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Coagulation–Adsorption of Suspended Solids and Residual Oil from Palm Oil Mill Effluent Using Chitosan

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A bench-scale study of suspended solids and residue oil removal from palm oil mill effluent (POME) was conducted. Residual oil and suspended solids constitute a severe problem in POME treatments. Preliminary analysis showed that POME contains about 4,000 mg/l of residual oil and 18,000 mg/l of suspended solids. These values are very high compared to the maximum limit allowed by the Malaysian Department of Environment (DOE) at about 50 mg/l for residual oil and 400 mg/l for suspended solids. *Chitosan*, poly-β (1-4)2–acetamido–2–deoxy–D–glucose (N-deacetylated), is a biodegradable cationic biopolymer obtained by extensive deacetylation of chitin. Chitosan was applied as a coagulant to sequester the suspended solid and as an adsorbent to adsorb the residual oil. In this study, the effects were analyzed using the jar test apparatus as the standard procedure for bench-scale testing. The effects of experimental parameters, such as dosage of chitosan, mixing time, mixing rate, sedimentation time, and pH, were performed to study and manipulate the optimum conditions. Results showed that a combination of 0.5 g dosage of chitosan, 15 min of mixing time, 100 rpm of mixing rate, and 30 min of sedimentation at pH 5 provide the most suitable condition for the removal of POME residual oil and suspended solids. The removal percentage for residual oil was 99% whereas for suspended solids the value was 250 mg/l. The Fourier transform infrared (FTIR) spectroscopy study proved the adsorption of residual oil on chitosan.

Keywords: Adsorption, chitosan, coagulation, palm oil mill effluent (POME), residue oil, *and* suspended solids.

INTRODUCTION

Palm oil processing mills generally discharge large volumes of wastewater. Thus, the environmental issues of palm oil industry are primarily related to the water pollution due to indiscriminate discharge of untreated or partially treated palm oil mill effluents (POME) into public watercourses. A number of treatment technologies have been used to treat POME, namely: ponding system, open-tank digester and extended aeration, closed-tank digester with biogas recovery and land application, thermophilic anaerobic contact digestion process, and decanter dryer system (Ma 2000). Many palm oil processing mills, however, still face major problems in treating wastewater. This challenge is due to the composition of POME which is very oily and dense.

POME is a colloidal suspension of 95–96% water, 0.6–0.7% oil and grease, and 4–5% total solids. This thick brownish liquid is discharged at temperatures between 80 and 90 °C. It is fairly acidic with a pH of 4.0 to 5.0. Table 1 shows the other characteristics of raw POME. The main ingredients though that cause severe problems in POME are residual oil and suspended solids.

Table 1. Characteristics of POME

Parameter	Concentration (mg/L)	Element	Concentration (mg/L)
Oil and grease	4,000–6000	Phosphorus	180
Biochemical oxygen demand	25,000	Potassium	2,270
Chemical oxygen demand	50,000	Calcium	439
Total solids	40,500	Boron	7.6
Suspended solids	18,000	Iron	46.5
Total volatile solids	34,000	Manganese	2.0
Ammonicals nitrogen	35	Copper	0.89
Total Nitrogen	750	Magnesium	615
		Zinc	2.3

Residual oil has to be removed in order to (a) prevent interfaces in water treatment units, (b) avoid problems in the biological treatment stages, and (c) comply with water discharge requirements. Emulsified oil droplets are sheltered from spontaneous coalescence into larger floc ones, making oil separation by simple gravity a difficult and time-consuming process (Zouboulis and Avranas 2000).

Suspended solids cause sludge deposits and anaerobic disposal problems and tend to accumulate in the environment. Ma (2000) reported that POME contains about 4,000 mg/l of oil and grease and 18,000 mg/l of suspended solids. Generally, residual oil is dissolved in total solid and suspended solid, emulsified in the supernatant while some float freely on the surface of the effluent. Norliza (2001) noted further that only about 2,000 mg/l of residual oil is emulsified in the supernatant of POME with the rest floating freely either in the suspended solid or on the surface of the POME itself. This means that by removing the suspended solids in the POME residual oil is also indirectly removed. The oil and grease droplets in POME are likewise solvent-extractable.

The extract of POME oil droplets consist of 84 wt% neutral lipids and 16 wt% of complex lipids (6 wt% glygolipids and 10 wt% phospholipids). The neutral lipids consist of 83% triglycerides, 0.3% diglycerides, 0.5% monoglycerides, and 0.2% free fatty acids. Palm oil mill residual oil also has a high concentration of surface active compounds of phospholipids at 10 wt% and glycolipids at 6 wt% (Chow and Ho 2002). These natural surfactants stabilize oil droplets rendering oil irrecoverable from the sludge as a homogeneous phase (Chow and Ho 2000). The maximum allowable limit set by the Malaysian Department of Environment (DOE) is at 50 mg/l for oil and grease and 400 mg/l for suspended solid (Environmental Quality Act and Regulations 2001). Therefore, the challenge of making waste more environmental-friendly requires a sound and efficient treatment and disposal approach.

Numerous methods have been used to remove residual oil from oily wastewaters, such as adsorption, flocculation, electrocoagulation, and flotation (Andrew et al. 2000). Whereas, to remove suspended solids, such methods as coagulation, flocculation, sedimentation, flotation, and filtration (American Water Works Association 1999) as well as biological growth (George 1991) have been adopted.

Destabilizing oil droplets, destroying emulsions, and removing suspended solids via the addition of alum and poly aluminum chloride (PAC) have been reported by Eilbeck and Mattock (1987) to be effective as pretreatment methods to separate oil and grease. Pinotti and Zaritzky (2001) pointed out that the coagulation method can be used to remove the turbidity caused by suspended solids. The sludge obtained from such a treatment, however, poses disposal problems and the treated water contains residual aluminum which has alarmed the public for being a probable cause of Alzheimer's disease (Pontius 2000). Hence, natural biopolymers made of polyelectrolyte are preferred. For oily wastewater adsorption, there are a number of natural adsorbents used for residual oil. Fibrous sorbents prepared from plants such as milkweed floss, kenaf, kapok, straw, corn cob or ear, wood fibers, sawdust, bark and cotton have been reported as potential adsorbents (Shukla et al. 2002, Setti et al. 1999, Haussard et al. 2003, Inagaki et al. 2002). Satisfactory results have been obtained using these natural adsorbents. Biopolymers are industrially attractive because they (a) are widely available, (b) possess a number of different functional groups to which ions bind either by chemical or by physical adsorption, and (c) are environmentally safe (Deans and Dixon 1992).

Chitosan is a natural, modified carbohydrate biopolymer. It is a partially deacetylated derivate obtained by alkaline treatment of chitin. *Chitin,* which is celluloselike, is widely distributed in nature, especially in the exoskeletons of marine invertebrates such as prawns, crabs, and squids (Muzarelli 1977). Chitosan is recommended as a suitable resource material because of its excellent properties, such as biodegradability, biocompability, adsorption property, flocculating ability, polyelectrolisity, and its potential for possible regeneration in a number of applications (Majeti 2000). It is largely used as a nontoxic flocculent in the treatment of organic polluted wastewaters and as chelator of toxic heavy and reactive metals (An et al. 2001). Chitosan is also famous for sequestering bile acids and fatty acids (Riccardo 1996). In contrast, crosslinked N,O–carboxymethyl chitosan had been used to absorb triglycerides from serum (Yu and He 1997). It is a white amorphous solid that is insoluble in water but is soluble in very dilute acids, such as acetic acid and formic acid, and whose solution undergoes a slow biodegradation (Chihpin et al. 2000). It is second only to cellulose in abundance.

Figure 1 shows the structural difference between cellulose, chitin, and chitosan. Whereby, the interplay of amine, amide, acetamide, and acetyl groups imparts differences in the physiochemical properties of chitosan and chitin from cellulose (Asbjorn and Even 2001). It has a high charge density and a positive charge that interacts strongly with negative surfaces to give electric neutrality (Pinotti et al. 1997). Therefore, chitosan, when added to oily wastewater could increase the rate of droplet destabilization and agglomeration of suspended solids. Whereby, it adsorbs the oil droplets electrostatically and/or through van der Waals attraction forces.

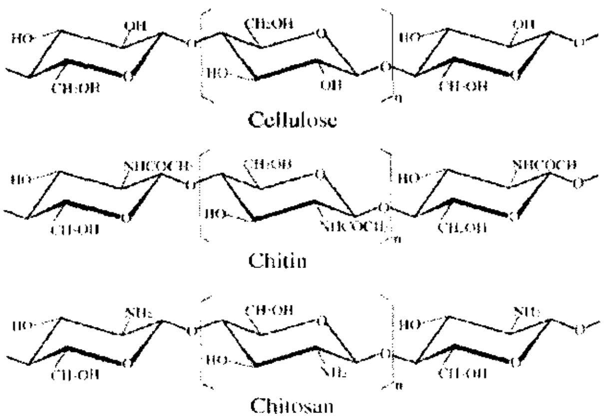

Figure 1. Comparative Structure of Cellulose, Chitin, and Chitosan

The objective of the present work is to study the effects of chitosan as an adsorbent for residual oil as well as coagulant for suspended solids in POME. It also seeks to determine the optimum dosage of chitosan, mixing time, mixing rate, sedimentation time, and pH needed to achieve the maximum removal of residual oil and suspended solids in POME.

MATERIAL AND METHODS

Experimental materials

Samples of POME were collected from United Palm Oil Mill, Sungai Kechil, Nibong Tebal, at a temperature of 80°C. These samples were allowed to cool to room temperature and left to sediment. Portions of this suspension were then withdrawn and analyzed for their turbidity, residual oil content, and pH properties.

Chitosan was supplied by Hunza Pharmaceutical Sdn. Bhd., Malaysia, in the form of off-white fine powder with a mesh size of less than 120. This chitosan was soluble in diluted 1% acetic acid with a 90% degree of deacetylation.

Distillated water was used to dilute the hydrochloric acid solution and dissolve sodium hydroxide pellets (Merck, Germany) to obtain solutions of 5 M. These solutions were then used for pH adjustment during the treatment process. Used as oil extraction solvent in oil-and-grease analysis, n-Hexane (Merck, Germany), a technical grade solvent, was obtained from Quicklab Sdn. Bhd., Malaysia.

Experimental procedure

The POME was sedimented for 1 h. Then, analysis of the POME's residual oil content and turbidity, before and after sedimentation, was done. A conventional jar apparatus, Stuart Science Flocculator model (SW1), was used to coagulate the samples of POME with chitosan. This apparatus could accommodate six beakers. The contents of each beaker can be stirred simultaneously at the same speed with the six-spindle steel paddles. Each beaker was filled with 1 L of POME. After adding chitosan, the suspension in the beakers were mixed rapidly with the mixing time and rate varying for different doses of chitosan. The suspension was then tested with different sedimentation time. The clarified suspension was then analyzed for its residual oil content and turbidity. Finally, pH adjustments were made to obtain the best pH condition to remove residual oil and suspended solids in the POME.

The parameters were the dosage of chitosan 0.08–0.8 g, mixing time 5–60 min, mixing rate 20–200 rpm, and sedimentation time 5–60 min. The pH adjustments were made by adding either 5.0M HCL solution or 5.0M NaOH solution prior to the addition of chitosan with a pH range of 3–8. The pH values of the suspensions were measured using a Hanna Instruments model HI98127 pH meter. Turbidity was analyzed using portable turbiditimeter model WTW "TURB 350 IR, Germany. The samples were diluted with distilled water at a ratio of 1:10 prior to each testing for the turbidity reading. Turbidity reading was done to verify the removal of suspended solids.

Analysis

The residue oil content was measured using the oil-and-grease method recommended by APHA Standard Method of Examination of Water and Wastewater (1992), with n-Hexane being used as the oil-extraction solvent. The oil-and- grease content in the suspension was determined for each sample of POME both before and after the experiment. Three replicates of each test were undertaken based on which the mean value obtained for residual oil content was calculated. All tests were carried out at an ambient temperature of 26–30 °C.

Prior to determining the oil concentration in the initial and treated sample, a 200-ml distillation flask was cleaned, dried, and preweighed to the nearest 0.1 mg before the weight of the flask was recorded. Then 100 ml of extracted POME was transferred to a separating funnel, 50 ml hexane added, and the resulting mixture was shaken vigorously for 2 min and then was left for 15 min to allow further separation.

After this time, the solvent was slowly drained into the preweighed flask through a funnel containing filter paper and 10-g anhydrous sodium sulphate. This extraction was repeated for another 50 ml of hexane and, finally, the separating funnel was rinsed with three separate 5-ml aliquots of fresh n-hexane to remove any oil film left on the funnel walls.

Then, the solvent was distilled using an evaporator and a distillation flask plus remaining contents placed in an oven to dry for 10 min at 103°C. The flask was then cooled in a desiccator for 30min. The drying and cooling steps were repeated until the weight became constant to the nearest 0.1 mg. The experiments were repeated three times to obtain a reproducible of ±5%.

Fourier transform infrared (FTIR) studies

The infrared spectra exhibited in this work were obtained with a Perkin Elmer-IR Spectrophotometer–Series II over the wavelength region 4,000 and 400 cm-1.

The FTIR spectra of chitosan before and after oil adsorption were determined using Potassium Bromide (KBr) pellets. The spectra recorded here were the results of 4 scans at the speed of 1 scan per 2 s. The spectras show the chemical changes in chitosan caused by the residual oil which was adsorbed.

RESULTS AND DISCUSSION

Initial concentration of residual oil in POME was about 1.5–2.0 g/l of POME. Different samples may contain different concentrations of residual oil and suspended solids. This variation depends on the palm oil processing procedure as well as on the environment of the production in the palm oil mill from day to day.

Effects of chitosan dosage

The POME suspension was treated with 8 different chitosan weight doses. The initial content of residual oil in POME was 2.0 g. Residual oil content after the treatment was analyzed. Figure 2 shows the effect of chitosan dosage on residual oil adsorbance. When the chitosan dosage was increased, the percentage of residual oil adsorbed was also noted to increase. The dosage of chitosan needed for the removal of 99% of residual oil from the POME is 0.5 g. Chitosan could even adsorb almost all residual oil in the POME at a lower dosage. Hence, about 80% of the residual oil in POME has been adsorbed at 0.1 g.

Chitosan has an amine functional group that attracts anionic ions to bind and bridge (Osman and Arof 2003). This factor causes the residual oil to bind and bridge with chitosan powder. Therefore, chitosan being a positively charged biopolymer could adsorb residual oil and destabilize the negatively charged colloids of residual oil and emulsion by the mechanism of *charge neutralization* (Jill et al. 1999). Residual oil adsorption was very promising for chitosan, which shows no noticeable advantage at higher dosage levels. These results can be explained on the basis of the higher charge density of chitosan, which requires lower doses to destabilize residual oil droplets.

Figure 2 also shows significant reduction in turbid value with the increase in chitosan dosage up to 0.7 g. While adsorbing residual oil on the surface of the suspended solid, chitosan is indirectly agglomerating the suspended solids into larger and bigger flocs which could be settled later at the bottom of the beaker.

Therefore, the coagulation of chitosan with POME not only adsorbs the residual oil but also agglomerates the suspended solids of POME making a clearer and less turbid effluent. The original turbididty of POME, which is about 350 NTU after 1:10 ratio dilution, reduces to as much as 28 NTU (1:10) after adding 0.3 g chitosan. This value represents almost 91% removal of the original turbidity.

The maximum dosage of chitosan needed to reduce turbidity to a minimum level of 15 NTU (1:10) is 0.5 g. Hence, if this turbidity value is compared to the turbidity–suspended solids calibration curve, the removal of suspended solids would be about 250 mg/l.

Effects of sedimentation time

Chitosan-coagulated POME produces flocs of better quality, which means larger flocs with faster settling velocity based on the experimental preview. The time needed for floc to settle is very

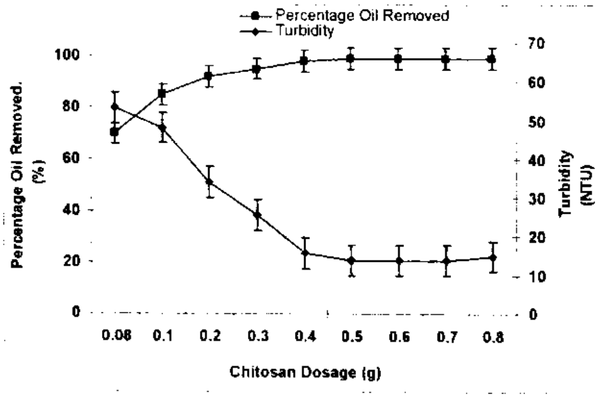

Figure 2. Chitosan Dosage vs. Percentage Residual Oil Removal and Turbidity

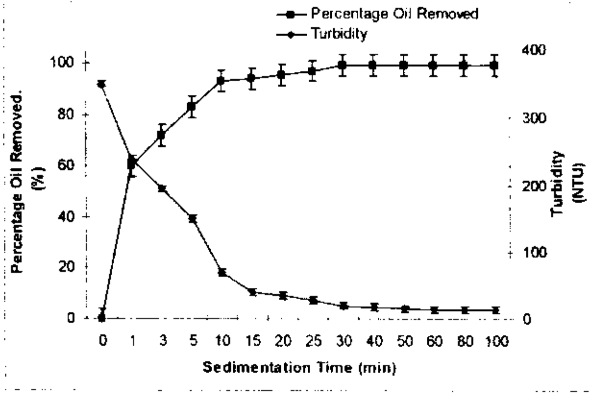

Figure 3. Sedimentation Time vs. Percentage of Residual Oil Removal and Turbidity

important in removing adsorbed residual oil. Chitosan is very hydrophobic; therefore, it helps suspended solids in POME to agglomerate better. Figure 3 shows the sedimentation time needed for the maximum removal of residual oil and turbidity in POME suspension. Note that 30 min of sedimentation can remove about 99% of residual oil.

Chitosan promotes the aggregation of colloids by forming (a) bridges between dispersed oil droplets and (b) particles of sufficient size which can be settled later (Zouboulis and Avranas 2000). The faster the flocs settle, the better the quality of the removal. After 30 min, there is no marked or efficient change in residual oil removal. This observation reveals that after 30 min, all the residual oil emulsified on the surface and in the suspended solids of the POME would have been bridged into flocs and adsorbed by the chitosan.

The turbidity of the coagulated sample also depends on the sedimentation effect. From the graph in Figure 3, it can be seen that there is a drastic reduction in turbidity value once the sample is left to settle for more than 30 min. Turbidity decreases as the dispersed particles and flocs settle to the bottom of the beaker. It would take about 60 min to reduce the turbidity to as low as 15 NTU.

Effects of mixing time

The effect of mixing time was conducted by varying the mixing time at a rotation speed of 100 rpm. The sample was left to settle for an hour. The dosage of the chitosan was fixed at 0.5 g. The mixing time allotted to mix chitosan with the POME suspension is very crucial in removing residual oil and suspended solids. Figure 4 shows that 30 min of mixing at 100 rpm can remove about 99% of residual oil in POME. The figure also shows that there is no noticeable change if the time was increased by more than 30 min to 1 h. At a shorter mixing time, however, the percentage of residual oil adsorbed was low; hence, 10 min of mixing shows only about 90% of residual oil adsorption.

Because the chances of the oil molecules and the chitosan particles to meet were low, the rate of adsorption decreases. At a longer mixing time, breakage of the oil droplets are enhanced and, thus, reduces the diameter of the oil droplets (*emulsification*) resulting in more interfacial area for the adsorption to happen (Michael, Heike, and Helmar 1994). Therefore, the interaction time between the oil molecules and the chitosan particles is likewise very important in the adsorption of residual oil. Figure 4 illustrates the turbidity effect of chitosan mixing time. To get a clearer effluent, chitosan had to be mixed for a longer period. The turbidity reading became stable after 40 min of mixing. This time, Figure 4 proves graphically that chitosan is a good coagulant and sorbent for POME.

Effect of mixing rate

The effect of mixing rate was analyzed using 0.5 g of chitosan at different time periods. After the coagulation process, the sample was let to sediment for 30 min. Figure 5 shows that the maximum mixing rate needed to adsorb about 99% of residual oil in POME is 100 rpm. Even if

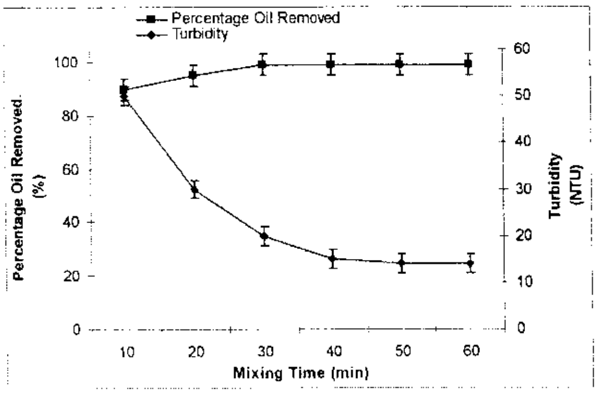

Figure 4. Mixing Time vs. Percentage of Residual Oil Removal and Turbidity

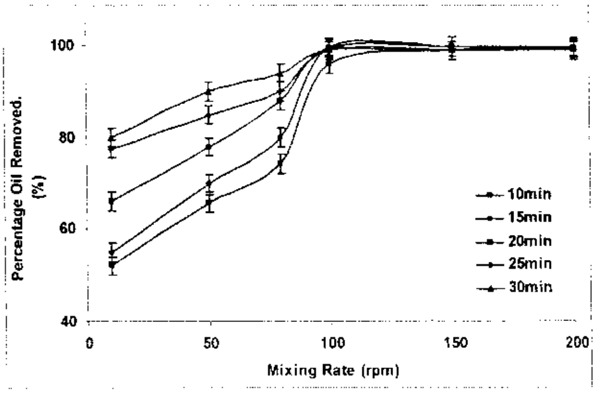

Figure 5. Mixing Rate vs. Percentage of Residual Oil Removal

the time of rotation was increased, the percentage removal remains at optimum level. This means that almost all the residual oil suspended in the POME's supernatant had been adsorbed on the chitosan after 15 min of mixing at 100 rpm; thus, proving that chitosan not only agglomerates residual oil but also binds tightly using its chemical and physical adsorption property. Figure 5 also shows that residual oil adsorption can also be achieved by increasing the mixing time. For example, 50 rpm at 30 min of mixing time showed better adsorption than 10 min of mixing. Whereby, about 64% of residual oil had been adsorbed at 10 min of mixing and almost 90% of residual oil was adsorbed after 30 min of mixing at 50 rpm.

This explanation proves that mixing time and mixing rate for both chitosan and POME are essential in adsorbing residual oil from the POME. Mixing rate also has its effects on turbidity reduction. The initial turbidity value of the POME was about 350 NTU. Figure 6 shows that at a minimum mixing time and mixing rate the turbidity removal were quite satisfying at about 45 NTU. For 30 min of mixing at 50 rpm, the turbidity clearance was at a value of 15 NTU. Mixing rates from 20 to 100 rpm shows a dramatic reduction in turbidity. However, the turbidity values increased again when the mixing rate and the time were increased. This phenomenon was due to the high rate and long agitation time which can cause the flocs to breakup and introduce turbidity again (Ahmad et al. 2002). This trend is mapped in Figure 6 where, from 100 to 200 rpm, the turbidity is shown to increase. So, to get the maximum turbid clearance at 99%-residual oil removal, the POME should be coagulated for only 30 min.

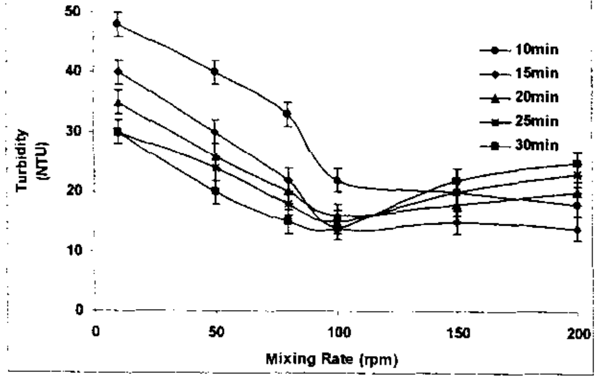

Figure 6. Mixing Rate vs. Turbidity

Effects of pH

Emulsion breaking is usually brought about by changing the samples' pH value or inorganic coagulants (Schulz et al. 1998). Hence, pH adjustments were also made to study the effects of adsorbing residual oil using chitosan. The adsorption was almost 99% at pH 5 as can be seen in Figure 7. Tests were conducted using the following optimum conditions: chitosan, 0.5 g; mixing rate, 100 rpm; mixing rate, 30 min; and sedimentation, 30 min. The original pH of POME is about 4.5 and Figure 7 shows that even at the initial pH value the removal was already very reliable at 97%. This encouraging fact could lead to the conclusion that pH adjustment on POME may be discarded in the actual process treatment for residual oil to be adsorbed using chitosan.

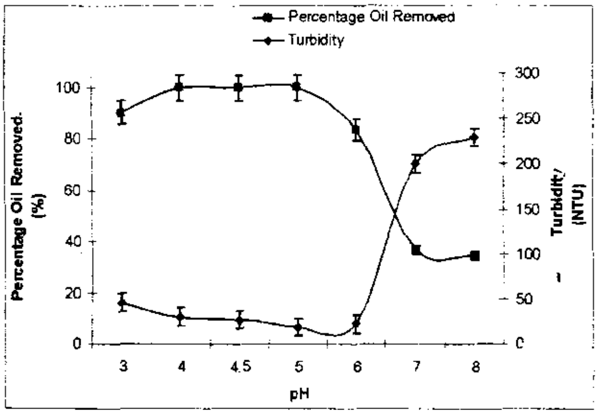

Figure 7. pH vs. Percentage of Residual Oil Removal

At a pH of more than 5.0, the percentage of residual oil adsorption decreased. This may be due to the destabilization of chitosan at weaker acid. Strong acidic conditions aggravate POME to form unstable flocs, wherein chitosan provokes a physiochemical effect, apparently to demulsify and increase the droplet size and enhance the adsorption of residual oil.

It is, therefore, at pH 5.0, when the concentration of H$^+$ ion and the density of the negative charges are relatively very small compared to more acidic pH or higher alkaline pH, that adsorption is at its best. At lower pH, more protons will be available to protonate amine groups of chitosan molecules to form groups -NH3$^+$ (Chiou and Li 2003), thereby increasing electrostatic attractions between residual oil molecules and adsorption site. Thus, the adsorption of residual oil also increases. It can then be concluded that at pH 5 the negative and positive charges in the solution were stabilized. Figure 7 also shows the turbidity of the POME suspension at various pH levels. The turbidity of the extracted POME was reduced with the change of pH. At pH 5, the turbidity was very good, falling below 20 NTU.

These results indicate that the turbidity clearance was at its best at a pH of 5–6. This is because as chitosan nears the neutral pH, it tends to form into a coiled structure which is able to produce larger and denser flocs (Jill et al. 1999). These flocs are very coarse and settle rapidly. Likewise, pH 5.0 shows the best removal of suspended solids from the POME. In summary, the maximum adsorption of residual oil and the removal of suspended solids from POME can be achieved at pH 5.

FTIR studies

Figure 8 shows the FTIR spectra of pure chitosan while Figure 9 shows the FTIR spectra of the chitosan which was used to adsorb residual oil.

The wavelength peak from 1,400 cm-1 to 1,700 cm-1 is the region where the carbonyl C=O-NHR, amine NH_2, and ammonium NH_3^+ bands are situated. The carbonyl C=O-NHR band was observed at ~1,650 cm-1; the amine NH_2 band at ~1,590 cm-1; while the ammonium NH_3^+ band appeared as a small shoulder at ~1,514 cm-1 (Osman and Arof 2003). These groups are able to adsorb molecules that have carbonyl groups.

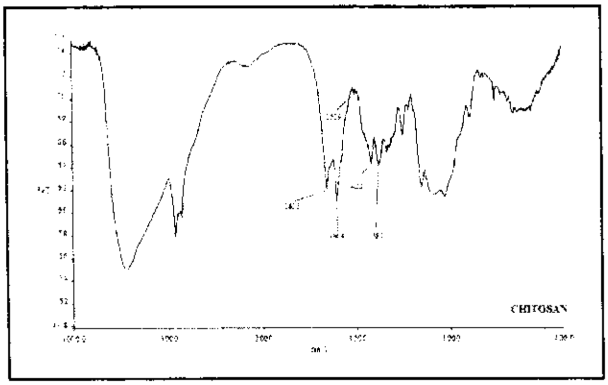

Figure 8. FTIR Spectra of Chitosan Before Residual Oil Adsorption

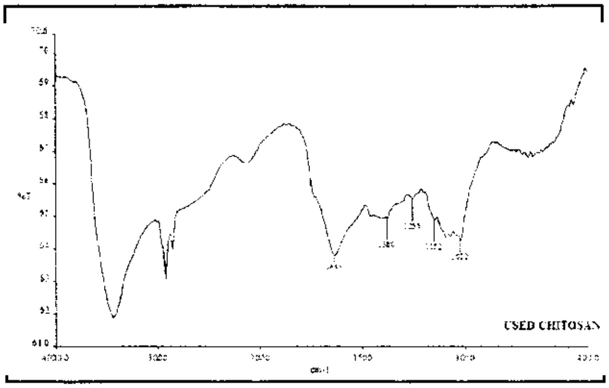

Figure 9. FTIR Spectra of Chitosan After Residual Oil Adsorption

In Figure 8, the spectrum for the amine band can be observed at 1,590 cm-1 and the ammonium band at 1,509 cm-1. The absence of these ammonium NH_3^+ and amine NH_2 bands in Figure 9 was due to the interaction of these functional groups of chitosan with the carbonyl group of POME.

In the present work, the carbonyl group C=O-NHR of the chitosan spectrum can be observed at 1,655 cm-1 in Figure 8. This band has shifted to a lower peak at 1,635 cm-1 in Figure 9. This value shows that some interaction have also occurred between the C=O-NHR and the carbonyl group of residual oil in POME. Therefore, these spectra show that chitosan can adsorb residual oil suspended in POME.

CONCLUSIONS

This investigation looked into the feasibility both of adsorbing residual oil and removing suspended solids from palm oil mill effluent (POME) with chitosan.

The destabilization of oil-in-water and the removal of suspended solids were successfully performed by the application of *chitosan,* an adsorbent as well as a coagulant t, which shows a synergistic enhancement for the effective adsorption of residual oil and suspended solids sequester. The addition of chitosan, a cationic adsorbent, is essential to allow the effective agglomeration of individual oil droplets.

The application of chemical and physical conditioning can remove a high percentage of residual oil and suspended solids from POME. While adsorbing the residual oil, chitosan is also agglomerating the oil attached to the suspended solids. The application of adsorption and coagulation treatment in the jar-test laboratory apparatus resulted in 99% residual-oil reduction and a good sequester of suspended solids from POME.

The probable reasons for such behavior were discussed. In order to reduce the oil-and-grease content of the influent residual oil, with a concentration of 2,000 mg/l to less than 20 mg/l and with a turbidity from 350 NTU to about 15 NTU, the following optimum parameters were determined: chitosan dosage, 0.5 g; pH, 5–6; 100 rpm, mixing rate; 15 min, mixing time; and 30 min, floc sedimentation. Whereas, by comparing the turbidity–suspended solid calibration curve, the actual suspended solid-content was successfully reduced to about 250 mg/l.

There are, however, two minor limitations to these findings:

1. The initial concentrations of suspended solids and residual oil in POME could not be specified for each experimental run. This was because the initial concentrations varied from day to day depending on the process used by the palm oil processing mill and the day's weather.
2. The optimized conditions in this study are specifically only for POME coagulation and adsorption treatment. Hence, for other types of activated oily sludge, preliminary studies have to be done before resorting to the application of chitosan.

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