

COMPERATIVE PERFORMANCES OF SINGLE AND DUAL MEDIA FILTERS OF SAND AND BURNT OIL PALM SHELL

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Abstract. Filtration is a common unit operation in water treatment plant. The most widely used filter media is in granular form such as sand, anthracite, coal, magnetite, garnet and coconut shells. The effectiveness of granular filter media in treating surface water has been already well established. However, there is a need to find an alternative source of granular filter media, since the costs of operation and water production have increased from time to time. Currently, a study has been conducted on palm shell as potential granular filter media. Palm shell is one of the industrial waste that is abundantly available. In this study, sand and burnt oil palm shell (BOPS) were used as single and dual media filters at different effective sizes, E_s (*i.e.* E_s of 0.4 and 0.6 for sand, E_s of 1.0 and 2.0 for BOPS) and flow rates (*i.e.* 10 and 15 $m^3/m^2 \cdot hr$). The performances of filter are influenced by filter bed depth, influent water quality, flow rate and effective size. Result suggests that all the filters are capable of producing water with acceptable turbidity unit (<1 NTU). The total running time and filtrate water quality produced by BOPS/sand dual media filter is much better than BOPS and sand single media filters (*i.e.* running time of BOPS/sand is four to nine times greater than single media filter).

Keywords: Single media filter; dual media filter; sand; BOPS; turbidity; rapid filtration

Abstrak. Penurasan merupakan unit operasi utama bagi loji olahan air. Media penuras yang lazim digunakan adalah berbentuk butiran seperti pasir, antrasit, arang, magnetik, garnit dan tempurung kelapa. Prestasi penuras media berbentuk butiran telah terbukti berkesan. Walau bagaimanapun, keperluan media penuras alternatif yang kos efektif masih diperlukan memandangkan kos operasi dan kos pengeluaran air sentiasa meningkat dari semasa ke semasa. Dewasa ini kajian telahpun dijalankan terhadap potensi butiran arang tempurung kelapa sawit sebagai media penuras. Bahan ini merupakan sisa buangan pepejal yang terdapat dengan banyaknya hasil dari pemprosesan industri minyak sawit. Dalam kajian ini, pasir dan butiran arang tempurung kelapa sawit (BOPS) telah digunakan sebagai penuras satu-media dan penuras dua-media pada beberapa saiz efektif, E_s (iaitu E_s 0.4 dan 0.6 untuk pasir, E_s 1.0 dan 2.0 untuk BOPS) dan kadar alir (iaitu 10 dan 15 $m^3/m^2 \cdot jam$). Prestasi penurasan adalah dipengaruhi oleh ketebalan penuras, kualiti air influen, kadar alir air dan saiz efektif media penuras. Keputusan menunjukkan bahawa penuras mampu menghasilkan kualiti air yang tinggi (<1 NTU). Jumlah masa penurasan dan kualiti air tertapis bagi penuras dua-media BOPS/pasir merupakan kombinasi lebih baik berbanding penuras satu-media BOPS dan penuras satu-media pasir

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(iaitu tempoh operasi bagi penuras dua-media BOPS/pasir adalah empat hingga sembilan kali lebih lama daripada penuras satu-media pasir).

Kata kunci: Penuras satu-media; penuras dua-media; pasir; BOPS; kekeruhan; penuras cepat

1.0 INTRODUCTION

In water treatment plant, filtration is a process commonly used for removal of relatively small flocs or particles after sedimentation process. Historically, filters are able to remove particulates, bacteria, chemical added in the pre-treatment, algae, iron and manganese oxides, colloidal humic compounds, viruses, radioactive particles, asbestos fibers, heavy metals, colloidal clay particulates, and others, provided that proper design parameters are used. In this paper the focus is on particulate removal since it can act as housing and food sources for bacteria which potentially affect the health of consumers. Moreover, particulates may cause distribution systems fouling at high bacteria level and corrosion [1].

Screens, diatomaceous earth and granular are the types of filter media being used. Polyethylene, stainless steel and cloth are examples of screen filter media, while diatomaceous earth media is normally from siliceous fossil remains [2]. However, the most commonly used filter media is in granular form such as sand, anthracite, coal, magnetite, garnet sand and coconut shells. All filter media have similar operating process characteristic where the particulates accumulate on or/and in the filter media, the filter effluent turbidity and pressure drop increase until either a pre-selected turbidity or head loss value is exceeded, and followed by backwash. The time to reach a limiting head loss is equivalent to the time to reach a specific effluent quality, which is known as optimization stage where the production of water reaches optimum level [3]. The mechanisms involved in filter bed are straining, adhesion, sedimentation, inertial impaction, hydrodynamic forces, diffusion and interception [4].

To design a filtration system that achieves an optimization stage, an understanding and knowledge on filter efficiency is extremely crucial especially when there are many factors influencing the filtration process. Generally, filter efficiency depends on the characteristics of liquid, suspended matters and filter media. The important properties include size and shape of grain, porosity of filter bed and arrangement of grains whether from fine to coarse or vice versa.

Typical granular filter in water treatment plant is either single or dual media. Although the existing granular filter media is sufficient to treat turbid water, discovering an alternative filter media from local source is also highly essential since it will help to reduce the cost of treatment, as it can be processed and produced locally. In this current study, palm shell is identified as a potential filter media. Palm shell is well known as a local solid waste material which is abundantly available in palm oil industry. The effectiveness of single and dual media filters by using sand and burnt oil palm shell (BOPS) were carried out in a local water treatment plant in Malaysia. This filtration unit was installed after sedimentation unit operation.

The objective of this study is to evaluate the performance of various filter media, that is single sand filter, single BOPS filter and dual media filter of BOPS and sands by assessing the effect of effective sizes, filter media and flow rates towards total running time, filtrate quality and head loss.

2.0 MATERIALS AND METHODS

Palm shells were burnt in a furnace at 300°C without oxygen and then grounded into granules before sieving to establish particles size distribution curve. Burnt oil palm shell and sand were graded into specific uniformity coefficient and effective sizes. The effective sizes for sand were 0.4 and 0.6 mm, and 1.0 and 2.0 mm for BOPS. Both sand and BOPS have the same uniformity coefficient of 1.5. Dual media was then prepared by combining BOPS and sand into a single filter bed. Effective sizes for BOPS/sand were 1.0 mm/0.5 mm and 2.0 mm/0.5 mm. The specific gravity for sand and BOPS were 2.65 and 1.40, respectively.

Overall, there are six filters prepared for investigation: two from sand single media filters; two from BOPS single media filters; and two from BOPS/sand dual media filters. Each filter media was placed into a filtration unit (placed after sedimentation tank) to determine the optimum bed depth of filtration for their specific effective sizes. The constructed filtration process unit was presented in Figure 1. The settled water

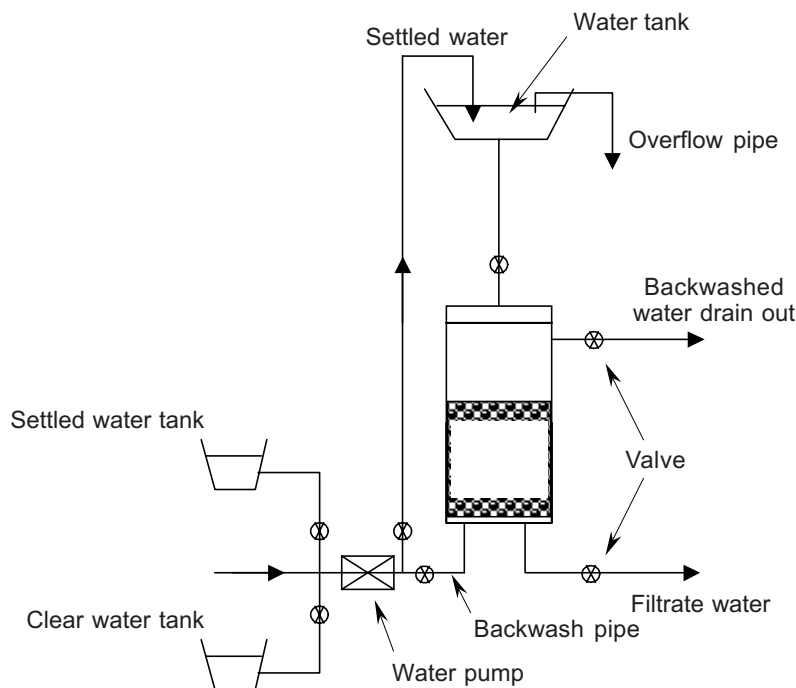


Figure 1 Layout of filtration unit

was used during filtration process and the clean water was used only for backwashing operation. This system requires a water pump to lift the settled water to the top of filter (water tank) and then the rest of the system is governed by gravity flow. The whole system was designed so that the hydraulic requirements were similar to proper unit operation in water treatment plant. The respective optimum bed depths for various effective sizes were then subjected to two different operating flow rates that were 10.0 and 15.0 m³/m²/hr. Common filtration in rapid sand filters range from 2.5 to 5.0 m³/m²/hr [5]. Therefore, current studies were considered rapid filtration since its flow rates were two to threefold of the normal rapid filtration flow rates.

During the filter operation, influent turbidity (settled turbidity), effluent turbidity (filtrate turbidity) and head loss at different heights of bed depth were recorded at different time intervals. The filtration system was backwashed when either pre-selected filtrate turbidity (1.00 NTU) or head loss (240.0 – 300.0 mm) was exceeded.

3.0 RESULTS AND DISCUSSION

The evaluation on the rapid filtration performances of single and dual media filters by using sand and BOPS as filter media are addressed with respect to optimum bed depth, water quality, running time and head loss. In addition, some of these factors are indirectly incorporated with the effects of flow rate and effective size.

By operating the filter column with specific influent turbidity for around 30 minutes of filter run, the effluent turbidity became stabilized. This was followed by conducting sampling of water samples at different heights of filter bed depth. When these water samples were subjected to the determination of turbidity, it was observed that the turbidity decreased gradually and later stabilized when optimum bed depth is reached.

As shown in Table 1, it is observed that there is a relationship between effective size and optimum bed depth. For all filter media, the increment of effective size generates a higher value of optimum filter bed depth. Although this is an easy step, its contribution shall not be taken lightly since utilizing greater bed depth of filter will increase cost of treatment as well as causes rapid increase of unwanted negative pressure or head loss in the filter media.

Table 1 Optimum depths for single and dual media at different effective sizes

| Filter media | Effective size (mm) | Optimum bed depth (cm) |
|--------------|---------------------|------------------------|
| Sand | 0.4 | 58.0 |
| | 0.6 | 66.0 |
| BOPS | 1.0 | 60.0 |
| | 2.0 | 80.0 |
| BOPS/sand | 1.0/0.5 | 60.0 |
| | 2.0/0.5 | 70.0 |

Observation on the changes of settled and filtrate turbidity with running time revealed that the influent turbidity of BOPS single media filter has a slight effect on the filtrate turbidity. However, this effect was less pronounced on sand single media filter. In fact, for BOPS/Sand, influent turbidity has no influenced on the dual media filter and this is mainly due to the presence of sand at the bottom of the filter.

For all filters, the quality of filtrate water produced follows this sequence: $FW_{BOPS/sand} > FW_{sand} > FW_{BOPS}$ (Figures 2, 3 and 4). The filtrate water produced by BOPS/sand media filter suggests that dual media filter is more reliable in producing a high quality water as compared to single media filters. The effectiveness of BOPS/sand is clearly presented in Figure 4, where the influent turbidity was reduced from 0.80 – 5.60 NTU to 0.09 – 1.10 NTU, after filtration.

The overall results of filtrate water quality produced by sand and BOPS in single and dual media filters were less than 1.00 NTU, which is within the limit recommended by WHO for drinking water quality for effective disinfection [6]. Only few filtrate water turbidity data recorded were greater than 1 NTU: 0 out of 49 turbidity data on sand single media filters, 3 out of 65 turbidity data on BOPS single media filters and 0 out of 84 turbidity data on BOPS/sand dual media filters, greater than 1.00 NTU for both flow rates (10.0 and $15.0 \text{ m}^3/\text{m}^2/\text{hr}$). The filtrate water quality produced by BOPS single media filters was less than the sand single media and BOPS/Sand dual media filters filtrate water quality. This is most probably due to the usage of larger effective size of BOPS compared to sand and also poorer quality of settled water (influent water) before entering BOPS single media filter.

Apart from evaluation on the water quality produced by rapid filtration, running time is another factor which contributes towards the effective performances of single and dual media filters. Running time normally known as operation time is defined as

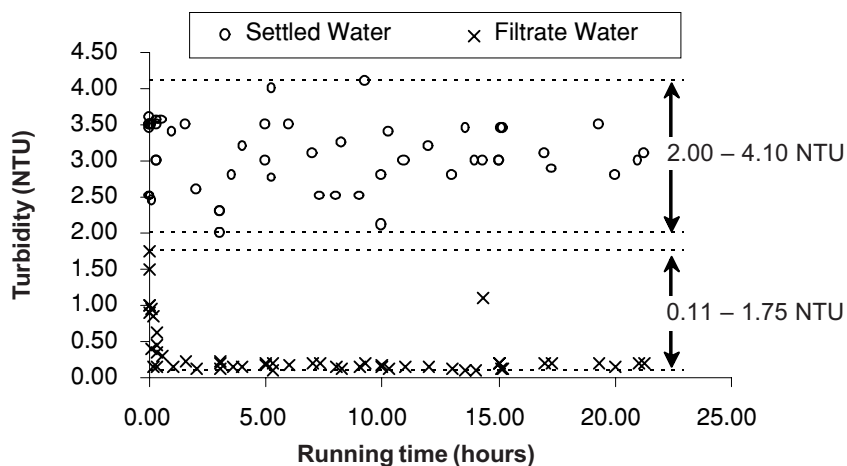


Figure 2 Settled and filtrate water turbidity for sand single media filters, 0.4 and 0.6 mm effective sizes at different flow rates (10.0 and $15.0 \text{ m}^3/\text{m}^2/\text{hr}$)

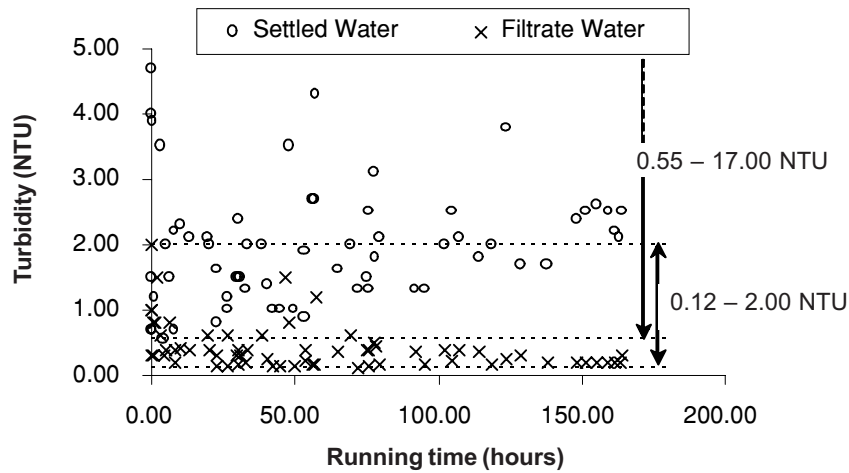


Figure 3 Settled and filtrate water turbidity for BOPS single media filters, 1.0 and 2.0 mm effective sizes at different flow rates (10.0 and $15.0 \text{ m}^3/\text{m}^2/\text{hr}$)

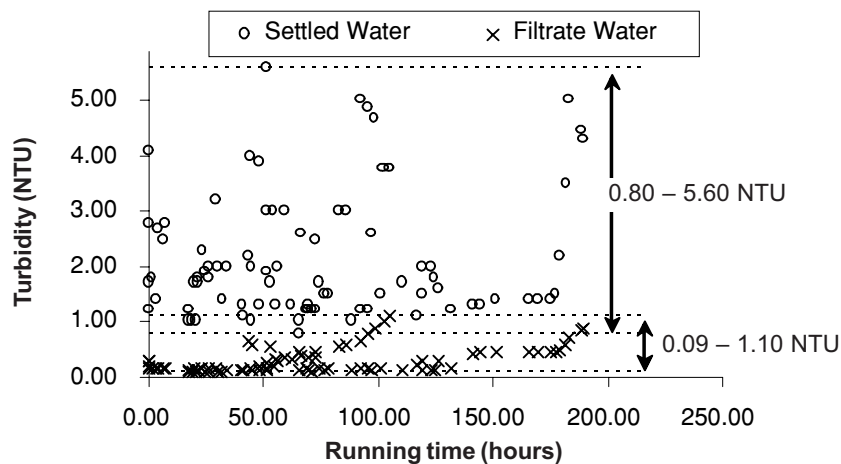


Figure 4 Settled and filtrate water turbidity for BOPS/sand dual media filters, 1.0/0.5 and 2.0/0.5 effective sizes at different flow rates (10.0 and $15.0 \text{ m}^3/\text{m}^2/\text{hr}$)

time between the beginnings of filtration until the filter either head loss reaches $240.0 - 300.0 \text{ mm}$ or filtrate water turbidity reaches 1.00 NTU . Running time is affected by size grain or effective size, filter bed depth, flow rate of settled water, concentration of settled water, flocs strength, deposit density, porosity and types of media used, but current study is only concentrated on effective size, influent water flow rate and media filter types.

Table 2 shows the total running time achieved for single and dual media filters for the particular total head loss and final filtrate turbidity values. Among all filters, sand media filter (at 0.4 mm effective size and $10.0 \text{ m}^3/\text{m}^2/\text{hr}$ flow rate) and BOPS/sand

dual media filter (at 2.0 mm/0.5 mm and 15.0 m³/m²/hr) were stopped for backwashing due to the final filtrate turbidity exceeding 1.00 NTU while other media filters were backwashed due to the 240.0 – 300.0 mm head loss achieved. To design a rapid filtration system that can achieve an optimize stage for total head loss and final turbidity to breakthrough at the same time, extended study on total running time of the filters at different effective sizes must be came out at different filtration rate for particular source of water quality.

Table 2 Running time, total head loss, final filtrate turbidity for single and dual media at different effective sizes and flow rates

| Media | E _s (mm) | Flow rate (m ³ /m ² /hr) | Total running time (hours) | Total head loss (cm) | Initial filtrate turbidity (NTU) | Final filtrate turbidity (NTU) |
|-----------|------------------------|---|-------------------------------------|-------------------------------|---|---|
| Sand | 0.4 | 10.0 | 14.30 | 163.0 | 0.14 | 1.11 |
| | | 15.0 | 15.18 | 280.0 | 0.85 | 0.12 |
| | 0.6 | 10.0 | 21.30 | 274.0 | 0.62 | 0.19 |
| | | 15.0 | 21.00 | 268.0 | 0.34 | 0.20 |
| BOPS | 1.0 | 10.0 | 123.50 | 265.0 | 0.30 | 0.26 |
| | | 15.0 | 53.42 | 265.0 | 0.80 | 0.26 |
| | 2.0 | 10.0 | 164.25 | 249.5 | 0.80 | 0.30 |
| | | 15.0 | 77.75 | 247.0 | 0.60 | 0.50 |
| BOPS/sand | 1.0/0.5 | 10.0 | 132.00 | 265.0 | 0.21 | 0.18 |
| | | 15.0 | 72.50 | 245.0 | 0.17 | 0.36 |
| | 2.0/0.5 | 10.0 | 189.25 | 252.0 | 0.28 | 0.90 |
| | | 15.0 | 102.25 | 234.0 | 0.28 | 1.00 |

It is observed that smaller effective size for particular flow rate and filter media has lower total running time while smaller flow rate for particular effective size and media filter has higher total running time, except 0.4 mm effective size of sand (Table 2). Although it is not logical to compare the total running time of different filter media at different effective sizes, the study suggest that existing effective sizes and flow rates of dual media filter of BOPS/sand gives the highest total running time when compared to single media filters of sand and BOPS.

It is known that pressure of liquid increases as depth of liquid increases. Pressure varies linearly with height of water. But when filter media was placed into the filter column, pressure drop was observed (at particular flow rate) which is known as initial head loss. As the filtration process continues, the removal of turbidity on the filter media generates pressure curves that concave to the left. Boller and Kavanaugh [7] have demonstrated that the rate of head loss build-up in a granular media filter, for a constant mass of solids being removed, is strongly dependent on the size of the particulates in suspension and the size of the granular media. Beside, Bai and Tien [8]

found that deposition in deep-bed filtration depends on both particle size and influent concentrations. However, in this experiment the size of particulates were kept constant. All these were observed for BOPS and sand in single and dual media filters (Figures 5, 6 and 7).

From BOPS single media filter (Figure 5), it is observed that the peak of head loss curves or also known as active zone takes place in the middle of filter bed depth, which revealed filtration process was well distributed from the surface and increased to peak in the middle of filter bed depth. However, for sand single media filter (Figure 6), it is observed that the peak is slightly lower or closer to the surface of filter. When both the particle and pore size distribution are of the Raleigh type, it is reported that the straining of the particles with Brownian motion behavior at the small pores were enhanced, thus resulted in higher permeability reduction [9, 10]. This suggests that most of the filtration process took place on the shallow surface of the filter. The flocs that are entrapped on the top of the sand single filter media eventually act as a new layer of filter and therefore, filtrate quality became better until an optimum storage level is achieved before breakthrough.

In BOPS/sand dual media filter (Figure 7), it is found that the head loss for sand increases more rapidly than BOPS. This is probably be due to the fact that effective size of sand is smaller than BOPS. Moreover, the peak of head loss for sand in dual media filter is nearly in the the middle of sand media height. During filtration process, the flocs with bigger size were entrapped by BOPS media in the upper layer and the flocs with smaller size were able to travel deeper in the filter bed. This leads to development of active zone at deeper filter bed height. Subsequently, it is found that the active zone

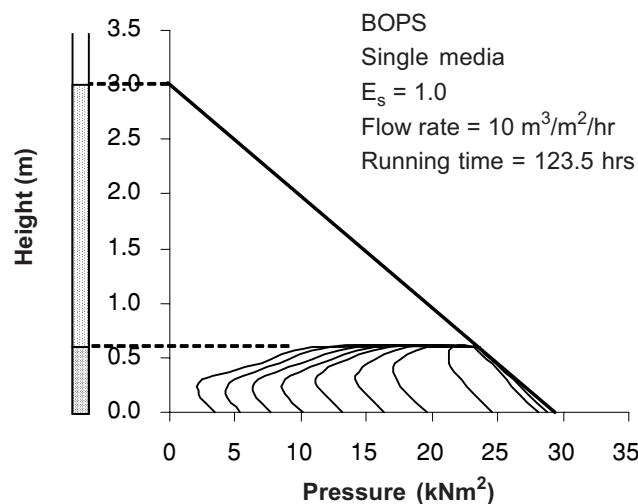


Figure 5 Profile terminal head loss of BOPS single media filter at $10 \text{ m}^3/\text{m}^2/\text{hr}$ flow rate and 1.0 mm effective size

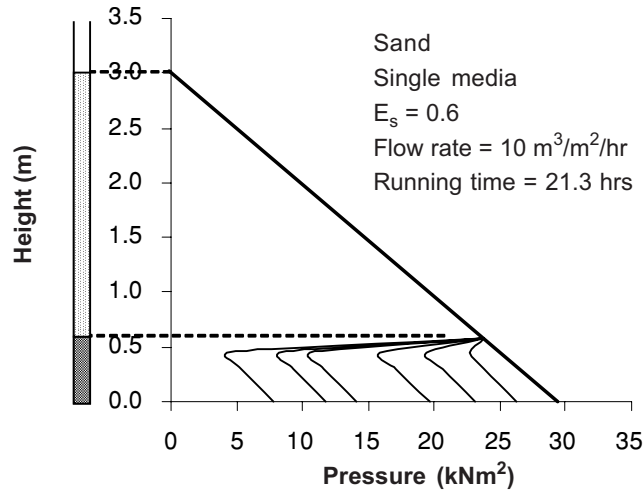


Figure 6 Profile terminal head loss of sand single media filter at $10 \text{ m}^3/\text{m}^2/\text{hr}$ flow rate and 0.6 mm effective size

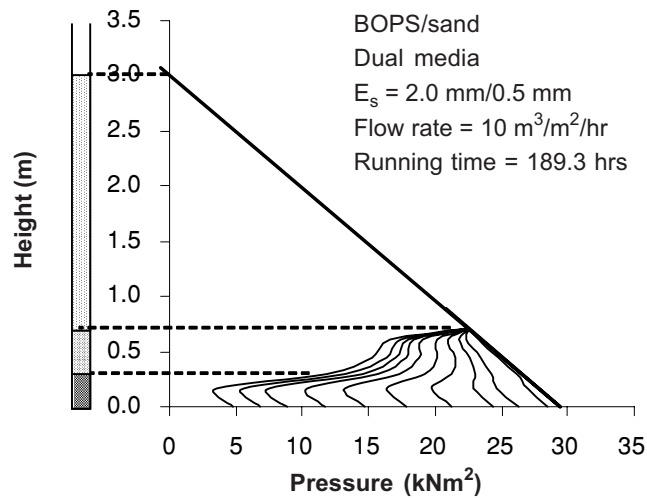


Figure 7 Profile terminal head loss of BOPS/sand dual media filter at $10 \text{ m}^3/\text{m}^2/\text{hr}$ flow rate and 2.0 mm/0.5 mm effective size

for sand is transferred from shallow surface into the middle of sand height and therefore, the running time for the operation unit is increased significantly.

4.0 CONCLUSION

Although all types of filters studied at two different flow rates and effective sizes were capable of producing water quality less than 1.00 NTU, the total running time varies

significantly with different effective sizes, flow rates and types of media used. In the aspect of total running time and filtrate water quality, it is found that BOPS/sand dual media filter is a better solution in treating turbid water, since it consists of BOPS as top filter media layer (capable of removing flocs with bigger sizes) and sand as bottom filter media layer (removing flocs with smaller sizes). With this combination, the operation time of the filter is extended and the quality of water produced is still within the acceptable limits. Eventually, the cost of operation is reduced and the quantity of water produced increases significantly.

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