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Removal of Oily Wastewater Using Chitosan-filled Filter Media

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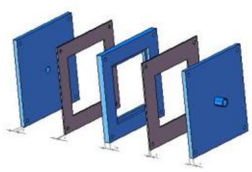
Graphical abstract



Abstract

The aim of this research is to evaluate the feasibility of the fibrous media for removal of total suspended solid and oil grease from palm oil mill effluent (POME). Wet lay-up method was adopted for filter fabrication where empty fruit bunches (EFB) were matted together with chitosan in non-woven manner. Chitosan-filled filter media were tested for their ability to reduce Total Suspended Solids (TSS) and Oil & Grease (O&G) from palm oil mill effluent. Filtration process results indicated that chitosan-filled filter media filtration only removed up to 28.14% of TSS and 29.86% of O&G.

Keywords: Chitosan; empty fruit bunches; filtration; oily wastewater; filter media

1.0 INTRODUCTION

In Malaysia, oil palm is the most important commercial crop. The explosive expansion of oil palm plantation has generated enormous amounts of waste. Although the oily effluent is the main waste from the industry, it was reported that Malaysia currently produces huge amount of oil palm biomass, including trunks, fronds, fruit waste and empty fruit bunches. Empty fruit bunches are annually renewable, available in abundance and of limited value at present.

For the removal of oily wastewater, which has a high suspended solids and organic matter content, several techniques have been proposed [1-3] and, among them, filtration at a pre-treatment stage has been reported as an efficient process [4]. However, the filtration process depends to a large extent on the costs of the filter media and, therefore, research has been focused on the use of solid waste materials or cheap and abundant natural products. A recent study has been conducted on oily wastewater treatment with depth filters, in which the packing is an ensemble of fibers. Bansal *et al.* (2011) pointed out that depth filtration is highly feasible and effective compared to other chemical and physical methods for the treatment of oily wastewater [4]. This is because, during an adsorption process, the removal of lighter emulsions by buoyancy and gravitational forces alone is difficult due to the low settling velocity of the emulsions. In contrast, in depth filtration, more oil water droplets are allowed to adhere, combine, and deform at filter media due to shear forces prior to permanent removal from the wastewater. However, the feasibility and effectiveness of fixed beds depends to a large extent on filter media. Indeed, with this in mind, recent research has focused on the use of solid waste materials, abundant natural fibers and environmentally acceptable filtration media.

Abdullah *et al.* (2010) conducted experiments using kapok as filter media to investigate the effect of packing density and flow rates on chemical oxygen demand (COD) and turbidity of oily wastewater [5]. The authors identified that the oil and water front movements were shown to be influenced by the affinity of liquid to kapok fibers. A deep-bed kapok filtration column constructed in the study was been successful in achieving 99% of COD reduction and more than 87% of turbidity reduction at all packing density and flow rates, respectively.

Pasila (2004) investigated the feasibility of reed canary grass, flax and hemp fiber as oil absorbing filter materials. The adsorption filtration processes was conducted on synthetic wastewater by means of depth filtration [6]. The author highlighted that ash content had a strong correlation with oil adsorption. This might be due to high ash content, which makes fine fibers easily detachable, thus in turn increasing the viscosity of the oil passing through the adsorption filtration. The results also showed that the surface area of adsorption material mainly determines the oil pick up ratio.

Lim and Huang (2007) studied the performance of kapok fibers in the removal of oils from a high concentration oil/water mixture in a deep bed filtration system [3]. Experimental results showed that oil sorption increased with larger effective pore size and waxy surface. It was found that the fiber had a greater potential to be developed into a filter product for oily water treatment because of its lower density, higher porosity, greater specific surface area and hydrophobic-oleophilic physicochemical characteristics.

Riahi *et al.* (2009) had investigate the application of date-palm fibers filtration as an efficient method to economically remove 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 fibers for the removal targeted matter under operational conditions (flow rate, filter depth, and diameter of the fibers). The results indicated that the diameter of the fibers had the most significant factor affecting the removal of targeted matter. Pilot test results indicated that date-palm fibers filtration removed up to 54.9% of turbidity, 80% of COD, 57.7% of phosphorus and 98% of helmint eggs.

The goal of this work is to assess the performance of empty fruit bunches as filter media for the treatment of oily wastewater, and to study the influence of the filter conditions. No research to our knowledge has been conducted to investigate the production of filter media from empty fruit bunches for wastewater application. In this study, empty fruit bunches filter media were manufactured by using chitosan as a binder as well as active agent. Removal efficiency of total suspended solid and oil & grease were investigated in varying the chitosan loading, flow rate of influent and filter depth of filter media.

■2.0 EXPERIMENTAL

2.1 Filter Media Preparation

The non-woven filter media were developed from alkali-treated EFB and a 2% chitosan concentration as a binder. The 10 mm fibers were fabricated by spray technique using the wet lay-up method. The slurry was suspended in water in a deckle box so that the fibers would be distributed evenly across the box. The slurry is then filtered to form a medium. Wet fibers on the blotter were sprayed with the chitosan solution of various loading. While still moist, the filters are removed intact from the screen and dried in an oven for 24 hours at 105^{o}C.

2.2 Palm Oil Mill Effluent

The raw wastewater of POME was collected from United Bell Palm Oil Mill at Pontian, Johor at the first outlet of discharge because of its accessibility and homogeneity of sample collected. It is important that all wastewater were collected at point where the flow is highly turbulent so that a well mixed of sample is obtained. Figure 1 shows the ponding system that applied at the United Bell Sdn. Bhd. and the sampling point of the study.

Wastewater samples were collected by grab sampling method. Samples were then placed in bottles, capped and stored in containers filled with ice cube to maintain temperature less than 4^{o}C in order to stop microorganism's activities in the samples before water quality tests were conducted on it. Large and bulky materials in the raw POME fibers were removed before dilution. Raw POME samples were diluted using tap water. For preservation, samples were refrigerated at about 4^{o}C in order to prevent the wastewater from undergoing biodegradation due to microbial action. These changes may have some affects on the amount of a chemical species available for analysis. The samples collected before and after filtration were analyzed for suspended solids, oil and grease and COD.

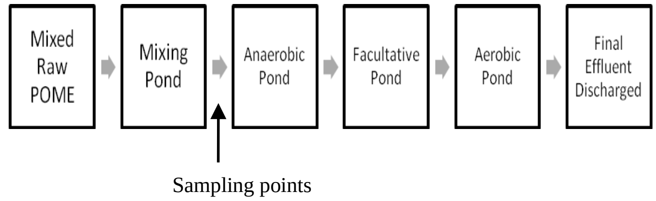


Figure 1 Ponding system used for POME treatment at United Bell Palm Oil Mill

2.1 Filtration System

A bench-scale filtration system were designed and fabricated to obtain data for evaluation of filtration removal patterns. The filtration unit is shown in Figure 2. The filtration unit were consists of a feed storage tank, pump, receiver tank, pressure gauges for measuring pressure drops across filter and filter cakes and three plate-and-frame filtration cells placed in series. The feed tank allowed placing up to 5 litres of wastewater in order to provide constant influent quality in each test. The wastewater was transferred from a tank into a filtration system by a Dosapro Milton Ray piston pump that allowed monitoring the flow rates.

Figure 2 Filtration system with plates and frame filter cells

The plate-and-frame filter cell was constructed for placing the filter media and it can be mounted in the filtration system easily and whenever required. Figure 3 shows the construction details of the plate and frames filter cell used. This type of filter cell consists of two stainless steel plates and a hollow frame. The dimensions of the filter cells are 90 mm X 90 mm.

The filter media was fitted in the hollow frame before it was tightly sandwiched between two stainless plates and closed by means of hand screw using nuts and bolts. A chamber is formed between the plates and the frame. The design provided for the deposition of filter cake in a chamber of the frames. The filter media must be mounted with care to avoid fluid bypass around the filter media. O-rings are use to prevent any leaks in the filter cell during filtration.

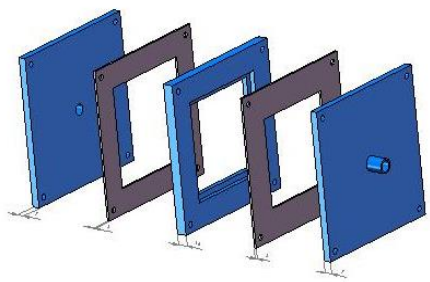


Figure 3 3D CAD drawing of plate and frame filter cell

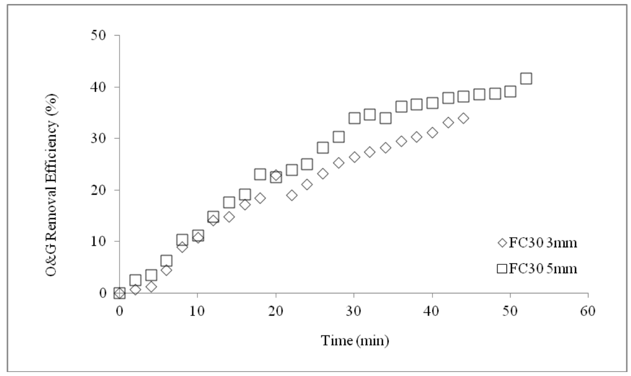


Figure 5 Effect of filter depth on O&G removal efficiency for POME filtration (30 g chitosan, 10 ml/min, 15000 mg/L COD)

3.0 RESULTS AND DISCUSSION

3.1 Effect of Filter Depth on Filtration Performance

The developed filter media have been analyzed in order to predict the filter media performance in terms of their filtration efficiency and pressure drop. The total suspended solids (Figure 4) and oil and grease (Figure 5) removal efficiencies have increased with an increase in thickness of filter media. This indicated that an increase in the filter depth, which is directly related to filter web density, allows treating a larger volume of suspended solids and oil and grease. Filter FC30-3 mm has less depth than Filter FC30-5 mm and therefore has a lower solids retention capability. Filter FC30-3 mm was able to remove suspended solids quickly but due to its thinness could not removal substantial quantities of the suspended solids over a long period of time. It is evident from these results that chitosan-filled fibrous filter media, with a thickness of 3 mm, is the most inefficient and chitosan-filled fibrous filter media, with a thickness of 5 mm, is the efficient for both TSS and O&G removal efficiencies.

Moo-Young and Tucker (2002) suggest that the filter with greater depth is able to retain a larger mass of particles before becoming clogged. This is due to the tortuous and channel-like nature of the depth filter media, the particles are retained throughout the medium within its structure, as opposed to on the surface. It was demonstrated that the depth filter media has the ability to retain particles throughout the medium channels, rather than purely on its surface. The authors point out that a lower depth of filter is able to remove the solids more quickly, however since the filter is thin; it has a lower solids retention capacity [8].

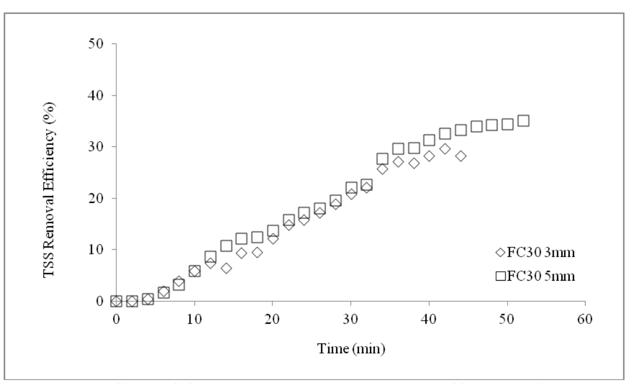


Figure 4 Effect of filter depth on TSS removal efficiency for POME filtration (30g chitosan, 10 ml/min, 15000 mg/L COD)

The pressure drop profiles across the filters are shown in Figure 6. The figure illustrates that the pressure drop increased slightly during 30 minutes of the filter run. One of the important results from the effluent sampling and the pressure drop monitoring was that the linear pressure loss increases when the depth of the filter media is increased. This phenomenon is explained by the presence of a higher web volume of filter media and additional filter cake that removes more influent thus increasing the surface area within the filter bed. However, at 35 minutes of the filtration process, the pressure drop in both filters increases exponentially with time. The exponential increase in pressure drop suggests the occurrence of clogging or surface straining in a deep layer of the bed.

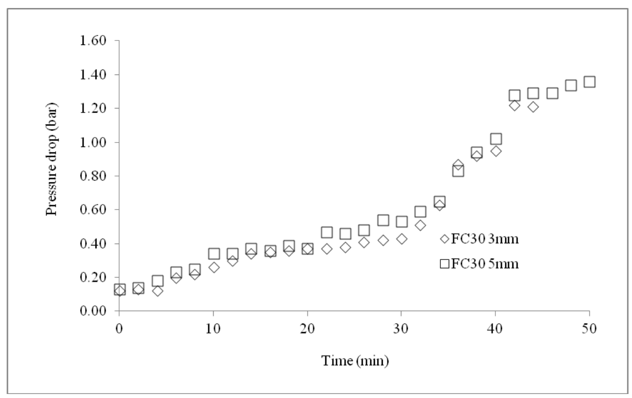


Figure 6 Effect of filter depth on pressure drop across the filter media (30g chitosan, 10 ml/min, 15000 mg/L COD)

3.2 Effect of Chitosan Loading on Filtration Performance

In the interpretation of the effect of chitosan loading on filtration performance, both efficiency profile and pressure drop profile were utilized in elucidating the filtration removal pattern. Figure 7 presents the effect of chitosan incorporated in filter media tested with their corresponding total suspended solid, oil and grease and COD removal efficiency of POME. For a low concentration of POME, the highest total suspended solids efficiency was about 28%, while the lowest was about 25% for filter media. This indicated that the chitosan loading is not significant on TSS removal efficiency. However, removal efficiency is particularly significant for oil and grease.

The highest oil and grease removal efficiency was about 29 %, while the lowest was about 22 %. The higher removal efficiency of oil and grease shows for filter media with the highest chitosan loading. The results clearly indicate that the amount of chitosan that is incorporated in the empty fruit bunch fiber played an important role in oil and grease removal. The results show that the chitosan is not only act as a binder but could also influence the removal of oil and grease.

According to Choi and Moreau (1993), the adsorption should be the most prominent mechanism of oil sorption on fiber because of the presence of waxes and grease giving a hydrophobic nature to the fiber, the scale like structure with large pores, and the fiber crimp providing the space for the deposition of oil and formation of capillary bridges of oil between the fibers [9].

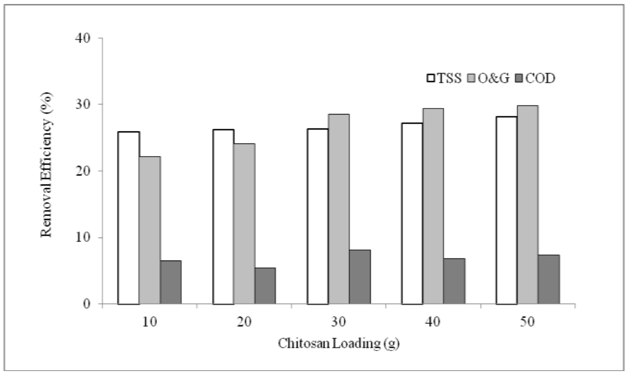


Figure 7 The effect of chitosan loading on removal efficiency of filter media (3 mm filter depth, 6 ml/min, 15000 mg/L COD)

From the Figure 8, it is easy to conclude that the filters supplemented with high chitosan loading have higher pressure drops and higher separation efficiencies than the filter with low chitosan loading. However, the optimum filter design is the one that has improved capture and separation efficiency but not the largest pressure drop. This means of the filters tested here, filter with 30g of chitosan loading could be considered as the optimum design. As a conclusion, the addition of chitosan improves the filter performance. The chitosan addition over inter-fiber spaces, make the spaces much smaller. Hence it is more difficult for particulates to pass through the filters without coalescing with other particulates. Thus, it was thought that the coalescing and straining were the main removal mechanism of the newly developed filter media.

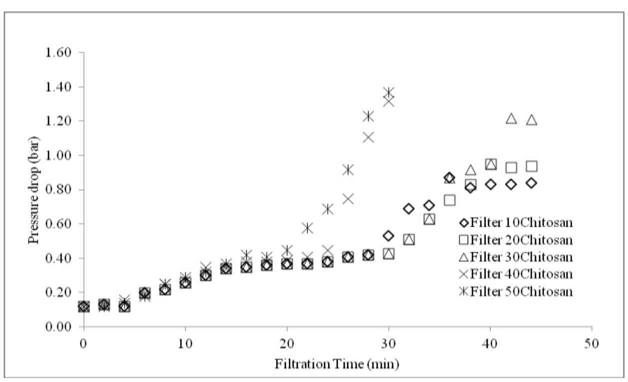


Figure 8 The effect of chitosan loading on pressure drop across the filter media (3 mm filter depth, 6 ml/min, 15000 mg/L COD)

3.3 Effect of Flow Rate on Filtration Performance

Filter media with a filter depth of 3 mm were subjected with two different operating flow rates, 5 ml/min and 10 ml/min. Figure 9 shows a curvilinear variation of TSS removal efficiencies with filtration time for two different filtration flow rates. The result shows that varying the flow rate had relatively little effect on the suspended solids removal efficiency of the filter media. The graph clearly shows that the efficiency of a filter may change slightly but this is not that significant due to small changes of flow. The filtration flow rates ranged from 5 to 10 ml/min without much change in filter removal efficiency. The filtration flow rate did not impact on the effluent quality as significantly as the depth of the filter media did. However, the filtration rate was important in determining how long the filtration period lasted. Higher filtration rates lead to shorter filtration periods as shown in Figure 9.

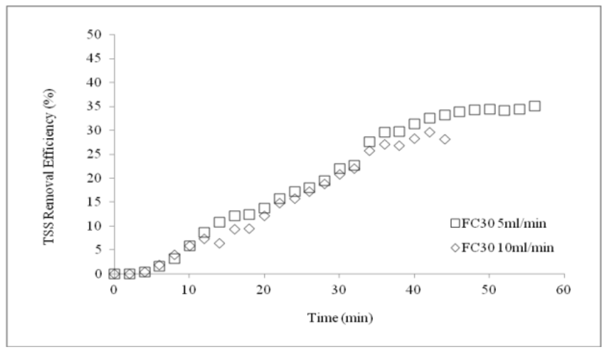


Figure 9 Effect of flow rate on TSS removal efficiency for POME filtration (30 g chitosan, 3 mm filter depth, 15000 mg/L COD)

In the case of O&G removal efficiency, the filter media performs better at low flow rates as O&G removal appears to decrease with flow rate as shown in Figure 10. The flow rate dependence can be accounted for by the fact that for lower values of flow rate, the contact time is longer, and hence the interaction between oil and grease and the filter media is also greater. This leads to higher rates of oil and grease sorption. This might be explained because the oil and grease droplets are large enough to be entrapped, as a result of longer residence times in the bed. On the other hand, for the higher flow rates, the contact time is shorter and the oil and grease sorption is lower, due to lesser interaction. In addition, at a higher flow rate, the filter bed is not able to retain the oil and grease present in the feed and it goes through the outlet effluent.

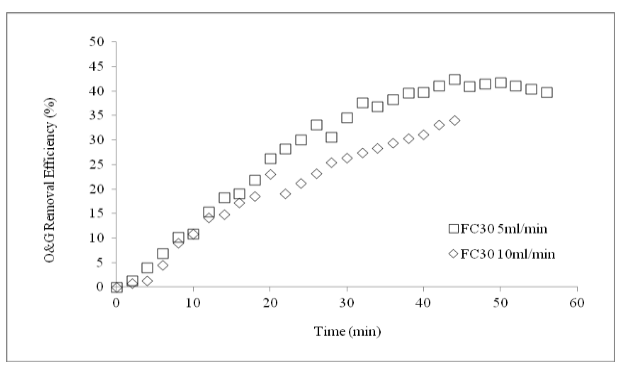


Figure 10 Effect of flow rate on O&G removal efficiency for POME filtration (30 g chitosan, 3 mm filter depth, 15000 mg/L COD

The rate increase in pressure drop over the course of a filter run is a function of the rate of solids retained by the filter (Figure 11). At the initial filtration run, the pressure drop pattern found in the filtration process was linear with respect to time. A higher pressure drop was observed for lower flow rates compared to the pressure drop of higher flow rates. However, at 45 minutes of the filtration run, an accelerating pressure drop was observed. The figure also shows that when the filter rate was increased, the exponential tendency was reduced. This might be due to the greater penetration of influent that had been promoted by the higher flow rate. According to Cambiella *et al*. (2006), particles deposited in the filter bed at lower flow rates occupy more space in the filter bed, which causes the fluid to experience more drag loss that results in higher pressure drop. At the same time, the higher flow rate allows particles to penetrate deeper into the bed, which results in a more homogeneous distribution of deposits along the filter bed [10].

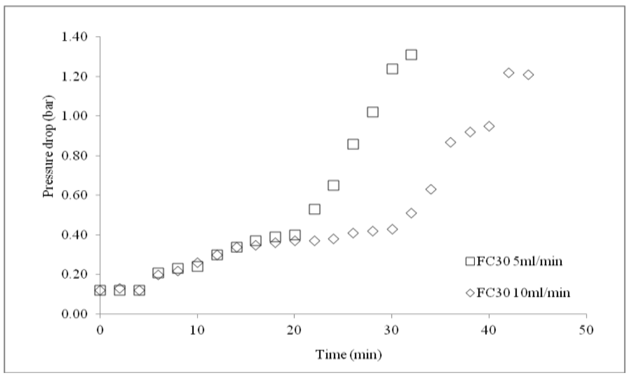


Figure 11 Effect of flow rate on pressure drop across the filter media (30 g of chitosan, 3 mm filter depth, 15000 mg/L COD)

■4.0 CONCLUSION

The chitosan that is incorporated in the empty fruit bunch fiber is not only act as a binder but also influence the removal of oil and grease. Filtration flow rate impacted TSS and O&G removal: increasing filtration rate reduced removal efficiencies to some degree. In addition, all filter media suffered permeability loss and were easily clogged, which renders it unusable for long term filtration. This type of filter media was not suitable for POME due to the clogging that occurred within an hour after filtration started. Because the removal efficiencies did not meet the requirement outlined under the DOE of Malaysia for wastewater treatment, particle destabilization processes, e.g., coagulation should be considered to enhance the removal performance of chitosan-filled filter media. However, due to their physical and mechanical characteristics this filter media can bring improvement into the overall properties of non-woven filter media in other applications. The developed filter media could be applicable for wastewater with lower concentration like rain water, grey water, storm water, etc.

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