitutes 4-11% and ash constitutes 0.6-1.7% of the fibre. Although typical cellulose contents of natural fibres range from 60-92% of total fibre material, the presence of lignin considerably increases the degradation resistance of natural fibres [8,9].

Fibre dimensions

A plant fibre is composed of several micro-fibres formed by cells of various forms (single or multi-cellular). Within the seed hair fibres group, literature [9] gives the range of cell length to be between 10 and 50 mm with an average length of between 19 and 25 mm. The corresponding single fibre length is known to range from a minimum of 15-56 mm to a maximum of 180-340 mm with several cells forming micro-fibres. Of special importance to filtration is the cell diameter which is known to range from a minimum of 0.003-0.02 mm to a maximum of 0.013-1.070 mm.

Physical properties

The plant fibres have a high breaking strength and elasticity modulus with a low extensibility and work modulus [9]. They approach glass in stiffness and are considerably stiffer than man-made fibres but have low toughness (fatigue strength). Plant fibres have spiral molecules that are highly parallel to one another.

Biology of *Luffa cylindrica*

Using the modern system of plant classification after Cronguist cited in literature [10], Luffa Cylindrica can be more specifically classified as follows:

Kingdom	-Plantae (Kingdom of Plants)
Division	- Spermatophyta (seed bearing plants)
Class	- Magnoliopsida
Order	- Violates, (Note that some authors place it in the uni-familial cucurbita ceae order)
Family	- Cucurbitaceae
Genus	- Luffa
Species	- Cylindrica

Hence the proper botanical name is *Luffa cylindrica.*

Properties of the plant

According to literature [11], *Luffa cylindrica* is a herbaceous climber or trailer up to 15 m. Its stems are finely hairy and the leaves are 60-180 mm long, 60-210 mm broad, dark green and the flowers deep yellow. Other related details can be found in literature [11].

Optimum growing conditions

Luffa cylindrica is widely distributed in the tropics and sub-tropics as an escape from cultivation. Luffa cylindrica persists in old plantations or farms and near habitations frequently becoming naturalized in forest, woodlands, bushlands, thicket, and grassland [11]. In Tanzania, *Luffa cylindrica* grows in areas having alluvial and quartenary type of soils and where the mean annual rainfall is between 600 and 1400 mm [11].

Literature [1,2,6, 7, 12] has reported the previous use of natural fibres like tow, hemp hair or cotton in the water industry. However, the use of most of these natural fibres was discontinued due to their tendency to taint water in the long-run.

DESCRIPTION OF THE PILOT PLANT

Pilot plant layout

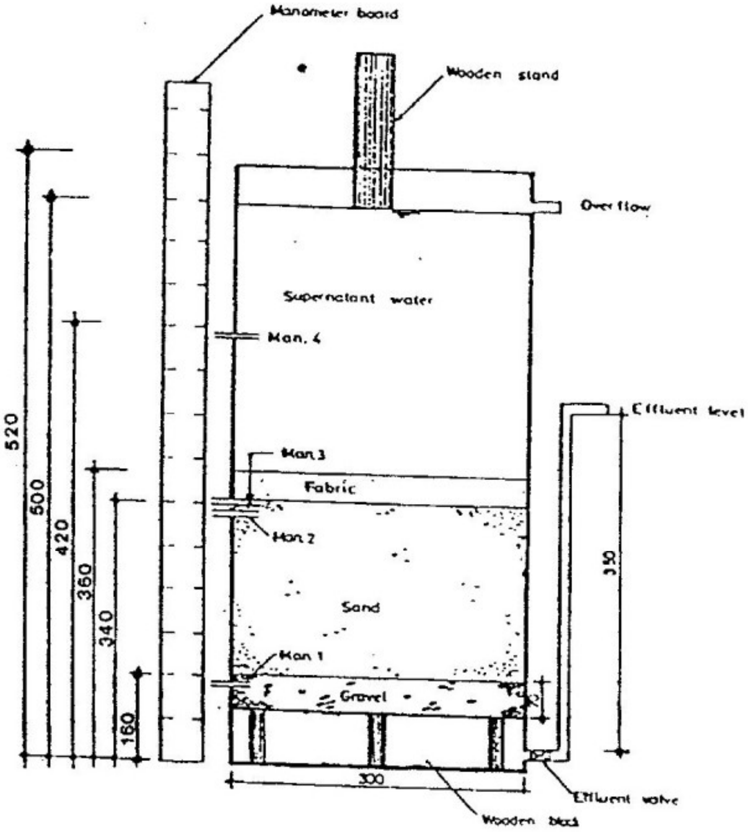
The natural fabric protected HSSF units operational and treatment performance was evaluated at a constant filtration rate of 0.10 m/h. The water was extracted from an impoundment located at the Faculty of Engineering premises at the University of Dar es Salaam. It was fairly algae laden water with a lot of weeds growing in the impoundment. The source of this water was established to have been leaking drinking water and some polluted shallow groundwater from areas upstream of the Faculty of Engineering block "A" buildings. During the rains, surface water runoff contributed a very big amount of water to the impoundment.

Three similar HSSF units (denoted by HSSF1, HSSF2, and HSSF3) were installed in parallel. 25.4 mm diameter hose pipes of 10.0 m length each, were used to abstract the inlet water from the impoundment and feed each of the three HSSF Units. The impoundment was on a slightly higher elevation than the filters so that the inlet water flowed to the HSSF units by gravity.

The HSSF units

The HSSFs were circular units manufactured at the Faculty from Ferrocement concrete with 15 mm wall thickness, a top inner diameter of 300 mm and an overall height of 520 mm each. The underdrainage system consisted of three 90 mm hardwood blocks on top of which a perforated aluminium sheet was placed. A thickness of about 70 mm of graded gravel was then put on top of the perforated aluminium sheet. On top of the gravel, an initial depth of 200 mm of sand was placed. The filtration rate control was a manually operated valve. The outlet pipe was raised up to 30 mm above the highest level of sand to ensure no accidental drainage of the sand bed. The initial depth of the supernatant water was 140 mm with a 20 mm overall freeboard allowance.

Four, 8 mm diameter holes were drilled in each of the HSSF units at heights of 160 mm (**man.1**), 320 mm (**man.2**), 360 mm (**man.3**) and 420 mm (**man.4**) from the bottom of the unit. 5 mm diameter Copper tubings fitted with stainless steel wire mesh were fixed onto the drilled holes with rapid hardening araldite and after 24 hours, plastic tubes were connected and then fixed onto a separate manometer board for each unit. Note that while **man.1** was placed in the bottom gravel layer, **man.2** placed within the top 20 mm of sand and **man.3** was placed at the bottom of the fabric layer(s). A graduated board was used to read off variations of the manometer levels. These manometers were used for filter bed head loss measurement. When not being read, the manometers were covered with coloured plastic bags to avoid algae growth in the tubes. The outlet pipes were used as sampling points and also for backfilling of the units with clean water before they were brought back into operation upon commissioning and after cleaning. Fig. 1 shows a typical cross section through such a HSSF unit.



Filter media characteristics

Two types of filter media were used in the HSSF units, the bottom layer comprised of sand while the top layer consisted of either *Luffa cylindrica* fabrics or NWF (Lab. No. 28, [2]). The *Luffa cylindrica* fabrics were originally in their dry form and separate pods. They were then pressed manually with the help of a vice. With the exception of the unit provided with un-sewn fabrics, the rest of the pressed *Luffa cylindrica* fabrics were sewn-up into individual monolithic layers. Then a circular sewn-up fabric was cut such that there was an overlap on the edges compared to the inner diameter of the HSSF units. This was done to avoid short circuiting along the edge of walls of the filter. In earlier research work conducted in UK

[2,13], it was established through experimental and numerical optimization that Non-Woven Synthetic Fabrics (NWF) with fabric porosity of approximately 90% and a specific surface area of betwween 12,000-14,000 m^2/m^2 fabric volume were ideal for protection of SSF. Hence the fabric Lab. No. 28 which was specially manufactured in UK according to the ideal NWF specification was also included in these experiments in order to enhance comparative performance analysis. For the sake of completeness, the basic properties of NWF Lab. No. 27 and No. 28 are given in Table 1. Both fabrics were made from polypropylene fibres. The NWF Lab. No. 28 was also cut in a similar manner. The different fabric layers were then placed on top of the sand in the order described in Table. 2. In the case of the unsewn-up fabrics, they were carefully laid in a manner similar to the sewn-up fabrics. To prevent floatation of the sewn-up fabrics or the NWF, a heavy circular metalic ring with a diameter slightly less than that of the inner diameter of the HSSF units was placed on top of the fabric layers.

Table 1: Properties of selected NWF,. Extracted from [2]

NWF Lab. No.	Mean Fibre diameter [μm]	Mean Fabric Thickness [mm]	Mean Fabric bulk density [g/cm³]	Calculated porosity [%]	Specific surface area [m²/m³]
27	33	3.6	0.108	88	14.431
28	33	4.8	0.100	89	13,266

In the case of the un-sewn fabrics, a wire mesh was applied on top instead of the circular metal ring in order to ensure that the fabric did not float in water.

Samples of sand placed over a depth of 200 mm in each HSSF unit were also subject to sieve analysis in the laboratory. The typical sieve analysis curve of the sand is given in Fig. 2. The sieve analysis was carried out as per DIN 4188, ISO 565 – 1972 standards with a Mettler (P3) balance. From the observed results, the effective diameter (d_{10}) of 0.14 mm is in conformity with literature recommendations on characteristics of optimum SSF media [14]. The porosity of both the natural form of the *Luffa cylindrica* fabrics and the pressed sewn-up fabrics were determined by displacement experiments. It was found that the average porosity of the fabrics before being pressed was 93% and the average porosity of the pressed and sewn-up fabrics was about 78%. The un-pressed porosity was closer to the optimum characteristics of an ideal fabric described earlier.

Table 2 gives the filter media installed in the HSSF units during the two phases of the reported study.

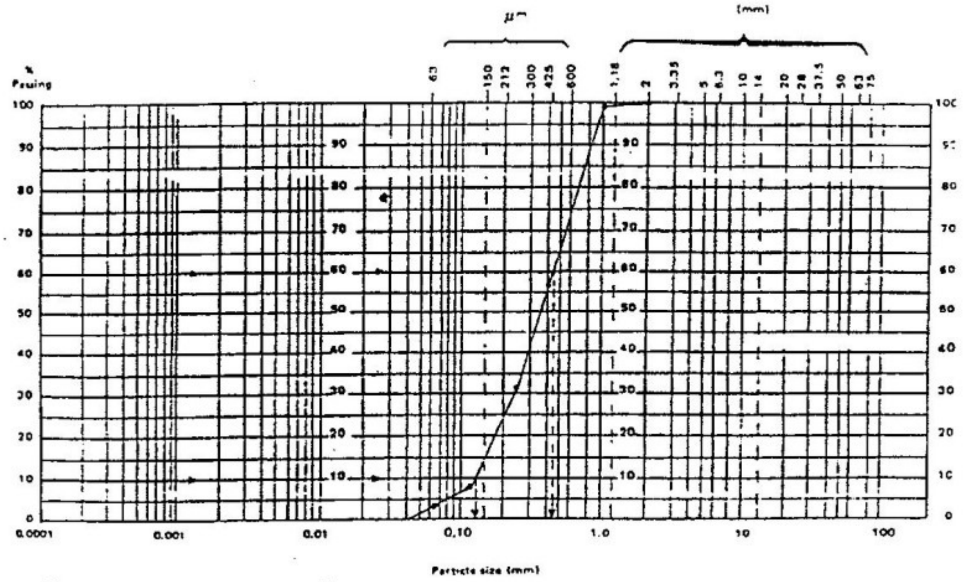


Table 2: Fabrics installed in the HSSF units

HSSF No.	Phase	No. of layers	Nominal thickness (mm)	Total thickness (mm)
1	I	3 (sewn LC)	16.6	50.0
2	I	2 (sewn LC)	15.0	30.0
3	I	None (sand only)	-	-
1	II	3 (sewn LC)	16.6	50.0
2	II	3 (NWF No.28	4.8	14.4
3	II	3 (Unsewn LC)	16.0	50.0

Legend: LC = *Luffa cylindrica*

Initial cleaning of the filter media

Luffa Cylindrica

The unpressed fibres (pods) were soaked in tap water for 12 hours after which they were removed and rinsed twice and left to dry. Upon pressing and sewing up, the fabrics were then soaked in tap water for another 12 hours and again rinsed twice and left to dry overnight after which they were cut to the desired size.

Sand

The SSF sand was soaked in tap water for 12 hours. Then it was rinsed three times and left to dry in an oven overnight at 30oC. The coarse gravel particles in the sand were removed by sieving out with a 4mm diameter sieve before cleaning and drying.

The NWF

These were also cleaned by soaking in tap water for 12 hours and rinsing three times before leaving them to dry in open air overnight.

CONDUCT OF LABORATORY AND FIELD TESTS

Two sets of experiments (phases I & II) were conducted with two different types of media as detailed in Table 2. The flow rate through the SSF units was maintained at about 0.1 m/h during both phases except for the first three days of commissioning (ripening period) or re-starting the filter which followed each cleaning operation. During these periods, the flow rate was maintained at about 0.05 m/h. Manometer readings were recorded daily (except for Saturday and Sundays) prior to adjustment of the filtration rates of the HSSF units. Upon termination of a HSSF run, the filter was drained and the fabrics were carefully removed and cleaned by a pressure hose [15]. In the case of the reference unit, (HSSF3 in phase I), a thickness of about 2 cm of the top sand was scraped. For fabric protected units, after removing and cleaning the fabrics, they were placed back on top of the sand in the same order as prior to cleaning. A similar procedure was used in the case of unsewn-up fabrics.

Analytical procedures

The headloss in the filters was determined using the difference in manometric levels. Other water quality parameters were analyzed in accordance with the standard Methods (APHA, AWWA, WPCF, 1995) [16]. The density of *Escherichia coli* was determined using the membrane filtration technique and subsequent colony counts. Apparent colour and turbidity were analyzed using HACH direct reading spectrophotometer at wavelength 455 and 450 mm, respectively. Temperature was measured using the thermometer in the Weilhem meter (Weiss Tech D812). Electrical conductivity and pH were measured using the conductivity meter (Hach model 44600) and the pH meter (WTW model 8120), respectively. In addition, the ability of the fabrics to protect the sand filter was assessed by visual inspection across the sand depth. Further detailed descriptions of the analytical procedures used can be found in literature [15]. Table 3 gives the frequency of analysis of the different water quality parameters analyzed.

Table 3. Frequency of analysis of water quality parameters

Parameter	**Frequency of Testing per week**
Temperature	5
PH	5
Turbidity	5
Bacteriological analysis *(E.coli)*	3
Electrical Conductivity	4
Apparent colour	4

RESULTS AND DISCUSSION

The results are discussed in three main sections. These include are; Hydraulic and operational performance, Water quality improvements/ changes and *Luffa cylindrica* fabrics cleaning/washability and durability.

Hydraulic and operational performance

Due to overall time limitations, the two phases of experiments were also limited in terms of the time schedule and hence as can be seen in Table 4, the second run of HSSF1 had to be stopped prematurely (i.e. after only 14 days) to allow phase I experiments to start.

Similarly, the second run in HSSF2 in phase II was also ended before attainment of the the maximum allowance head loss in order to comply with the retirement deadlines of the research grant. If time had allowed, all these runs should have been allowed to proceed until the longest filter run times could be recorded. As a result of the above mentioned constraints, the hydraulic performance data collected was very limited and hence one has to guard against extending conclusions too far only three typical head loss distribution curves of HSSF units are described while disregarding the differences in the actual time when they were recorded. This approach is plausible in view of the limited quality variations of the inlet water observed largely due to the periodic influence of the surface water runoff on the impounded water. It should also be noted that the manometer tube No. 3 (**man.3**) placed at the bottom of the fabrics in the HSSF units was not able to register any head loss in the fabric layers presumably because it was not sufficiently extended beyond the side wall. The foregoing observation is likely to be more relevant than the assumption that the majority of the impurities penetrated onto the sand bed. This was colloborated by visual inspection of the sand beds after removal of the fabrics at the end of the filter runs.

Figs. 3 through 5 show the typical head loss patterns for the three HSSF units. Fig. 3 represents a typical filter run of an unprotected conventional HSSF unit while Fig. 4 represents a typical head loss distribution of a HSSF protected with three layers of sewn-up *Luffa cylindrica* fabrics. Fig. 5 represents a typical head loss distribution of a NWF (Lab. No. 28) protected HSSF unit. It can be observed that the on-set of the exponential increase of the head loss in the *Luffa cylindrica* protected unit was fairly similar to the NWF protected unit (i.e. both about 21 days). Furthermore, visual inspection of the sand beds after draining the water and removal of the fabrics indicated that while the HSSF units protected with three layers NWF Lab. No. 28 and three layers of the sewn-up *Luffa cylindrica* were fairly clean, the other units protected with two layers sewn-up *Luffa cylindrica* and three layers of randomly arranged un-sewn *Luffa cylindrica* showed obvious penetration of an appreciable amount of impurities onto the sand beds.

On the basis of a basic threshold head loss of 80 mm, Table 4 gives the number of filter run times attained by the three HSSF units during the period of this study. A close analysis of the filter run times shows that the reference (unprotected) HSSF units had an average filter run time of 14 days. As expected, this was the shortest run time since all impurities were directly captured on the sand grains. However, in phase 1, the HSSF1 with three layers of sewn-up Luffa cylindrica fabric extended the filter run time by a factor of 1.6.

In fact, the average recorded filter run time extension factor for a SSF protected with 4 layers of the Lab. No. 27 NWF and having a total

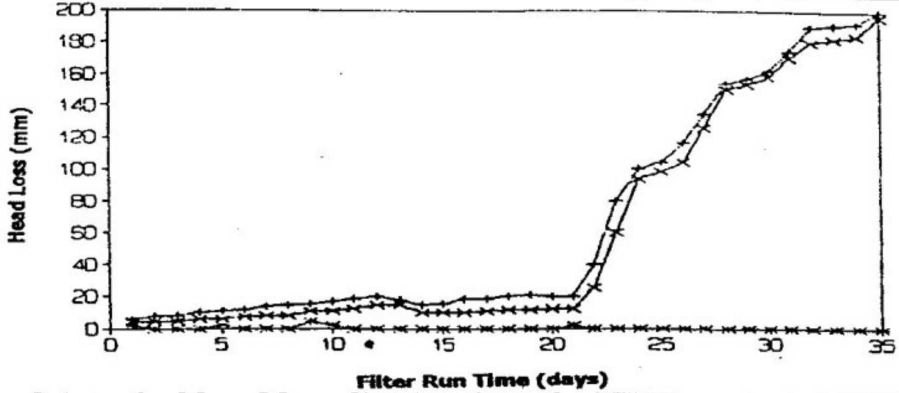


Fig. 3 A typical head loss distribution of a NWF protected HSSF unit

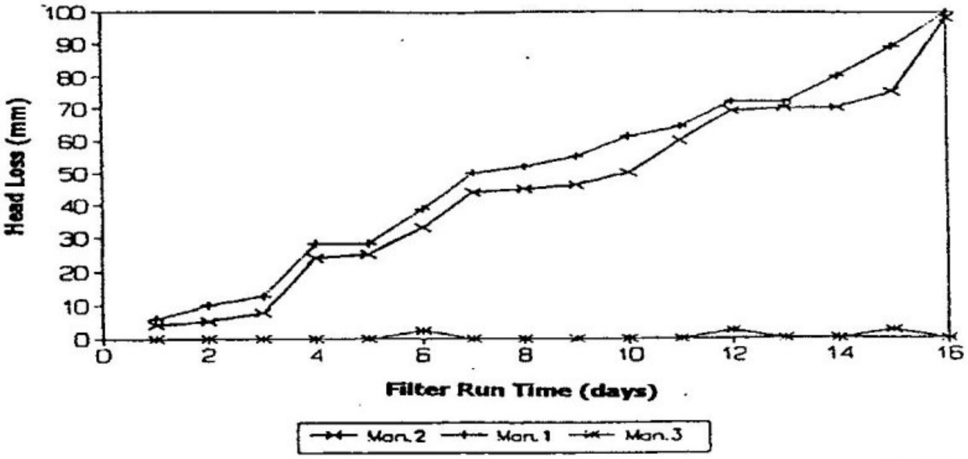


Fig. 4 A typical head loss pattern of unprotected/conventional HSSF unit

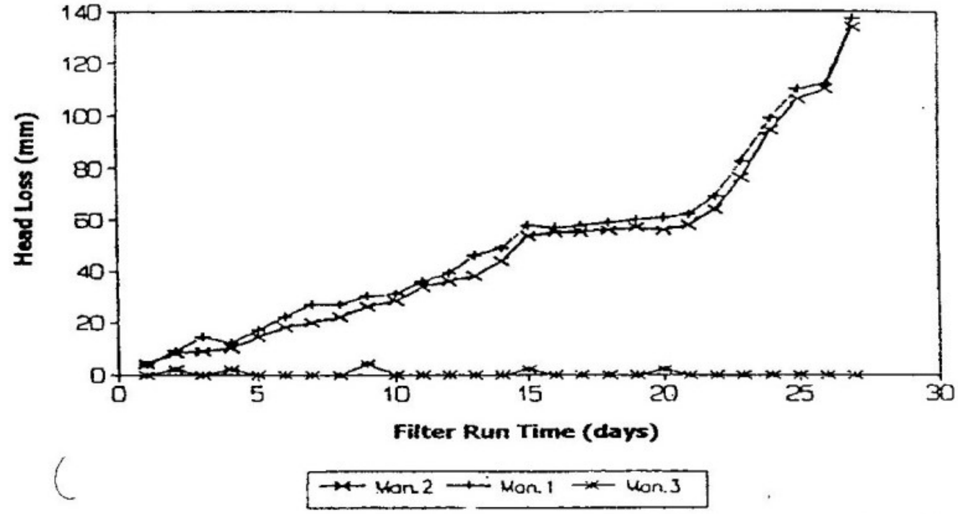


Fig. 5 A typical head loss distribution of a HSSF protected with three layers of sewn-up Luffa cylindrica

Table 4. Filter run times attained by the HSSF units

Phase	HSSF Unit	Filter Media	Filter Runs Completed	Filter Run Time (Days)	Remarks
I	1	3 layers (*Luffa cylindrica*)	1	23	Second Run terminated after 14 days*
I	2	2 layers (*Luffa cylindrica*)	2	13,22	Normal end of Runs
I	3	Sand only (reference)	2	15,14	Stopped after end of second Run
II	1	3 layers (*Luffa cylindrica*)	1	15	First Run ended after 15 days**
II	2	3 layers (NWF, Lab. No. 28)	1	-	Incomplete Run, terminated after 22 days only and ΔH= 14mm**
II	3	3 layers (Unsewn *Luffa cylindrica*)	1	21	First Run terminated after 21 days**

* ***To allow phase II experiments to start.***

** ***Due to being time barred.***

thickness of 14.4 mm went up to 2.0 during the studies carried out in the UK [2]. However, although both units protected with 3 and 2 layers of sewn-up Luffa cylindrica extended the filter run time by a factor of 1.6, (if the first run of HSSF2 is ignored), further consideration must be given to the relative protection ability of the sand beds as assessed by visual inspection. It can be concluded that of these two, the best protection was afforded by the unit with three layers of sewn-up Luffa cylindrica during phase I.

The three layers of sewn-up Luffa cylindrica fabrics in HSSF1 demonstrated its outstanding ability to reduce the rate of increase of head loss in phase I in comparison to HSSF2, and HSSF3. Regarding phase II experiments, both fabric protected units were already demonstrating an outstanding ability to reduce the rate of head loss build up. However, the NWF Lab. No. 28 out-performed the three layer sewn-up Luffa cylindrica in terms of delaying the on-set of exponential head loss development as can be seen on Figs. 4 and 5. Unfortunately, time did not allow continuation of monitoring the HSSF units for an appreciable time during phase II such that the end of the filter runs of the longest filter could not be attained.

Water quality improvements/changes

Table. 5 shows the mean treatment performance for the five main water quality parameters monitored during phase I.

Table 5. Mean treatment performance, (Phase I)

Parameter	Inlet Water	Filtrates from		
		HSSF1	HSSF2	HSSF3
pH	7.0	7.6	7.5	7.4
Turbidity (FTU)	5	1	1	1
E-Coli count (No./100ml)	202	92	56	16
Conductivity (µs/cm	188	256	239	218
Apparent colour (mg.pt.co/l)	19	7	7	2

It should be recalled that during Phase I, while HSSF1 was provided with 3 layers sewn up *Luffa cylindrica*, HSSF2 had 2 layers only while HSFF3 acted as a reference i.e. was un-protected. On the basis of the results presented in Table 5, it can be noted that the conventional (un-protected) HSSF unit still demonstrated an appreciable treatment performance in terms of bacteriological removal, turbidity and apparent colour reduction. Both units with three and two sewn-up layers of *Luffa cylindrica* fabric did not show any additional ability to improve further the water quality. Overall, these tests confirmed the well established fact from literature [2] that fabric protection cannot be expected to increase the already high treatment efficiency of the conventional slow sand filters. Furthermore, on the basis of the limited tests done, there was no indication that the filtrate from natural fabric protected HSSF units became adversely tainted during the study.

Luffa cylindrica fabrics cleaning/washability and durability

In general it was not as easy to clean the *Luffa cylindrica* fabrics with a pressure water hose as it was for the Non-Woven synthetic Fabrics Lab. No. 28. Moreover, the cleaning of the top fabrics for all the configurations installed took more time than for lower layers due to the intensive growth of the schmutzdecke on it. The easiest to clean were the bottom fabric layers in the configuration where three layers were used. The washing of the top layer of *Luffa cylindrica* was especially difficult since right from the end of the first filter run, these fabrics were already showing weaknesses especially along the sewn-up joints. For this reason, the first two layers of the 3 layer sewn-up *Luffa cylindrica* fabrics were too weak to be re-used in the second phase of the research. During phase II the weak fabrics were replaced with two new sewn-up fabrics on top of which the bottom layer(s) (during phase I) was/were put. After washing of the sewn-up *Luffa cylindrica* fabrics, their colour turned greenish-brown.

From the above discussions, it is clear that one has to select very carefully the threads used for sewing up the fabrics to ensure the joints do not become the weak points. Therefore, the use of synthetic fibre threads like polypropylene should be a top priority. To improve further the mechanical strength of the *Luffa cylindrica*, the possibility of chemically treating the fibres with view to reduction of the lignin content of the fibres should be investigated to make the fabrics even more durable.

ASSESSMENT OF THE SUITABILITY OF APPLYING *LUFFA CYLINDRICA* FABRICS FOR PROTECTON OF HOUSEHOLD SAND FILTERS (HSSF)

Local and foreign currency cost component

Since NWF fabrics are not produced in many developing countries, their continued use in water treatment plants would mean a constant demand of foreign currency which may not be readily available when replacement becomes necessary. Then, the objective of supplying clean water may also not be guaranteed thus forcing consumers to resort to the traditional untreated or polluted water sources. On the other hand, *Luffa cylindrica* grows locally in many developing countries with favourable weather and there would be no demand of foreign currency, hence a fairly reliable supply of relatively clean water can be maintained if *Luffa cylindrica* fabrics are used to protect the HSSF in view of the resulting improvement of the operational performance of small scale SSF Units.

Operational costs

Since in phase II the unit HSSF2 had just registered a head loss of 14mm after running for 22 days and HSSF1 and HSSF3 had already registered head losses of 194 mm and 80 mm, respectively after running for a similar duration, it can be confidently projected that the NWF would have to be cleaned less frequently than the *Luffa cylindrica* fabric, thus the operational costs of NWF protected SSF would be likely to be less than the operational costs of *Luffa cylindrica* protected SSF. However, the over-riding factor would have to be the capital costs for purchase of fabrics from abroad.

Economic suitability

The fact that *Luffa cylindrica* fabrics are more abundant than NWF makes the *Luffa cylindrica* fabric more economically viable than the NWF until such a time that non-woven synthetic fabrics can be manufactured or purchased in developing countries at affordable prices. Even if in future NWF will be produced locally in most of developing countries; they will still be likely to be more expensive than *Luffa cylindrica* fabrics in terms of capital costs. Hence the most viable comparison basis will have to consider both the capital and operational costs based on the established respective economic lifetimes. From existing data, while a single layer of one square metre of a sewn-up *Luffa cylindrica* fabric currently costs about US$ 1.5, the equivalent price of a similar size of a Lab. No. 28 fabric is US$ 4.0.

These capital costs would have to be discounted and added to the annual operation and maintenance costs to compare the two alternatives on the basis of longterm studies of the HSSF units performance.

CONCUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results of this study the following conclusions can be made:

This study has demonstrated that by placing several, layers of the natural fabric *Luffa cylindrica* on top of the HSSF sand bed, one can subsequently ensure low rates of head loss development in the filter.

A filter run time extension of up to 1.6 times can be attained by protection of the HSSF units with a number of layers of *Luffa cylindrica* fabrics. However, such an extension factor is low compared to the reported performance of NWF protected SSF from literature.

It is possible to concentrate the majority of impurities in the *Luffa cylindrica* fabric multi-layers such that routine maintenance could involve cleaning of the fabrics only at the end of the filter runs. However, further optimization of the *Luffa cylindrica* fabric properties and performance based on its total thickness and quality of incoming water is necessary.

Because the filtrate quality of conventional SSF is usually of such an excellent quality, no additional treatment performance of the HSSF can be achieved by protection with *Luffa cylindrica* fabrics. Moreover, no deleterious effect on the quality of the filtrate was observed after use of the *Luffa cylindrica* fabric layers to protect HSSF.

Recommendations

Longer field tests be done with *Luffa cylindrica* fabrics sewn-up with plastic polymer threads (e.g. polypropylene) to establish its durability and hence its useful economic lifetime apart from its longterm operational performance.

Further research with the *Luffa cylindrica* as a fabric protection layer should involve some preliminary treatment of the fibres with a suitable chemical to improve its durability.

Parameters like odour and taste of the filtrates from the SSF units should be monitored in future studies in order to establish if *Luffa cylindrica* protected HSSF can produce palatable water continuously.

Once longterm performance data of both the *Luffa cylindrica* fabrics and NWF are available for tropical areas, a detailed economic analysis of their viability should be made by considering both the capital and operational costs.

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