The Malaysian Journal of ANALYTICAL SCIENCES ISSN 1394-2506

EFFECT OF CHITOSAN BINDER ON WATER ABSORPTION OF EMPTY FRUIT BUNCHES FILTER MEDIA

(Kesan Kitosan Sebagai Pengikat Keatas Penjerapan Air Media Penapis Tandan Kosong Kelapa Sawit)

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Abstract

The potential of chitosan as filter media binder was investigated in this study. Chitosan solution with different concentrations were applied to the empty fruit bunches using two different deposition techniques, namely, spray method and addition method. In this study, a water absorption test was used to study the sorption behaviour of empty fruit bunches filter media. The water absorption study showed that the water uptake for empty fruit bunches filter media without the chitosan binder increases with time, until the water sorption reaches the equilibrium state. It was observed that the water uptake decreased from 23% to 14% for the chitosan-filled filter media as compared to binder-less filter media, over the duration of 24 hours. For 1% chitosan concentration, the water uptake is higher compared to 3% chitosan-filled filter media. The water absorption is relatively lower for filter media with a higher concentration of chitosan due to the high compatibility achieved at this interfacial region between empty fruit bunches fibres and chitosan. Alkali-treated filter media showed the lowest water uptake compared to diethyl ether, ethanol and hot water pretreatment methods.

Keywords: empty fruit bunch, filter media, chitosan, water absorption

Abstrak

Potensi kitosan sebagai pengikat media penapis telah dikaji dalam kajian ini. Pelarut kitosan dengan kepekatan yang berbeza telah digunakan untuk tandan kosong buah kelapa sawit dengan menggunakan dua teknik penyaduran yang berbeza, iaitu, kaedah semburan dan kaedah tambahan. Dalam kajian ini, ujian penyerapan air digunakan untuk mengkaji kelakuan serapan media penapis dari tandan kosong buah kelapa sawit. Kajian penyerapan air menunjukkan bahawa pengambilan air untuk tandan buah kosong penapis media tanpa pengikat kitosan meningkat dengan masa, sehingga penyerapan air mencapai keseimbangan. Diperhatikan bahawa pengambilan air sepanjang 24 jam, menurun daripada 23% kepada 14% untuk media penapis berisi kitosan berbanding media penapis tanpa pengikat. Untuk kepekatan 1% kitosan, serabut media mempunyai jurang lebar yang lebih tinggi berbanding dengan penapis kitosan yang berkepekatan 4%. Penyerapan air untuk penapis media dengan kepekatan yang lebih tinggi adalah rendah kerana keserasian yang tinggi dicapai pada rantau di antara permukaan serat tandan kosong kelapa sawit dan kitosan.

Kata kunci: tandan kosong kelapa sawit, media penapis, kitosan, penjerapan air

Introduction

The application of non-woven media in filtration has become increasingly popular. Non-woven manufacturing capability has made significant strides in the last few years allowing for the production of filtration media that has both a performance and cost advantage over traditional materials for filter manufacture. There is a wide range of industries that use non- woven media for liquid filtration applications. They range from food and beverage, biotechnology, pharmaceutical, potable water, hydraulic oils, fuels, solvents, acids and bases. Each application has a different contaminant that must be removed. However, due to strong emphasis on environmental awareness worldwide, it has brought much attention in the development of recyclable and environmentally sustainable filter materials. Most of the currently available filter media in the market are made of synthetic polymers. Many of these polymers and fibers are petroleum-based and do not break down in nature after disposal. End of life disposal of these filter media is becoming critical and expensive. The engineering challenge in replacing conventional synthetic filter media by biodegradable or natural materials is to develop filter that are fully functional and structurally stable during filtration process. The ultimate challenge is to do so in a cost effective and environmentally-friendly manner in order to win public and political acceptance and still compete with the existing dominating filter media in the markets.

Several studies have attempted to use low cost, easily available materials for the removal of metal [1], hexavalent chromium [2], cadmium [3], dye [4] and nutrient [5] from domestic and industrial wastewater at different operating conditions. Many studies have also been conducted on the wastewater treatment or potable water treatment with depth filters, in which the packing material is an ensemble of fibres. Results have demonstrated that these filters are effective in removing nutrients, particulates and heavy metal species whilst they are supposedly inexpensive, recyclable, biodegradable and sustainable.

Lignocelluloses material exhibit interesting capacities as pollutant adsorbents, whilst chemical modification of lignocelluloses materials has been shown to improve their performance. Recently, a new treatment using lignocelluloses filter media and metal membrane filters was investigated in relation to the reuse of grey water and rainwater in a cost effective manner [6]. Chemical modification of the recycled wood fibres filter using aluminium oxide was performed to enhance the removal of phosphate and heavy metals. It appears that the fibre filter media not only rejected particulate pollutants but also removed soluble ions. The fibre filter media is known to remove contaminants in rainwater through an ion exchange mechanism. Cation exchange reaction occurs for metal removal and anionic exchange occurs for nitrogen and phosphate removal. The approach successfully addressed the sustainable water management whilst the employed lignocelluloses biomass has shown great possibilities to lower the cost of water treatment and secure sufficient amounts of alternative water resources.

A recent study has seen Riahi et. al. (2009) investigate the application of date-palm fibres filtration as an efficient method for the economic removal of turbidity, phosphorus, organics in term of COD and helminth eggs of secondary domestic wastewater from an activated sludge treatment process [7]. Column experiments were used to study the efficiency of the fibres for the removal of targeted matter under operational conditions, namely flow rate, filter depth, and diameter of the fibres. The results indicated that the diameter of the fibres represented the most significant factor affecting the removal of targeted matter. Pilot test results indicated that date-palm fibres filtration removed up to 54.9% of turbidity, 80% of COD, 57.7% of phosphorus and 98% of helminth eggs. In comparison with traditional granular media filters, because of its elasticity, the date-palm fibres filters allow for higher filtration rate, lower head loss, and longer filtration run time. Due to the low density of these materials, the date-palm fibres filters can be backwashed at a much lower backwash water flow rate than the conventional sand filter. The low backwash water flow rate reduces the size of the backwash water pump and the power requirement. It could certainly be concluded that the date-palm fibres could offer an appreciable economic and environmental potential. This study focused the effect of chitosan on the water absorption of the filter media. The study also examine the effect of alkali, diethyl ether, ethanol and hot water pretreatment on the water absorption properties of fibrous filter media from empty fruit bunch fibers.

Materials and Methods

Fibers Preparation

The lignocelluloses used in the study are empty fruit bunches (EFB). They are obtained freshly from Sabutek (M) Sdn Bhd. The EFB were obtained in the form of long strands of fibres. The fibres were dried in the oven at 60°C to remove the moisture content. The fibres were oven dried until the weight of the fibres was constant. Then, the fibres were ground into small particles using a grinding machine and sieved to 2 mm and 10 mm mesh sizes. The EFB was then re-dried in the oven for 24 hours and stored in an air-tight container that contained silica gel in order to prevent moisture attack.

Binder Preparation

In order to study the effect of chitosan addition on the water absorption of the non-woven EFB filter media, different concentrations of chitosan solution were prepared. Chitosan of deacetylation degree DD = 75% in the form of powder, was dissolved in a 1 % (w/v) aqueous acetic acid to obtain 1 % (w/v) to 3 % (w/v) of chitosan solutions. The resulting solution was stirred at room temperature for about 6 hours. The resultant bright yellow solutions with different viscosities were then carefully filtered.

Filter Formulation

Binder-less non-woven filter media are formed from the slurry of the fibres in water. The wet lay-up method was adopted for filter fabrication following the TAPPI Test Method T205. The fibres were suspended in water in a deckle box so that the fibres would be distributed evenly across the box. A deckle box is a bottomless frame that is placed over a screen. A mat was formed on a fabric mesh (screen) as the water was flushed out at the bottom of the box. Randomly oriented mat fibres were prepared by using a forming box of 90 mm × 90 mm. The mat was then dried in an oven at 105^{o}C for approximately 24 hours before being pressed in a Carver Laboratory Press to obtain a more condense mat with varying thickness. The binder-less filter media was then characterised and subsequently tested in the permeability experiments.

Chitosan solution was applied to the fibre using two different deposition techniques. The first method was spray application. The wet lay-up method is a classical 'contact method' that involves deposition of the fibres in a rectangular mould and its physical impregnation with the liquid binder. In this method, still-wet fibres on the blotter were sprayed with the chitosan solution of various compositions. At this point the mat contained about 30% fibre and 70% water, which allowed rapid and uniform distribution of sprayed chitosan solution within the wet fibre web. While still moist, the filters were removed intact from the screen and dried in an oven for 24 hours at 105^{o}C.

The second method is the addition of chitosan in the slurry of the fibres in water. The fibres were weighed and dispersed in a known quantity of water in a slurry tank using a stirrer set up. The slurry was continuously stirred for about 15 min. Once the fibres were dispersed evenly, a known quantity of the chitosan was added to the slurry. The slurry was stirred for an additional 30 minutes prior to forming the filters to ensure sufficient mixing of the ingredients to obtain good media uniformity. The slurry was then filtered to form a medium. The formed medium was then thermally baked in the oven at 105^{o}C for 24 hours to evaporate all the water and to bind the fibres together. The chitosan-filled filter media was then characterised and subsequently tested in the filtration experiments.

Water Absorption Study

Water absorption studies were carried out for both binders-less and chitosan-filled fibrous filter media from untreated and treated empty fruit bunches fibres. The test was carried out by using standard ASTM Designation D 570-98. The absorbency of the sample was measured as water absorbency (WA) ratios. The test specimens were in the form of a bar (76.2 mm × 25.4 mm) were weighed and immersed in 500ml of distilled water at room temperature. They were removed at 12 hour intervals, being gently blotted with tissue paper to remove the excess water on the surface, and then the weight was recorded. Three replicates were tested, and the results were presented as an average of three. The filter media from untreated fibres was used as a control in this study. The effect of binder, method of binder application, fibre size and filter thickness on the percentage of water sorption were highlighted in this study.

Results and Discussion

Water sorption in filter media receives considerable attention owing to its theoretical and practical significance, as they are important for wastewater treatment application. Water sorption has significant effects on physical properties of the filter media and can affect the matrix structure and the fibre-matrix interface resulting in changes of bulk properties, such as dimensional stability and mechanical properties [8]. Water sorption in a fibrous filter media is dependent on temperature, fibre loading, area of exposed surfaces, duration of the immersion, processing techniques, diffusivity, and surface morphology of the fibres and the structural arrangement of the fibres within the matrix.

Figures 1 shows the effect of chitosan on the water sorption of the chitosan-filled fibrous non-woven filter media using spray method. The figure shows that the rate of water sorption for fibrous non-woven filter media could be conveniently divided into three main phases. Phase one is corresponding to the highest rate of water sorption occurring during the first day of immersion time. In this phase, the increasing rate of water sorption was observed with time. The second phase, where the rate of water sorption is slower than the first phase with a decreasing rate, was observed with time until the equilibrium state was reached. Phase three was where the rate of water absorption was zero and there was no longer water sorption occurring; the water content in the fibrous filter media became saturated.

From Figure 1, it is clearly seen that the water uptake for untreated empty fruit bunches fibres filter media without the chitosan binder increases with time, until the water sorption reaches the equilibrium state. The water sorption of empty fruit bunches fibres is greatly affected by its morphology, both on physical and chemical structures [9]. Empty fruit bunches fibres being lignocelluloses are highly hydrophilic in nature and are easily permeable to water. Empty fruit bunches fibres are lignocelluloses having 65% cellulose, 19% lignin content and waxy materials [10]. The fibre is highly hydrophilic due to its polarity owing to the free hydroxyl groups from cellulose and lignin. These hydroxyl groups can hold water molecules by hydrogen bonding. The authors reveal that oil palm fibre surface has micro-pores on its surface structure that facilitates the capillary action of water during the sorption. At the same time, the porous internal structure and cross sections of the fibres also facilitate the access to the penetrating water. In addition, the waxy materials present on the fibre surface also help to retain the water molecules onto the fibre.

The Figure 1 also shows that the water sorption increased with soaking time for chitosan-filled fibrous filter media. It has been noticed that when chitosan was added into fibrous filter media, the degree of water sorption was lower compared to that of binder-less filter at the first day of soaking time. It was observed that the water uptake decreased from 23% to 14% for the chitosan-filled filter media as compared to binder-less filter media, over the duration of 24 hours. One of the reasons could be attributed to the formation of intra-hydrogen and inter-hydrogen in chitosan-filled filter media that restricts the moisture sorption by water and consequently reduces the water uptake by the chitosan-filled filter media. Pure chitosan is hydrophilic [11], however, the strong hydrogen bonding in the chitosan-filled filter media is likely to reduce the water sorption. Beyond 24 hours interval time, the water sorption of fibrous filter media has similar trends with binder-less filter media, where the water absorption increases gradually until the equilibrium state is reached.

It is interesting to note that the percentage of water sorption is slightly lower for chitosan-filled fibrous filter media as compared to binder-less filter media and the percentage decreases as the chitosan concentration increases. When the chitosan-filled filter media immersed in water, it caused de-bonding between the chitosan matrix and the EFB fibres. This de-bonding encouraged the fibre to absorb water, expand and created voidage. This process will then weaken the interfacial adhesion between the matrix and the fibre and sorption of water will then reach its maximum level and maintain at this stage. However, the water absorption is relatively lower for filter media with a higher concentration due to the high compatibility achieved at this interfacial region between empty fruit bunches fibres and chitosan. In addition, the higher concentration of chitosan would promote a strong electrostatic attraction between opposite-charged groups present in chitosan and cellulose fibre in the filter network.

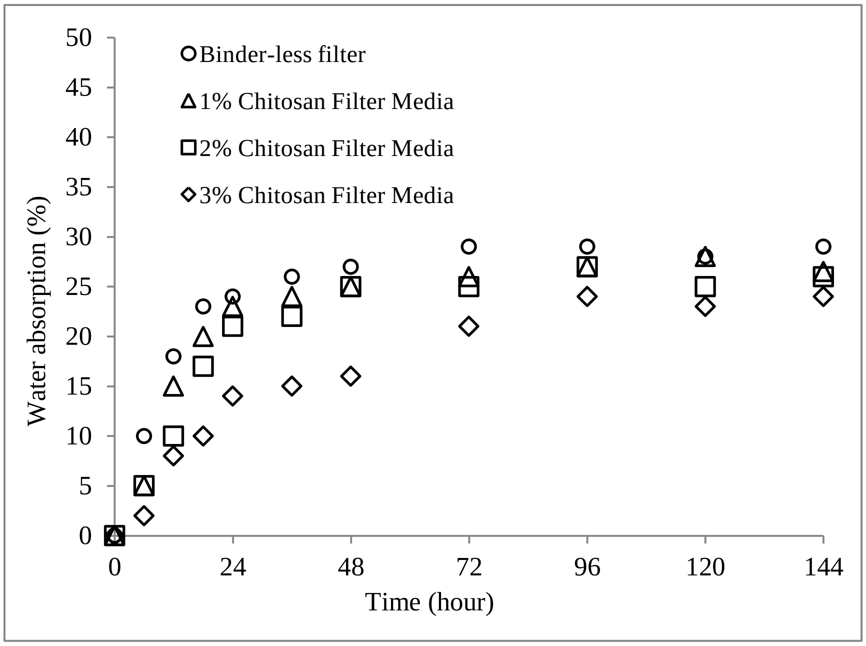
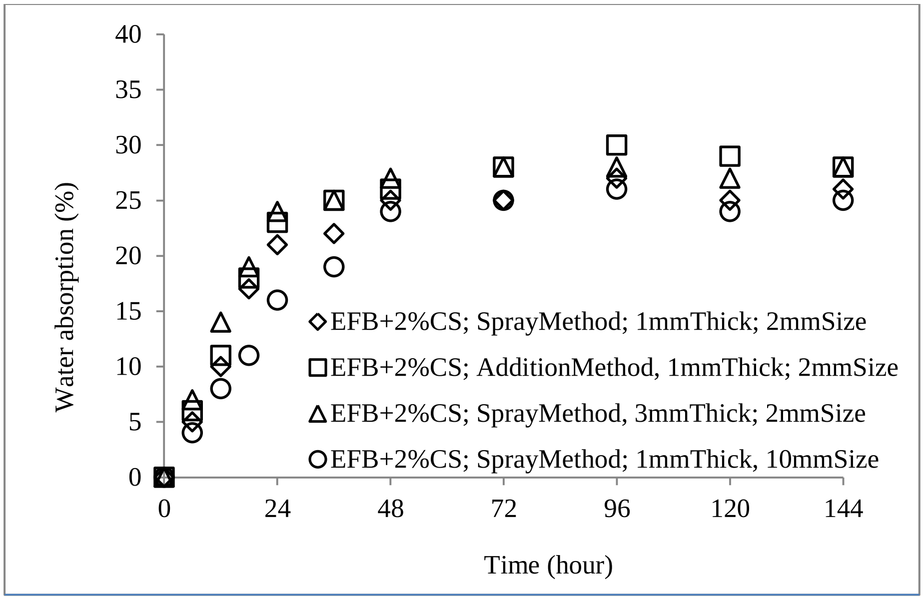


Figure 1. The effect chitosan concentration on the water sorption of the untreated filter media (spray method, 1-mm thick, 2-mm size)

From the Figure 2, the result shows that the incorporation of chitosan in the spray method on the filter media exhibits lower water uptake compared to the addition method for 2mm size and 1 mm filter thickness. The application of chitosan using the spray method will reduce the capability of the filter media to absorb water, which can be attributed to the formation of a thin layer of chitosan content on the surface of the filter media. The thin layer of chitosan increases the concentration of NH_2 and OH groups present in chitosan-filled filter media, which consequently increases the adhesiveness between chitosan matrix and empty fruit bunches fibres. Umemura et al. (2009) investigated the application of chitosan as a binder for manufacturing bagasse particleboard. The author found that the chitosan is inherently insoluble in water, and has good adhesiveness for wood in water. The particles are bonded closely to each other in the high density board[12].

Figure 2 also showed that water sorption of 2% chitosan filled filter media using spray method was comparatively higher in filters having 3 mm of filter thickness compared to 1 mm thick. When increasing the thickness, the extent of sorption is considered increased. Since the fibres are a dense filter media, the water uptake will affect the volume of the filter media significantly. High water sorption behaviour of the thicker filter media may be attributed to the swelling of the fibres leading to the crack formation in the filter media. Micro-crack formation created a pathway for the water molecules to diffuse into the filter media hence enhancing the water sorption mechanism in the filter media.

The Figure 2 also shows that within 24 hours of immersion in distilled water, 2% chitosan-filled filter media which employed spray method with a fibre size of 10 mm showed the lowest percentage with 16% of water sorption. The lower water sorption at higher fibre size of the chitosan-filled filter media is due to the increased fibre-matrix adhesion for the larger size of the fibre. The compatibility oil palm fibre and chitosan lead to strong chemical interaction at fibre-matrix interface. In contrast, 21% of water sorption for 2% chitosan-filled filter media with 2 mm fibre size was recorded, when the filter media fibres were dipped in distilled water for a similar duration. A relatively weaker 2% chitosan-filled filter media was produced with smaller size of the empty fruit bunches fibres. This increased the water sorption, where a looser network facilitated the diffusion of the water into the system.

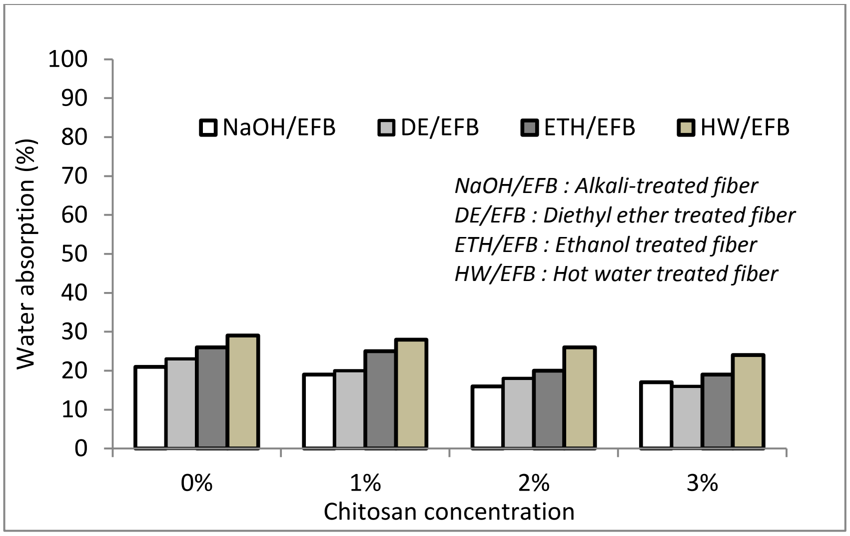


Note: EFB = empty fruit bunches; CS = chitosan

Figure 2. The effect of different parameter of filter media on the water absorption of the non-woven filter media (untreated empty fruit bunch)

In the present work, the effect of pre-treatment of fibres on the water absorption tendency of fibrous filter media was also been investigated. Figure 3 show the effect of pre-treatments of empty fruit bunches fibres on water sorption of filter media. There was no significant difference in water sorption of the different treatments up to 6 days of the test. Figure 3 shows that the water uptake increases up to only 16% for the alkali-treated 2% chitosan-filled filter media as compared to 20% for alkali-treated binder-less filter media. The results show that the alkali treated filter media with binder absorbs less moisture than the untreated binder-less filter media. The moisture absorbed by the fibres can be reduced by chemical modification of fibres, such as alkali treatment, acetylation, methylation or acrylation [13]. It was observed that water absorption of filter media from treated fibre was reduce upon alkali treatment, which agrees with previous studies [14]. This could be attributed to the lower hemicelluloses and slightly higher crystalline of fibres from alkali-treated fibres [15].

From Figure 3, it can also be seen that water absorption of fibrous filter media from diethyl ether-treated fibres, ethanol-treated fibres and hot water-treated fibres show similar results as fibrous filters from alkali-treated fibres. However, the fibrous filter media from alkali-treated fibres show lower absorption of water compared with fibrous filter media from other treated fibres. The findings show that the water absorption behaviour of the fibrous filters depends on the ability of the fibre to absorb water due to the presence of hydroxyl groups. This may be due to higher removal of lignin and hemicelluloses components of fibre by alkali-treatment compared to the other pre-treatments of the fibres. In other words, the hydrophilic nature of alkali-treatment of fibre had changed into a more hydrophobic nature compared to other surface modification treatment.



Note: NaOH/EFB = Alkali-treated fiber; DE/EFB = Diethyl ether treated fiber; ETH/EFB = Ethanol treated fiber; HW/EFB = Hot water treated fiber

Figure 3. The effect of different parameter of filter media on the water absorption of the non-woven filter (spray method, 1-mm thick, 2-mm size)

Conclusion

In this study, the newly developed non-woven media are composed of randomly oriented fibrous fibres and the media integrates the functions for both the deep filtration and mechanical screen, which will be ideal material of the filters in wastewater treatment industry. The effect of binder concentration, method of binder application, fibre size and filter thickness on the percentage of water sorption were highlighted in this study. The binder-less filter media showed the highest water absorption compared to chitosan-filled filter media. Spray method was showed to increase the resistance for water uptake for all chitosan-filled filter media. The treatment on the surface of the fibres is also one of determining factor in the water absorption properties of chitosan-filled fibrous filter media. The alkali-treated filter media showed the lowest water absorption due to changes in the physical and chemical structure of the treated fibres.

Acknowledgement

The authors would like to thank MOHE and Universiti Teknologi Malaysia (through the GUP Grant Vote 07J35) for sponsoring this research.

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