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Head Loss Characteristics in a Burnt Oil Palm Shell Granules Filter Compared to a Sand Filter and its Application in Rapid Filtration

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ABSTRAK

Kajian dijalankan tentang kehilangan turus awal dan kehilangan turus semasa penurasan yang berlaku di dalam penuras-penuras satu media pasir dan butiran arang tempurung kelapa sawit. Kemudian kajian yang sama dilakukan terhadap penuras dua media, gabongan pasir dan butiran arang tempurung kelapa sawit. Keputusan daripada ujikaji untuk kehilangan turus awal didapati menepati ramalan yang dicadangkan oleh formula Fair dan Hatch. Demikian juga keputusan ujikaji untuk kehilangan turus semasa penurasan hampir sama seperti yang diramalkan oleh formula Ives. Penuras dua media, gabongan pasir dan butiran arang tempurung kelapa sawit, adalah satu teknik yang kos efektif kerana ianya mewujudkan masa operasi yang lebih lama disamping mengekalkan kualiti air bermutu tinggi.

ABSTRACT

Studies were carried out on the initial head loss and the operational head loss occurring in single medium filters of sand and burnt oil palm shell (BOPS) as well as in a dual-media filter consisting of these two materials. The experimental initial head loss values in filters were shown to agree with the values predicted by the well-known Fair and Hatch formula. The characteristics of the experimental operational head loss were quite similar to the Ives's prediction. The dual-media filter proved to be a cost effective technique for water filtration due to its long running time and high quality filtered water.

Keywords: head loss, filtration, burnt oil palm shell (BOPS), potable water

INTRODUCTION

Granular deep bed filtration is commonly used for removal of particulate matter in potable water treatment and advanced wastewater treatment. The performance of deep bed filtration is described by the extent of solids removal and the subsequent increased head loss or resistance to fluid flow as a function of characteristics of water (temperature, viscosity and density), filter media (size, shape, porosity and arrangement of media) and surface properties of suspended particles. Fundamental models with head loss predictive capabilities are useful for the design and operation of the filters. The objectives of this paper are to briefly review existing models and to compare the model predictions with the results of the present study.

HYDRAULIC CONSIDERATIONS

The basic hydraulic formula for the initial head loss, h, in a single size medium filtration was developed by Darcy as follows: (Tebbut 1988)

$$\frac{h}{L} = \frac{V}{K} \tag{1}$$

A more comprehensive relationship was later developed for homogenous and stratified bed by Fair and Hatch (1933). The formula for stratified bed is

$$\frac{h}{L} = k\frac{V}{g}\upsilon\frac{(1-f)^3}{f^3}\left(\frac{6}{X}\right)^2\sum_{i=1}^{n}\frac{P_i}{D_i} \tag{2}$$

This equation predicts the head loss characteristics of a clean bed with stratified bed media. However, during a filtration process, the filter receives water containing suspended matter whereby some or all of these particulates are trapped in the bed, thus reducing the void space and increasing the head loss. Therefore the total head loss across a filter bed is the combination of initial clean bed head loss plus an additional or operational head loss due to deposits within the bed.

For a clean bed, Iwasaki (1937) showed that the removal of suspended solids is proportional to the concentration, C, of particles in suspension, which can be presented mathematically in the form

$$-\frac{\partial C}{\partial L} = \lambda C \tag{3}$$

According to Ives (1970), the additional head loss is a function of the specific deposits, σ. Thus the total head loss, H, during a filtration process is given by

$$H = H_o + \int_0^L k\sigma dL \tag{4}$$

This has been approximated as

$$H = H_o + \frac{kVC_o t}{(1-f)} \tag{5}$$

MATERIALS AND METHODS

The filter column utilized in this study was fabricated from clear perspex and equipped with a backwashing facility as shown in *Fig. 1*. The column was designed to operate as a gravity flow process with adjustable regulating valves to compensate for the increasing head loss and maintain a constant rate of flow. The influent water in this study was a mixture of kaolin clay in water with concentrations between 30 and 100 mg/l.

Initially, single media filters of BOPS with effective sizes of 0.8 and 1.0 mm and sand with effective size of 0.5 mm, both with a uniformity coefficient of 1.5, were used in the study. The depth of BOPS and sand media were 480 and 260 mm respectively. Later, a dual-media filter with a combination of BOPS in the upper layer and sand in the lower layer was studied. The depth of the dual-media filter was 380 mm with a depth ratio of 2 to 1 for BOPS and sand.

The filter column was operated at flow rates of 3 and 6 $m^3/m^2/hr$. Filter performance was monitored by observing the head loss development and measuring the filter influent and effluent concentrations at regular intervals.

Head loss build-up was measured using multiple tube manometers installed at specific intervals from the top to the bottom of the filter. The head loss build-up was observed by the differences in the readings of the water level during a filter run. Before and after every run, the filter was backwashed.

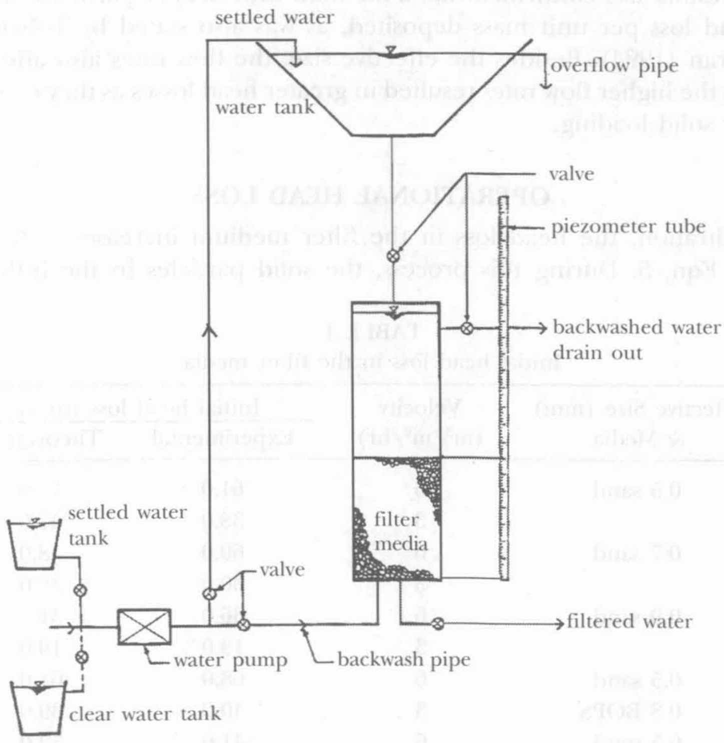


Fig. 1. Layout of the filtration model

RESULTS AND DISCUSSION

Initial Head Loss

When water passes through a clean granular porous medium, energy losses occur due to both form and drag friction at the surface of the medium. Furthermore, energy losses or pressure drops occur due to continuous contraction and expansion experienced by the fluid as it passes through pore spaces in the media. The formula developed by Fair and Hatch (Eqn. 2) was used to predict the head loss through a clean media.

The head loss depends on a wide range of variables, including porosity, size and size distribution of the granular media, the particle shape, roughness, packing arrangement, and type of flow (i.e., laminar or turbulent). The experimental and predicted results of the initial head loss are shown in Table 1. In most cases the experimental results were very close to the prediction values. The minor deviations in the results could be due to the assumptions taken in terms of the shape factor. According to Tebbut (1988), the shape factor for anthracite varies from 0.28 to 0.65 and for sand it varies between 0.73 and 0.89. In addition, the shape of the BOPS prepared was not uniform.

The results also confirmed that a medium with smaller particles size causes more head loss per unit mass deposited, as was also stated by Tobiason and Vigneswaran (1994). Besides the effective size, the flow rates also affected the head loss: the higher flow rates resulted in greater head losses as they contributed to higher solid loading.

OPERATIONAL HEAD LOSS

During filtration, the head loss in the filter medium increases with time, as stated in Eqn. 5. During this process, the solid particles in the influent are

TABLE 1
Initial head loss in the filter media

Effective Size (mm) & Media	Velocity ($m^3/m^2/hr$)	Initial head loss (mm)	
		Experimental	Theoretical
0.5 sand	6	61.0	75.0
	3	38.0	47.0
0.7 sand	6	60.0	48.0
	3	30.0	30.0
0.9 sand	6	36.0	31.0
	3	19.0	19.0
0.5 sand	6	68.0	61.0
0.8 BOPS	3	40.0	39.0
0.5 sand	6	41.0	52.0
1.0 BOPS	3	21.0	32.0

trapped in the pores between the medium granules, thus reducing the pore volume and increasing the resistance to the flow. Comparison has been made between the head loss obtained from the tests and the head loss calculated from Eqn. 5.

In the analysis, V was assumed constant since the flow rate was adjusted to be constant during the filtration process. C_o was the influent concentration at the beginning of an interval. According to Adin and Rebhun (1987), the accumulation term is a function of particle flux which may be represented by the weight of suspended solids passing through a filter layer per unit of time. Therefore, the porosity f was assumed to decrease linearly with time, starting with the porosity value of a clean filter bed. The experimental results for the three types of filters seem to be quite similar to the prediction of Eqn. 5, as can be seen in *Fig. 2a-c.*

From the manometer readings, profiles of the head loss were drawn at the various depths of a filter bed at different times throughout a filtration run. The results are depicted in *Fig. 3a, b.* For the sand medium, the effective filtration depth in which the suspended solids could penetrate was in the

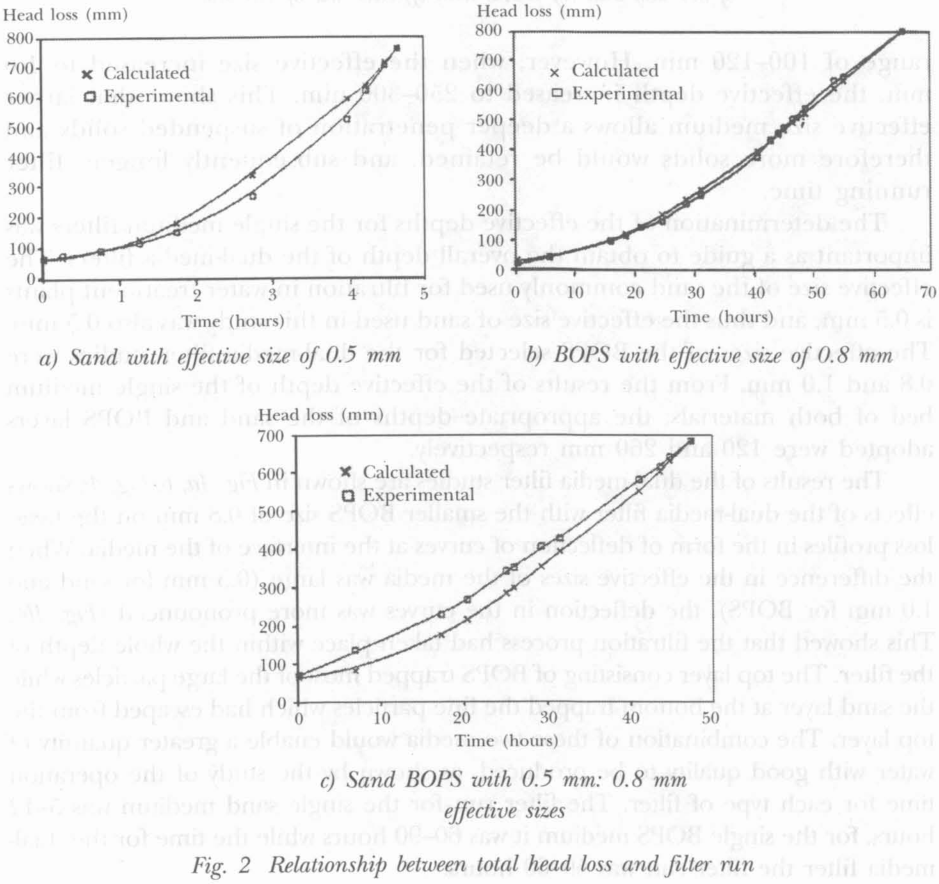


Fig. 2 Relationship between total head loss and filter run

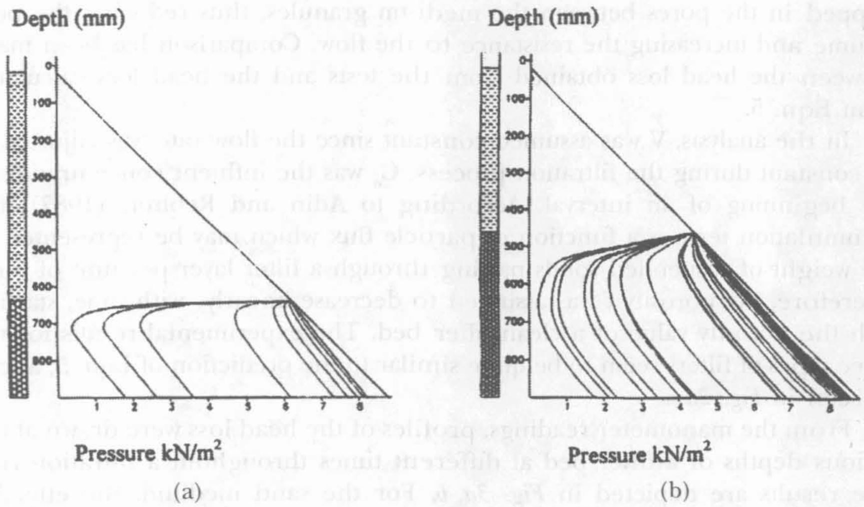
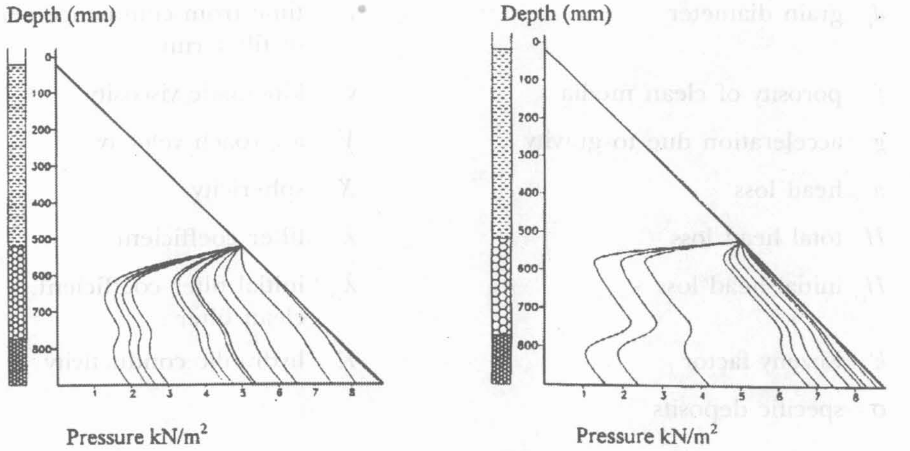


Fig. 3 Head loss profile for single medium filter; (a) sand with effective size of 0.5 mm and (b) BOPS with effective size of 1.0 mm

range of 100–120 mm. However, when the effective size increased to 1.0 mm, the effective depth increased to 250–300 mm. This shows that larger effective size medium allows a deeper penetration of suspended solids and therefore more solids would be retained, and subsequently longer filter running time.

The determination of the effective depths for the single medium filters was important as a guide to obtain the overall depth of the dual-media filters. The effective size of the sand commonly used for filtration in water treatment plants is 0.5 mm, and thus the effective size of sand used in this study was also 0.5 mm. The effective sizes of the BOPS selected for the dual-media filter studies were 0.8 and 1.0 mm. From the results of the effective depth of the single medium bed of both materials, the appropriate depths of the sand and BOPS layers adopted were 120 and 260 mm respectively.

The results of the dual-media filter studies are shown in *Fig. 4a, b*. *Fig. 4a* shows effects of the dual-media filter with the smaller BOPS size of 0.8 mm on the head loss profiles in the form of deflection of curves at the interface of the media. When the difference in the effective sizes of the media was large (0.5 mm for sand and 1.0 mm for BOPS), the deflection in the curves was more pronounced (*Fig. 4b*). This showed that the filtration process had taken place within the whole depth of the filter. The top layer consisting of BOPS trapped most of the large particles while the sand layer at the bottom trapped the fine particles which had escaped from the top layer. The combination of these two media would enable a greater quantity of water with good quality to be produced, as shown by the study of the operation time for each type of filter. The filter run for the single sand medium was 5–12 hours, for the single BOPS medium it was 60–90 hours while the time for the dual-media filter the filter run was 50–60 hours.



(a) (b)

Fig. 4 Head loss profile for dual media filter; (a) sand: BOPS with 0.5 mm: 0.8 mm effective size and (b) sand: BOPS with 0.5 mm: 1.0 mm effective size

CONCLUSIONS

The effective size of a filter medium and the flow rate are the two major factors influencing the initial head loss. Other factors may also affect the head loss but their contribution is minimal. The operational head loss is affected by the effective size and solid loading. Larger effective size produces greater effective depth of filtration. The head loss profile can be used to determine the filtration performance as well as the appropriate depths of the sand and BOPS in a dual-media filter.

The experimental initial head loss values in filters were shown to agree with the values predicted by Fair and Hatch formula. The characteristics of the experimental operational head loss were quite similar to the Ive's prediction. The dual-media filter proved to be a cost-effective technique of water filtration due to its long running time and high quality filtered water.

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NOTATION

C	concentration of particles in suspension	L	bed depth
C_o	concentration of particles in suspension, before filtration	P_i	media fraction within adjacent sieve sizes

d_i	grain diameter	t	time from commencement of filter run
f	porosity of clean media	v	kinematic viscosity
g	acceleration due to gravity	V	approach velocity
h	head loss	X	sphericity
H	total head loss	λ	filter coefficient
H_o	initial head loss	λ_o	initial filter coefficient, clean filter
k	Kozeny factor	K	hydraulic conductivity
σ	specific deposits		

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