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DUAL-MEDIA FILTRATION WITH SAND AND PALM KERNEL SHELLS

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SUMMARY

Dual and multi-media filters, made with anthracite-over-silica sand or anthracite-over-sand-over-garnet, have been studied and used for the filtration of water in the last two decades or so. This paper reports on a study in which palm kernel shells and silica sand were used for filtering water. It was found that in terms of quality and quantity of water produced and headloss developed, a combination of charred palm kernel shells (0·85–2·36 mm) on fine sand (0·425–0·850 mm) gives good results. Furthermore, uncharred palm kernel shells were found to hold great promise if their characteristic but objectionable odour and taste could be eliminated through a suitable process. Initial headlosses were calculated to a reasonable degree of accuracy using the Blake–Kozeny equation.

1. INTRODUCTION

Water, which has passed through the coagulation unit (or the softening unit) and then settled, is invariably passed through a filter before it is disinfected and supplied to the users. The most common filter used in conventional treatment plants all over the world is made up of silica sand, underlain by gravel, and it filters water at rates ranging from 80 to 250 litres per minute per square metre of the surface area of the filter.

A single-medium filter, such as that referred to above, has one important deficiency, namely that a large part of the bed is not efficiently used. This is because, as the finer particles occupy the top and the coarser the bottom of the bed, removal of solids takes place largely in the top layers. Furthermore, removal of influent solids in the top layers leads to higher leadlosses than would be the case if removal were not so localized, but distributed throughout the column.

Since about 1960, various studies have been made on dual-media and multi-media filter beds, such as anthracite-over-silica sand and anthracite-over-silica sand-over garnet.[1–4] These beds take advantage of the relative (increasing) densities of anthracite, silica sand and garnet which permit larger particles of anthracite to settle (following backwashing) over the finer particles of silica sand, for example. The 'reversed' gradation thus achieved, causes pore sizes to decrease from the top of the bed to the bottom and, as a result, filtration efficiency is enhanced.

Significant efforts have already been made, and studies carried out on suitable local filter materials, with the object of eliminating or reducing the burden of having to import large quantities of filter sand from developed countries to less developed countries where such sand cannot be found. These include studies on local sands[5–7] and investigation of granular palm kernel shells as a filter material.[8] Palm kernel shells particles are less dense than sand particles, and therefore, in order to further the course of

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optimum water production, it is logical that the performance of beds consisting of palm kernels and sand should be studied.

The objective of this study is to compare the performance of sand and palm kernel shell dual-media filters, to those of single media filters made with the same materials. Specifically, the purpose of the study is to evaluate performance from the point of view of quantity of water produced per filtration cycle, the quality of the water produced, and headloss incurred. An attempt has also been made to compare the initial headloss in each of the filters with the corresponding headloss calculated from the Blake–Kozeny equation.

2. MATERIALS AND METHODS

Palm kernel shells were obtained from the Okitipupa Oil Mill in the Ondo State, Nigeria. Palm nuts and other impurities were removed, and a portion of the shells was then fed into a hammer mill* for crushing into appropriate particle sizes for filters. Because palm kernel shells are very hard and difficult to crush, attempts at obtaining crushed shells in sufficient quantities in the particle size range of 0·4–1·0 mm were not successful. For this reason it was decided in this study to use crushed shells in the particle size range of 0·85–2·36 mm.

In a parallel series of tests, palm kernel shells were charred until their oily constituents had been burnt off; the charred shells were then quickly poured into cold water for rapid cooling. Experience shows that rapid cooling in this way is necessary for reducing the amount of 'floaters' usually present in the crushed shells. The charred shells, which are much easier to crush than the uncharred shells, were subsequently crushed; the portion passing the 2·36 mm sieve, but retained on the 0·85 mm sieve, was separated for later use so that a proper comparison with uncharred shells could be made.

Crushed shells, both charred and uncharred, were washed separately and thoroughly with detergent, and rinsed until the wash water was clean. They were then sun-dried and sieved again to ensure particle size distribution within the range of 0·85–2·36 mm in each batch.

Unfortunately, perspex or plexiglas tubes, commonly used in filtration studies, could not be obtained. Therefore, as a reasonable alternative, a filter box measuring 500 mm×200 mm (cross-sectional area=0·10 m^2) and 1500 mm deep was constructed with 16-gauge (1·30 mm) galvanized sheet metal and used in the tests. Important features of that box, shown in Figure 1, include: a float-valve to ensure that filtration occurs under the constant-head condition; sampling ports and headloss ports (connected to water manometers). Both sets of ports were located at depths of 150, 300, 450 and 600 mm measured from where the top of the filter media would be; and 19 mm GI pipes, perforated for use as under-drains and for backwashing. The projections of both sampling and headloss ports into the filter box were securely wrapped with pieces of fine-mesh wire-gauge in order to prevent any blockages of the ports, and also to minimize any disturbance to the media and solid deposits during sampling. The bottom 100 mm of the filter box (i.e. around and on top of the under-drains) was filled with gravel of size 5–10 mm, and the next 100 mm also with gravel but within the size range of 3·35–5·00 mm. The next and final layer, upto the 800 mm mark, was filled variously with sand, crushed palm kernel shells, or a mixture of sand and crushed shells. Figure 2 shows the various types of filter beds used in the tests.

Effluent from the sedimentation tanks of the Opa Water treatment plant† was siphoned and used as the filter influent. Each set of media was used and backwashed several times before being replaced by another set. Backwash water was provided through an elevated tank. As filtration progressed, water turbidity (influent and effluent) and filter headloss were measured at the appropriate ports. Flow rates were also measured every 15 minutes, using a bucket, a measuring cylinder, and a stop watch. The filter effluent valve was kept fully open throughout each run. Thus, the filtration cycle commenced at the highest possible filtration rate which declined as filtration progressed.

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* Designed and constructed by the Department of Agricultural Engineering, University of Ife, Ile-Ife, Nigeria.
† The waterworks of the University of Ife.

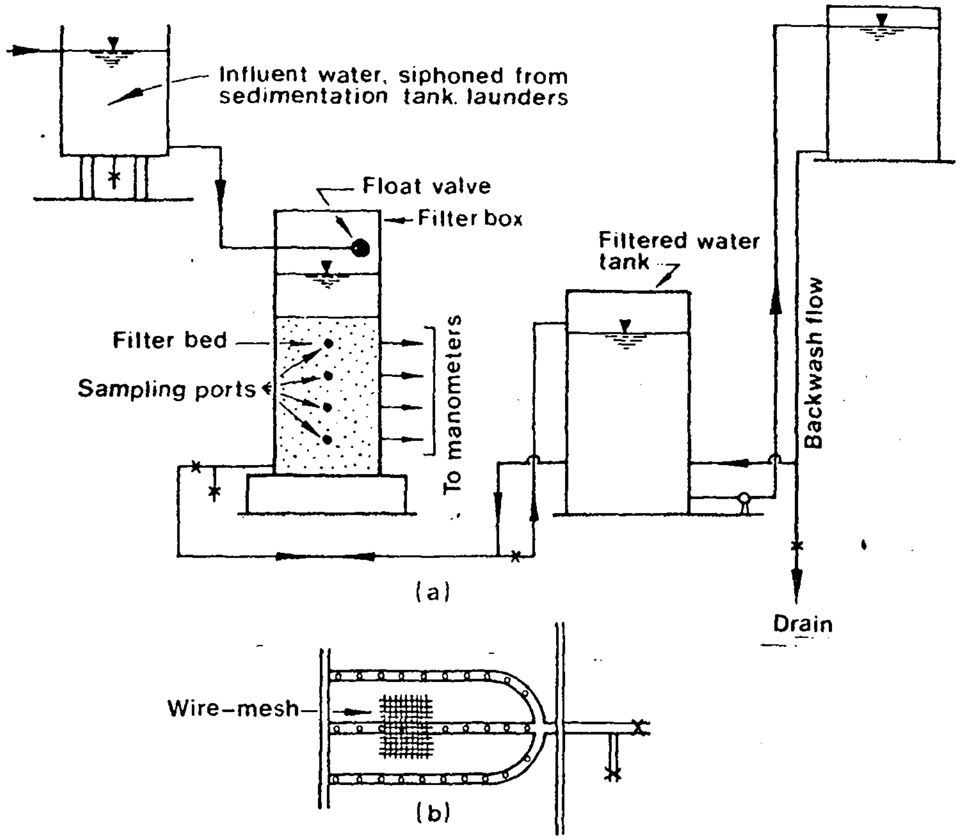
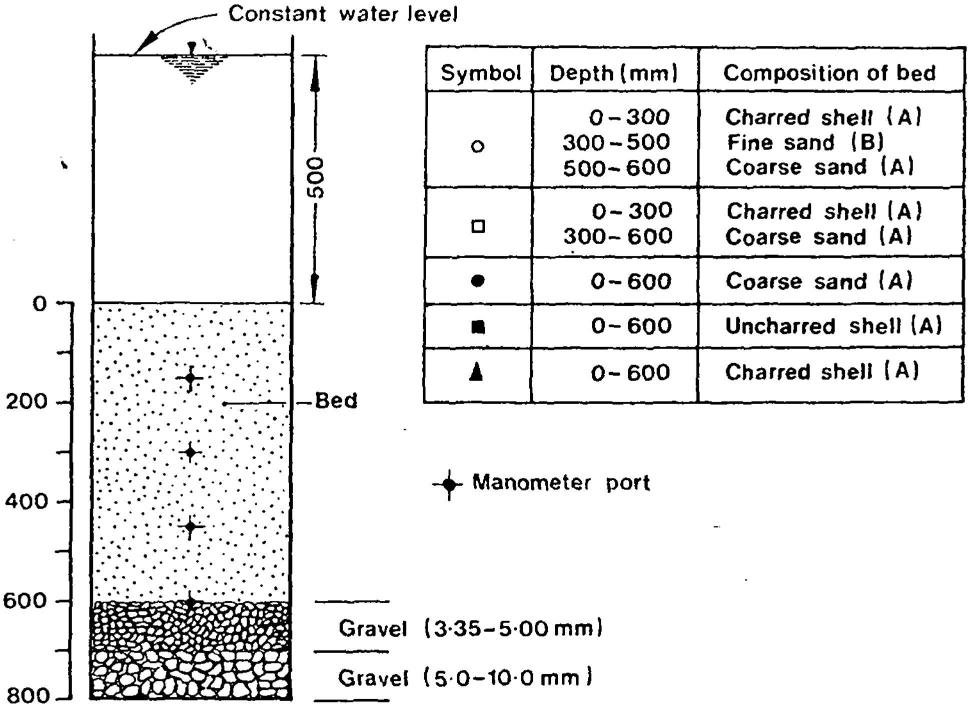


Figure 1. (a) Schematic arrangement of the filter unit (sampling ports are made of 13 mm copper tubes, rubber tubing and clips). (b) Details of under-drains; 6 mm holes 50 mm c/c on 19 mm pipe



Symbol	Depth (mm)	Composition of bed
○	0–300 300–500 500–600	Charred shell (A) Fine sand (B) Coarse sand (A)
□	0–300 300–600	Charred shell (A) Coarse sand (A)
●	0–600	Coarse sand (A)
■	0–600	Uncharred shell (A)
▲	0–600	Charred shell (A)

Figure 2. Description of the five different types of filter beds tested (all dimensions are in mm. Letter A denotes particle size range of 0·85–2·36 mm; B denotes the range of 0·425–0·850 mm)

Apart from the filtration tests, some physical properties of the various stocks (charred shells, uncharred shells, and sand) were investigated. These included: specific gravity (ρ), bed porosity (e), and sphericity (ψ). Determination of sphericity was based on the method proposed by Hsiung.[9] The settling velocities (V_s) of representative particles were determined from settling tests, and the settling velocity (V_n) of a spherical particle of equal size was calculated from the well-known Stoke's equation; sphericity was then calculated from the relationship:

$$\psi = (V_s/V_n)^2 \tag{1}$$

3. RESULTS AND DISCUSSION

3.1 *Headloss in filtration*

The plot of headloss against time, Figure 3, shows that the bed made of uncharred palm kernel shells offered overall the least resistance to flow during the test period of 8 hours. During the first 5 hours of filtration, the charred palm kernel shell bed (0·85–2·36 mm), the coarse sand bed (0·85–2·36 mm), and the bed with a 300 mm layer of charred shells over coarse sand, all showed smaller headlosses than when the bed was made up of charred shells on fine sand, i.e. 300 mm of charred shells (0·85–2·36 mm) over 200 mm of fine sand (0·425–0·850 mm) on 100 mm of coarse sand (0·85–2·36 mm). However, between the 5th and the 8th hour of filtration, the charred shell-on-fine sand bed showed a smaller headloss compared with those incurred by single-medium beds, both charred shell and sand, and, interestingly, this was found also to be true to a greater extent, perhaps understandably, in the case of the charred shell-over-coarse sand bed. In other words, for dual-media beds the slope of the headloss versus time plot is gentler than that for a single-medium bed. This finding establishes a potential for longer filtration cycles in dual-media filters over those with a single medium, at least in so far as headloss constraints are concerned.

3.2 *Turbidity removal*

A filtration run would normally be terminated when, either the headloss across the bed becomes excessive, or the quality of the water produced declines to an unacceptable level. Either condition, high

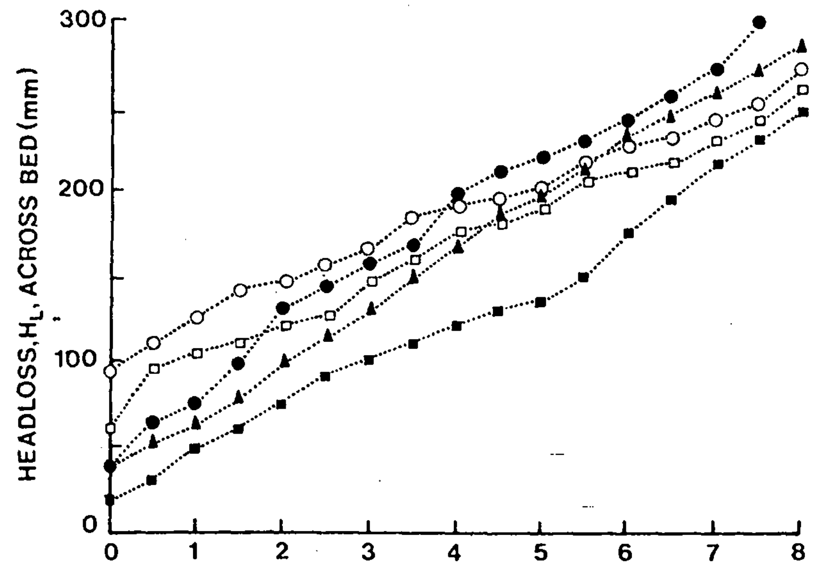


Figure 3. Headloss developed across different beds versus filtration time (measured at the 600 mm deep port). See Figure 2 for explanation of symbols

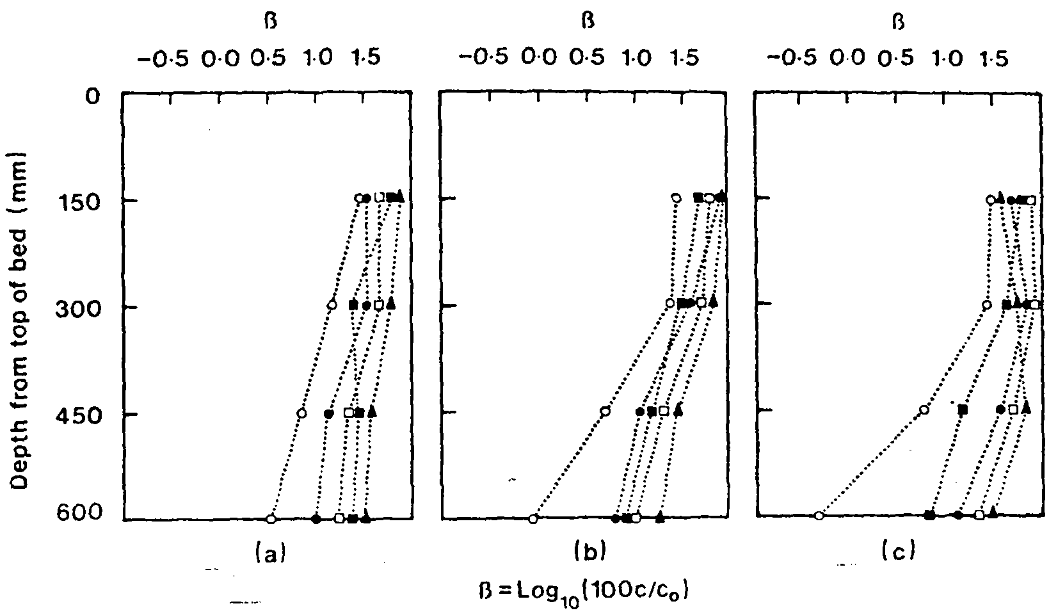


Figure 4. Plots of turbidity removal versus media depths for different media. (a) One hour of filtration; (b) Three hours of filtration; (c) Six hours of filtration. See Figure 2 for explanation of symbols

headloss or high turbidity, could occur first. A judgement on the relative performances of the five different filters, considered in this study, cannot therefore be made solely on the basis of headloss incurred since, clearly, a consideration of turbidity is also necessary.

An attempt has been made in Figure 4 to present the inter-relationships between residual turbidity, type of filter media used, and different thicknesses of each medium. Relationships at the beginning (the first hour of filtration), near the middle (the third hour) and near the end (sixth hour) are shown in this Figure.

In Figure 4 the logarithm to base 10 of percentage turbidity remaining, i.e. $\log_{10}(100c/c_o)$, was used for the ease of plotting (c_o denotes the turbidity of the influent water, and c the residual turbidity at the port under consideration). The effluent turbidity readings covered a wide range of values, from about 0·05 NTU to approximately 8·0 NTU, while the influent turbidity remained practically constant at about 10·0 NTU. Thus, the abscissa range in Figure 4 is from $\log_{10}(0{\cdot}05 \times 100/10)$ to $\log_{10}(8{\cdot}0 \times 100/10)$, which works out at −0·3 to 1·8. These extreme values correspond to turbidity removal efficiencies of 99·5 and 20·5 percent, respectively.

It will be seen from Figure 4 that during the first hour of filtration and, indeed, throughout the run, the shell-on-fine sand bed produced the best water quality at all depths. Assuming that a maximum residual turbidity, not exceeding 1·0 NTU (i.e. 90 percent turbidity removal), is to be achieved, the pertinent value of $\log_{10}(100c/c_o)$ thus being 1·0, effluents at 150 and 300 mm depths are unacceptable in any of the beds tested. Only the shell-on-fine sand bed produced acceptable effluents at a depth of 450 mm throughout the filtration cycle. At a depth of 600 mm, the shell-on-fine sand bed and the coarse sand bed both meet the stated quality standard at the end of the first hour of filtration, and, all but the charred shell bed meet the standard after three hours. The uncharred shell bed, as well as the shell-on-fine sand bed meet the standards from the 3rd to the 6th hour of filtration. Variations of turbidity with time for samples collected at depths of 450 and 600 mm are shown more clearly in Figures 5 and 6. These generally support the above statements.

It would appear from the above discussion that the bed made up of charred palm kernel shells on fine sand has very good turbidity removal capability throughout the run; that all the other beds perform

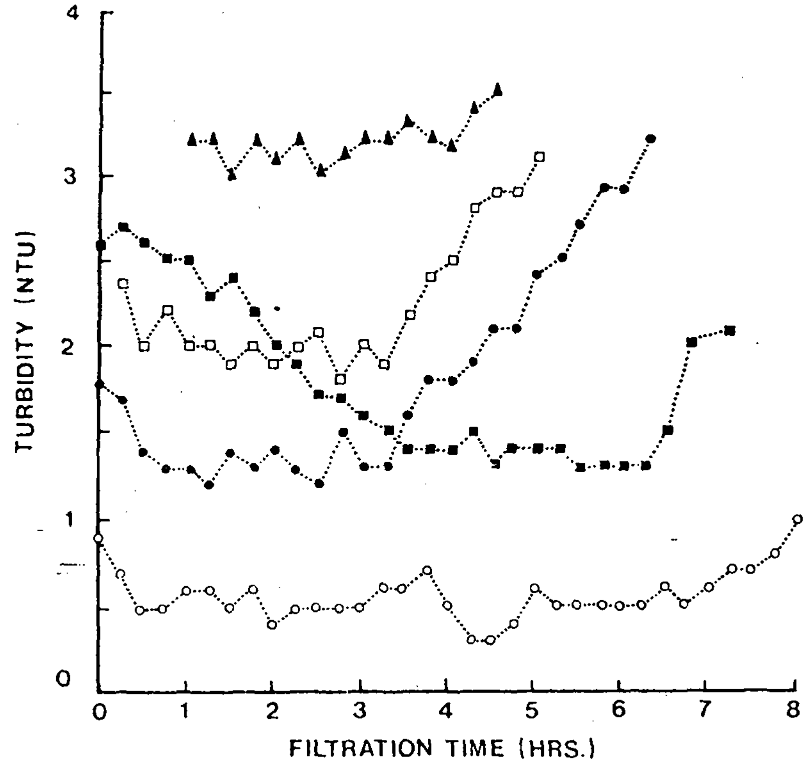


Figure 5. Variation of turbidity with time in various filter beds tested (measured at the 450 mm deep port). See Figure 2 for explanation of symbols

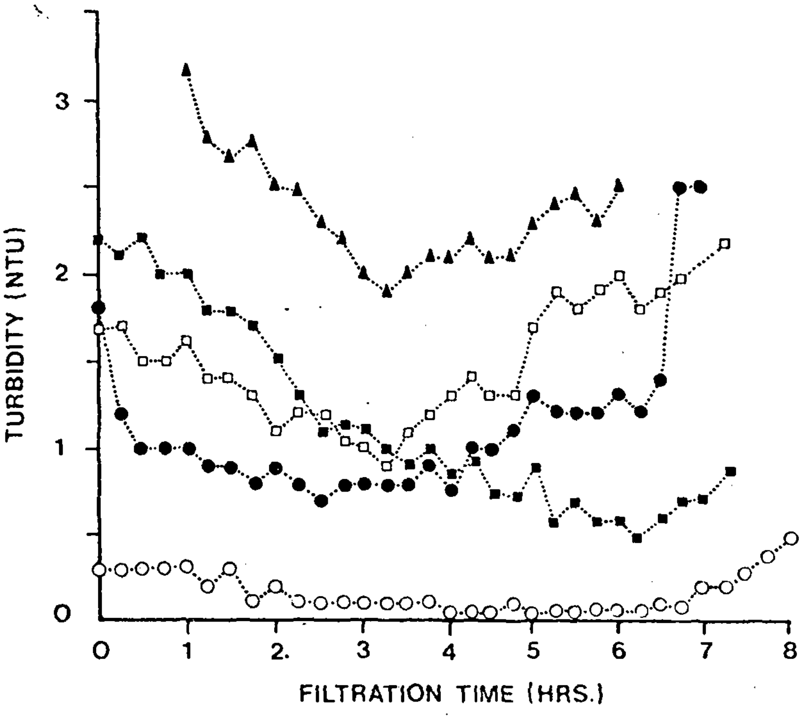


Figure 6. Variation of turbidity with time in various filter beds tested (measured at the 600 mm deep port). See Figure 2 for explanation of symbols

relatively poorly during the first hour of filtration, but their performance improves somewhat as filtration progresses; and that the performance of the uncharred shell improves remarkably with time.

Table 1 shows the physical properties of the various filter materials and the beds made from them. These include particle sphericity, bed porosity, average grain diameter, etc. More importantly, this Table gives results of calculation of resistance to flow at the commencement of filtration runs.

The resistance of a clean bed of particulate material, such as sand, to flow was calculated using the Blake–Kozeny equation[10]

$$H_L = \frac{5\mu v}{\rho_w g}\frac{(1-e)^2}{e^3}\left(\frac{6}{\psi d}\right)^2 L \tag{2}$$

in which H_L denotes headloss through the filter media (cm), μ the absolute viscosity of the fluid (poise), ρ_w the mass density of the fluid (g/cm^3), v the approach velocity at the top of the bed (cm/sec), g gravity acceleration (cm/sec^2), e the porosity of bed, and L the depth of the bed (cm). ψ denotes the sphericity (or shape factor) of representative particles, and d the diameter characterizing the filter-media grains (cm).

In general, non-uniform filter media particles such as those used in this study, and the selection of diameter d which characterizes the filter-media grains, require some thought. Hazen chose the 10 percentile (i.e. D_{10}) as the hydraulically effective size, because he had observed that the hydraulic resistance of unstratified sand beds was relatively unaffected by size variation (up to D_{60}/D_{10} of about 5) as long as D_{10} remained unchanged.[10]

It has been suggested by Wen and Yu,[11] on the other hand, that for particles of mixed sizes (i.e. non-uniform media) an average particle diameter, d, can be defined as

$$1/d = \sum_{i=1}^{n} (x_i/d_i) \tag{3}$$

in which x_i denotes the weight fraction of particles in the i-th sieve, and d_i the mean of sieve openings of the i-th and the $(i+1)$-th sieves. This, in fact, forms the basis of headloss calculations given in Table 1. All values of the Reynold's number were found to be below 3, thus indicating that the flows were laminar.

Headloss through each filter, calculated and given in Table 1, are compared with their corresponding measured values in Table 2. Clearly, in the case of beds made of charred shells and those with charred shells-on-coarse sand, the calculated headloss values are about the same or slightly smaller than those found from tests. Moreover, although in all cases the calculated values are greater, there does not appear to be a consistent pattern. Nevertheless, the fact that the predicted (calculated) and measured values are of the same order of magnitude, would appear to be remarkable considering the inherent inexactness in the determination of sphericity and average particle diameter which occur in equations (2) and (3). Table 2 shows, furthermore, that the total quantities of water produced by the filters in 6 hours range from 30,793 l/m^2 for the shell-on-fine sand bed, to 37,005 l/m^2 for the uncharred shell bed. Output from the shell-on-coarse sand bed, 33,105 l/m^2, is only 7·5 percent greater than that from the shell-on-fine sand bed, while that from the coarse sand bed is a mere 4·9 percent greater. The initial flow rates through the filters reflect the same pattern as the filter effluent volume produced in 6 hours. The quantities of backwash water, not shown in Table 2, were found to remain virtually constant at 8–10 percent of the total quantity of water produced.

The effluent from the filter bed made with uncharred shells was found to have the characteristic but objectionable odour and taste of palm nuts. Clearly, this seriously diminishes the value of uncharred shells as a filter material, unless of course a suitable method can be found to remove the oil from the palm without charring.

4. CONCLUDING REMARKS

A series of tests were conducted to assess the suitability of crushed palm kernel shells as a filtering medium to produce good quality water. The following concluding remarks are made on the basis of

Table 1. Headloss computations for various single and dual-media filters under conditions prevailing at the beginning of each filter run

Variable	Charred shell (A*)	Uncharred shell (A*)	Coarse sand (A*)	Coarse sand and shell		Fine sand and shell*	
				Sand (A*)	Shell (A*)	Sand (B*)	Shell (A*)
Depth of filter, L (mm)	600	600	600	300	300	300	300
Particle sphericity, ψ	0·85	0·70	0·85	0·85	0·85	0·90	0·85
Average grain diameter, d (mm)							
(a) From equation (3)	1·49	1·65	1·35	1·35	1·49	0·79	1·49
(b) With $d = D_{10}$	0·98	1·09	0·95				
Porosity (e)	0·45	0·49	0·41	0·41	0·45	0·38	0·45
Approach velocity, V_s (mm/sec)	1·82	2·07	1·73	1·81		1·66	
Water temperature (°C)	22·00	26·00	26·00	24·00		26·00	
Viscosity, μ (poise)	0·009608	0·008746	0·008746	0·009161		0·008746	
$R_e = \psi \rho_w v d / \mu$ (d from (a))	2·40	2·73	2·27	2·27	2·50	1·35	2·55
H_L in mm from equation (2):							
With d from (a) above	39·80	33·00	63·90	35·00	18·90	110·20	16·50
With d from (b) above	93·00	75·60	129·00				

* A denotes particle size range of 0·85–2·36 min; B denotes the range of 0·425–0·850 mm.
$\rho_w = 1{\cdot}0$ and $g = 981$ cm/sec^2.

Table 2. Some filtration characteristics of the various filter beds tested

Composition of bed	Initial headloss (mm) Measured	Initial headloss (mm) Calculated*	Initial flow rate ($l/min/m^2$)	Volume of effluent water in 6 hours (l/m^2)	Odour/taste of effluent water
600 mm deep bed of charred shells (A†)	40·0	39·8	109·2	34,139	None
600 mm deep bed of uncharred shells (A†)	20·0	33·0	124·2	37,005	Odour and taste of palm nuts
600 mm deep bed of coarse sand (A†)	41·0	63·9	103·8	33,302	None
300 mm deep bed of charred shells on 300 mm coarse sand (A†)	60·0	53·9	108·6	33,105	None
300 mm deep bed of charred shell on 200 mm of fine sand (B†) on 100 mm of coarse sand (A†)	95·0	126·7	99·6	30,793	None

* Calculation given in Table 1.
† A denotes particle size range of 0·85–2·36 mm; B denotes the range of 0·425–0·850 mm.

results of those tests:

(a) Dual-media filter beds, made with palm kernel shell-on-sand, are potentially useful for water filtration, permitting as they do longer filtration cycles and increased production of good quality water.

(b) At a bed depth of 600 mm, uncharred shell beds were found to be very attractive in terms of a reasonably good effluent, low headloss and high water production per cycle. However, the water was found to have objectionable odour and taste.

(c) Although the dual-media bed, made with charred shell-on-fine sand, developed greater headlosses at the beginning of filtration runs than all other beds considered, the slope of its headloss curve was found to be more gentle than those of single-medium beds. The total quantity of water produced from it in 6 hours of filtration was, as a result, only slightly less than that produced from the other beds tested. But, more importantly, good water was produced consistently, from the beginning of the cycle to the end, from the shell-on-fine sand bed.

(d) The Blake-Kozeny equation was found to be able to predict initial headloss with reasonable accuracy.

Clearly, further studies are needed, especially on uncharred palm kernel shells, to examine ways in which objectionable odour and taste can be removed from the effluent water. It should be noted, however, that the process as described can be very useful for the tertiary treatment of wastewaters. Optimum grain sizes of charred shells and sand still need to be ascertained.

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NOTATION

c	Residual turbidity at the port under consideration.
c_o	Turbidity of influent water.
d	Characteristic diameter of filter-media grains.
e	Porosity of filter-media grains.
g	Gravity acceleration.
H_L	Headloss across the filter-medium.
L	Depth of filter bed.
V_n	Settling velocity of a spherical particle of equal size.
V_s	Settling velocity of representative particles.
v	Approach velocity at the top of the filter bed.
μ	Absolute viscosity of fluid.
ρ	Specific gravity of filter-bed material.
ρ_w	Mass density of fluid.
ψ	Sphericity of filter-bed particles.