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REACHING THE UNREACHED: CHALLENGES FOR THE 21ST CENTURY

Natural fabrics in slow sand filtration

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PREVIOUS RESEARCH AT Imperial College, London, UK has shown that slow sand filters protected by layers of non-woven synthetic fabrics, namely polypropylene have increased run times in between periods of shut down and regular maintenance, compared to un-protected slow sand filters by up to a factor of 8. This is achieved by the application of fabric layers on the surface of the sand bed. Through careful selection of fabrics, the filtration processes can be concentrated in the fabric layers, hence preventing solids penetration through to the sand, resulting in a reduction in the rate of head loss development. So, as well as extended run times, fabric protected sand filtration can also eliminate the need for sand removal and cleaning.

This paper is concerned with replicating these earlier findings through the use of natural fabrics, to a) open up new markets for natural tropical fibres and, b) make available the advantages of protected slow sand filtration to developing countries, utilising local materials and / or minimising the use of foreign exchange.

The research has been solely a feasibility study to determine whether natural fibres are suitable materials for the protection of slow sand filters. Other factors, although important, are not considered at this stage.

Natural fibres

Natural fibres are those which are either animal-based or grown as a crop. The criteria for fibre selection was: availability both in terms of location and volume, rate of microbial degradation, fibre properties (diameter and density), and the cost and ease of processing a fibre into a high density filtration fabric.

As a consequence all of the fibres of interest have been vegetable fibres due to the high cost and relative limited availability of animal fibres. After a period of research into the compatibility of selected natural fibres to the above criteria, the fibres identified for initial consideration were ramie, jute, coir, sisal and abaca. These fibres all differ in their properties, chemical composition and geographical availability, but it was anticipated from initial theoretical calculations that the filtration performance of these fabrics could be broadly comparable to that of synthetic fabrics.

Importance of fibre/fabric properties

When considering the use of natural fabrics for filtration purposes, the four factors of importance are the fibre properties, fibre diameter d_f, and fibre density ρ_f, and the manufactured fabric properties, weight per square metre, and thickness. The theoretical performance of a filtration fabric can be determined from the calculated values of porosity $\varepsilon 0$, and specific surface area, s.s.a. These are calculated from the fibre and fabric properties.

We have learnt from previous research with synthetic fabrics that an ideal filtration fabric has a porosity of approximately 90 per cent, and a specific surface area of between 12,000-14,000m^2/m^3(Graham & Mbwette, 1991, Mbwette & Graham, 1988, and Mbwette, 1989). This will be a high porosity and moderate to high density fabric. A fabric should have a high porosity, so as not to contribute to the head loss development, and an intermediate specific surface area, so as to act as an efficient straining layer. The porosity of sand is 40-50 per cent, so at 90 per cent porosity the fabric will become blocked by solid and bacterial matter at a much reduced rate compared to sand. The specific surface area of a fabric is dependent on the porosity, and is a measure of how compacted the fibres are into a given thickness. If the porosity is significantly lower than 90 per cent the fabric will be one with more densely packed fibres, hence filtration efficiency will be high but head loss development will be introduced. Consequently, if the porosity is higher than 90 per cent the fabric will have loosely compacted fibres and although head loss will be eliminated, solids penetration through the fabric and into the sand will occur.

The porosity and specific surface area of a fabric are used as theoretical expressions. However, for natural fabrics, theoretical predictions will not always hold true, due to inconsistency and variability of the fibre properties. The diameter of a given natural fibre will not be constant, and when wet will swell by approximately 20 per cent (Doraiswamy, 1995). It has been previously demonstrated that slight changes in the fibre diameter have considerable effects in the theoretical results of porosity and specific surface area.

Although theory can be used as a basis for experimental work, it can not be assumed that the results of the two will be equal. Hence, experimental work has played a significant role in this research.

Natural fibre degradation

By far the biggest single issue in the use of natural fabrics in filtration is fibre degradation from water-borne bacteria, algae, fungi etc. This will be particularly important on a slow sand filter, where biological activity forms a major part of the treatment process. All natural fibres will degrade but the rate of degradation will vary according to the chemical composition. With continued degradation, the volume of fibres within the fabric will reduce, affecting the fabric properties, and resulting in a reduction of the filtration effectiveness of the fabric. The aim is that the life of the fabric is long enough so that a significant increase in the filter run time is achieved despite degradation. The major chemical constituent in vegetable fibres is cellulose which is readily degradable by bacteria. Typical cellulose contents range from 70 - 95 per cent of total chemical composition (Oszanlav, 1994, and PCARRD, 1988). Lignin is a minor constituent of vegetable fibres, but the presence of lignin considerably increases the degradation resistance of a fibre.

Degradation experiments were carried out by placing sealed samples of loose fibres and manufactured fabrics on the surface of a slow sand filter in the UK. The effects of degradation were measured by calculating the weight loss of the fibres or fabrics over a 4 week period. The results are summarised in Table I.

The results show coir and jute to be the most favourable as far as resistance to degradation is concerned. Coir contains 40 per cent lignin so is a highly resistant fibre (Siu, 1951), however the coarse nature of the coir fibres limit their potential to be manufactured into a filtration fabric. Flax is primarily a European fibre but the tests with the loose flax fibres and a flax moderate density fabric, illustrates a significant increase in the degradation resistance of a processed fabric compared to that of loose fibres of the same material.

Fabric manufacture

Selected fabrics were manufactured at the Natural Fibres Organisation, Silsoe Research Institute, UK, and at the Department of Textile Industries, University of Leeds, UK.

In order to produce the relatively high density fabrics required for filtration, non-woven techniques must be employed, as opposed to simpler woven techniques such as weaving or knitting. A non-woven fabric is one where the fibres are randomly intertwined in order to give the fabric it's structural form and properties. The fabrics were produced by passing the prepared fibres through a loom, to be repeatedly punched by a bed of needles, producing fabrics with a density in the range of 700 to 900g / m^2.

Table 1. Natural fibre degradation

Material	*Weight loss in 4 weeks (%)*
Coir fibres	2
Jute fibres	12
Abaca fibres	18
Sisal fibres	26
Ramie fibres	33
Flax fibres	41
Flax fabric	21

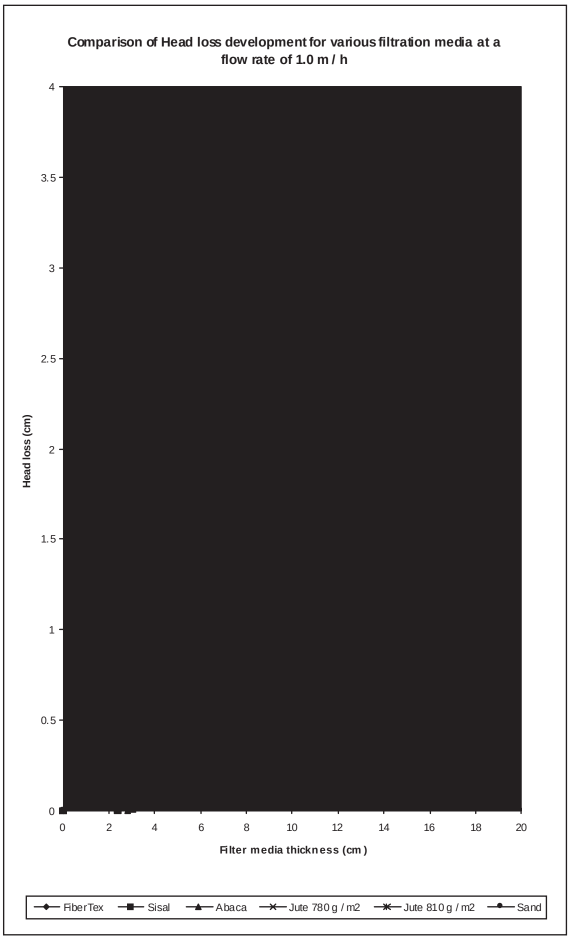

Figure 1. Head losses generated at 1.0m/h

Laboratory testing of fibres

Laboratory experiments took place to investigate the filtration and permeability performance of the fabrics. They were carried out in a perspex column, 100mm in diameter, split onto sections by a flange plate, into which a screen was located to support the fabrics.

The permeability tests involved passing a constant flow of water, with a constant head above the fabric layers, through a given thickness of fabrics, and measuring the head loss. Head loss occurs due to the resistance to flow caused by the fabrics, and values were observed for flow rates in the range of 0.3 to 1.0m / h, and with fabric thicknesses over a range of up to 18cm thick. Results were plotted as a graph of head loss against fabric thickness for each flow rate.

The filtration tests are carried out to determine the filtration coefficient, λ_0 of each fabric. The filtration coefficient is determined from the ratio of the influent and filtrate particle counts for a given particle size, and the thickness of the fabric layer. The filtration coefficient is

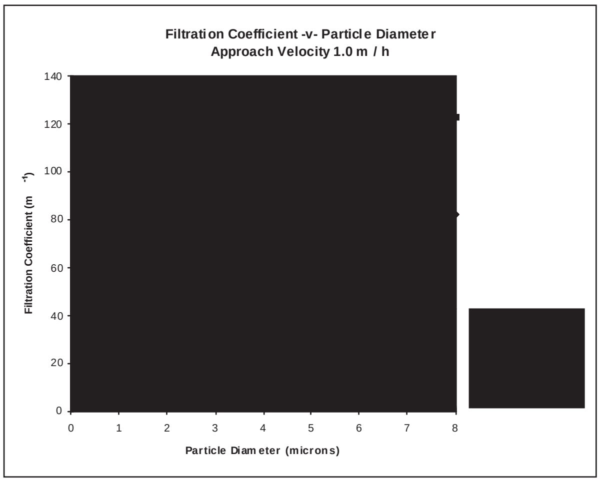

Figure 2. Filtration coefficient -v- particle diameter at 1.0m/h

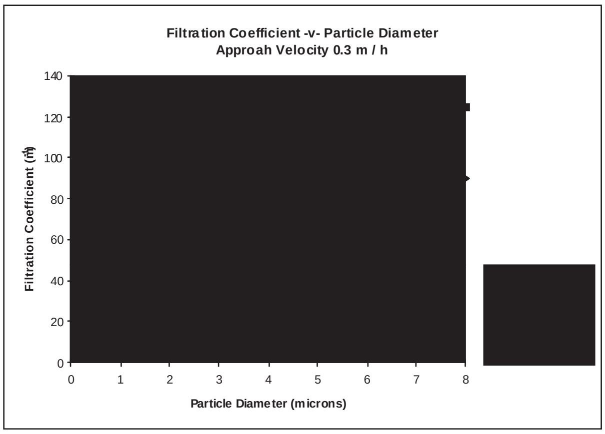

Figure 3. Filtration coefficient -v- particle diameter, at 0.3m/h

dependent on the flow rate through the fabrics. A suspension of kaolin powder at 75mg / l with a particle size range of 1.0 to 110µm was fed through the fabric, at a typical filtration thickness of approximately 3cm, at 0.3 and 1.0m / h. By comparing of influent and filtrate particle size distributions, a filtration coefficient was determined at each flow rate.

For both permeability and filtration tests comparisons were made with the behaviour of filter sand.

Laboratory results and discussion

Figure 1 below shows the comparative head losses generated by various filtration media at an approach velocity of 1.0 m / h across a range of filtration media depths. Figures 2 and 3 show the filtration effectiveness of each media in removing a range of particle sizes between 2 and 8mm at approach velocities of 0.3m / h and 1.0m / h.

With reference to Figure 1, a wide range of head losses were generated. *FiberTex* polypropylene was used as a reference media as it is commonly used as a slow sand filter protection media in developed countries. Hence, it was the results of polypropylene which it was hoped would be replicated by the natural fabrics.

The original problem was demonstrated by the high head loss development with sand (approximately 5 times greater than that of polypropylene). The figure also shows that the jute fabrics produced head losses that closely matched those of polypropylene.

Referring to Figures 2 and 3 it can be seen that polypropylene has the highest filtration coefficient, while jute and sand have filtration removal efficiencies in a similar range. Filtration performance is greater with increasing values of λ_0. As expected, for each media, particle removal is more efficient with increasing particle size and lower approach velocities.

From this then it would appear that jute is a suitable natural fabric alternative to synthetic fabrics. Coupled with it's comparatively low degradation rates, further investigation was recommended.

High or low head losses are not a direct result of the fibre material, rather a consequence of the density of the manufactured fabric. The densities for all the natural fabrics were suitable in a dry condition, approximately 800g / m^2, with a thickness of 5-6mm (≈140 kg / m^3). However, with the abaca and sisal samples, severe swelling of the fibres when wet resulted in a much less dense fabric, and consequently a greater area of pores within the fabric and reduced filtration performance. Further investigation is required to determine whether increased density fabrics can be manufactured to compensate for this effect.

Table 2 shows a comparison of the predicted and experimental porosity of the fabrics. The differences can be attributed in the main to changes to the fabric properties on becoming wet.

The predicted values were derived from fabric theory, where the porosity is, ε = 1 - (bulk fabric density / fibre

Table 2. Predicted and experimental porosity

	Jute 1	*Jute 2*	*PP*	*Abaca*
Predicted clean bed porosity ε_0 per cent	90	90	89	90
Experimental clean bed porosity ε_0 per cent	83	85	90	94
	Sisal	*Sand*		
Predicted clean bed porosity ε_0 per cent	89	45		
Experimental clean bed porosity ε_0 per cent	97	-		

Jute 1 = 780 g / m^2, Jute 2 = Jute 810 g/m^2, PP = Polypropylene density). Experimental values are from theoretical and experimental relationship curves, between permeability factor and fabric porosity for a given fibre diameter.

Conclusions

Natural fibres have a potential for being used as a protection media for slow sand filter units. Early work shows jute to be the most promising material, although further manufacturing modifications are to be carried out to make other materials more suitable.

During the summer of 1996, pilot plant tests will be carried out on slow sand filter beds 1 metre in diameter, with 0.3m gravel and 0.3m sand, protected by the most promising natural fabrics, to observe the head loss development, filtrate quality, and filter run times, and also to monitor any deterioration in filter performance as a result of microbiological degradation of the fabric.

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