TURBIDITY REMOVAL FROM SURFACE WATER AND LANDFILL LEACHATE USING CACTUS *OPUNTIA*

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ABSTRACT

The effectiveness of cactus opuntia, a natural macromolecular coagulant, for turbidity removal was studied via jar test. The jar test was conducted to remove turbidity from two aqueous solutions, namely, surface water and landfill leachate. The surface water studied were estuarine and river water. Initial turbidity values measured at 499 NTU and 547 NTU for estuarine and river water respectively were reduced by as much as 98% (estuarine) and 70% (river). Other parameters such as pH as well as alkalinity were also studied. High turbidity removal effectiveness shown in this bench-scale study indicates that cactus opuntia has the potential to be utilised for surface water treatment applications. Turbidity removal was less effective in the case of landfill leachate (31.6 - 41.9%) but the removal percentage was observed to increase in the presence of Mn^{2+} *(bivalent cation).*

Keywords: *Alkalinity, Cactus Opuntia, Landfill Leachate, pH, Surface Water, Turbidity*

1. INTRODUCTION

Coagulation is a vital process in the treatment of both surface water and industrial wastewater. Its application includes removal of dissolved chemical species and turbidity from the aforesaid water via addition of chemical-based coagulants such as alum ($AlCl_3$), ferric chloride ($FeCl_3$) and polyaluminium chloride (PAC). While the effectiveness of these chemicals as coagulants are well noted [1,2] there are, nonetheless, drawbacks associated with usage of these coagulants such as relatively high procurement costs, detrimental effects on human health, production of large sludge volumes as well as the fact that they significantly affect pH of treated water. It is therefore, desirable to replace these chemical coagulants with cost-effective natural coagulants to counteract the aforementioned drawbacks.

Research on natural coagulants have been focused on *Moringa oleifera* [3-7] for the past two decades but more researchers are studying application of other natural coagulants such as long bean extract and cactus *opuntia*. It was determined, via two separate studies, that standalone long bean extract [8] was ineffective in removing turbidity while cactus *opuntia* [9] exhibited high turbidity removal efficiency for sewage and seawater treatment. Hence, the positive outcome of the latter study justifies further research on usage of cactus opuntia as a natural macromolecular coagulant to treat other types of highly turbid wastewater such as landfill leachate.

The objectives of this study were to evaluate the effectiveness of cactus *opuntia* for turbidity removal from surface water (estuarine and river) and landfill leachate via jar test and determine the effect of dosage of cactus powder on turbidity, pH and alkalinity of the water and leachate.

2. MATERIALS AND METHODS

A. COLLECTION OF RAW WATER SAMPLES

Estuarine water samples were collected from the estuary of Klang river at Port Klang, Selangor. It was observed that the samples were turbid and brown-yellowish in color. It was presumed that the samples were contaminated with oil and grease that originated from spent diesel spilled from boats in addition to other turbid-causing substances such as silt and plankton within the estuary. River water samples were collected from Renggam River located within Shah Alam, Selangor. These samples were also turbid possibly due to high concentrations of silt along the river. Raw landfill leachate samples were collected from the leachate pumping station at the Taman Beringin Landfill in Kepong, Kuala Lumpur. All the samples were collected via grab sampling and stored in clear plastic containers prior to immediate experimentation.

B. PREPARATION AND CHARACTERISATION OF CACTUS POWDER

Cactus *opuntia* used in the study was collected from a nursery in Sg. Buloh, Selangor. The cactus was washed with tap water and subsequently sliced into small pieces to facilitate drying. The sliced cactus was then dried in oven for 8 hours at 80˚C. The dried cactus was ground into fine powders using pestle and mortar and subsequently sieved to size range of 53 – 106 μm.

Elemental analysis of the cactus powder to determine its carbon, hydrogen and nitrogen contents was carried out using Thermo Electron Flash EA 1112 Elemental Analyser. The pH of cactus powder was determined by mixing the powder in distilled water at dosages of 13, 53, 213 and 853 mg/L and stirred at 130 rpm for 3 minutes prior to measurement.

C. TURBIDITY REMOVAL FROM SURFACE WATER

Jar test was used to determine the effectiveness of using cactus powder for turbidity removal of surface water. The test was conducted via jar test apparatus (Chemix Floc-Tester – CL6) using 300 mL-capacity jars. Cactus powder of dosages of 13, 53, 213 and 853 mg/L for each water samples were tested. These tests were conducted in duplicates. In the mixing stage, raw estuarine or river water samples of 300 mL each were stirred at 130 rpm for 3 minutes after the cactus powder was added. After 3 minutes, the coagulation stage commenced where the samples were stirred at 80 rpm for 30 minutes. This was then followed by the settling stage, where samples were allowed to stand for 30 minutes after which treatment was completed. Turbidity, pH and alkalinity of samples before and after the jar tests were measured and tabulated. Turbidity values were determined via 2100P HACH Turbiditimeter while pH values were determined via Mettler-Toledo Delta 320 pH meter. Alkalinity values were determined by using HACH basic laboratory test kit via Method 8203.

D. TURBIDITY REMOVAL FROM SURFACE WATER

Tests on turbidity removal of landfill leachate were conducted in two separate parts with similar experimental procedure as Section 2.3. For the first part, only cactus powder of dosages 0.8, 1.7, 3.3 and 6.7 g/L were added in each jar. For the second part, the jar test was repeated for cactus powder of dosage 6.7 g/L with addition of manganese (II) sulfate ($MnSO_4.4H_2O$) at 1.7, 3.3, 6.7 and 13.3 g/L dosage. This was to examine the effect of addition of bivalent cation on the effectiveness of cactus powder to remove turbidity from landfill leachate. Manganese (II) sulfate used in the study was reagent grade and provided by Fisher Chemicals (UK).

3. RESULTS AND DISCUSSION

A. ELEMENTAL ANALYSIS AND PH OF CACTUS OPUNTIA

Elemental analysis (Table 1) was carried out to provide a preliminary comparison between the elemental compositions of the cactus with that of a conventional natural coagulant, *Moringa oleifera* as determined by Ndabigengesere, *et. al*. [5]. In this study, it was determined that cactus opuntia contained 2.3% nitrogen, 29.4% carbon and 1.7% hydrogen. From Table 1, it was evident that the carbon percentage of both the shelled and non-shelled *Moringa* were almost twice the carbon percentage of cactus. This was perhaps attributed to the composition of *Moringa* which consisted of more organic matter as compared to cactus.

Table 1: Elemental analysis of natural coagulants

	Cactus *opuntia*	Shelled *Moringa* seeds [a]	Non-shelled *Moringa* seeds [a]
N (%)	2.3	6.1	5.0
C (%)	29.4	54.8	53.3
H (%)	1.7	8.5	7.7

[a]As determined by Ndabigengesere *et al.* [5]

Table 2: pH of natural coagulants

	Cactus *opuntia*	Shelled *Moringa* seeds [b]	Non-shelled *Moringa* seeds [b]
Water only	7.00	7.30	7.30
13 mg/L	6.88	-	-
53 mg/L	6.50	-	-
213 mg/L	6.21	-	-
853 mg/L	6.00	-	-
50,000 mg/L	-	6.40	5.8

[b]As determined by Ndabigengesere *and Narasiah* [10]

Table 2 shows the pH of the natural coagulants mixed in distilled water (cactus) and tap water (*Moringa*). The latter was determined by Ndabigengesere and Narasiah [10]. Both coagulants were slightly acidic in the presence of water. It was observed that increased cactus dosages correlated with decreased pH.

B. EFFECT OF CACTUS DOSAGE ON TURBIDITY REMOVAL FROM SURFACE WATER

It was observed that the powdered cactus formed large flocs with impurities in the sample which facilitated settling and as a result, clear supernatant was produced. Similar observation was also noted for treated river water. Figure 1 shows the effect of dosage of cactus powder on residual turbidity of surface water. It should be noted that the residual turbidity with no presence of cactus dosage corresponded to initial turbidity. Initial turbidity values measured were 499 and 547 NTU for estuarine and river water respectively. Turbidity removal efficiencies after treatment at various dosages ranged from 93.1 – 98.2% for estuarine water and 49.9 – 69.7% for river water. From Figure 1, the optimum dosage for both water was approximately 13 mg/L which incidentally, was the smallest dosage used in the study. This was compared with the finding of a study conducted by Zhang *et al.* [9] where the optimum dosage of cactus *opuntia* used for turbidity removal of seawater (980 NTU) was 60 mg/L. In that study, the highest removal efficiency reached 99% which was comparatively similar to the highest removal efficiency obtained for treated estuarine water (98.2%) in this study.

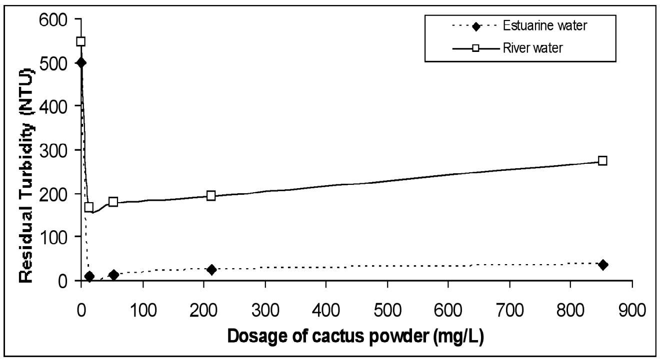

Figure 1: Effect of dosage of cactus powder on turbidity of estuarine and river water

C. EFFECT OF CACTUS DOSAGE ON PH AND ALKALINITY OF SURFACE WATER

Figure 2 shows the effect of dosage of cactus powder on final alkalinity and pH of the water. It appeared that increased cactus dosages from 13 to 853 mg/L had a marginal effect on the final pH of the water with values ranged from 7.25 to 7.69 (estuarine) and 7.83 to 8.49 (river). This result implied that even though the dosages were substantially increased, the final pH of the water were relatively unaffected as compared to the usage of chemical-based coagulants. This notion was supported by a study conducted by Fatoki and Ogunfowokan [11] involving coagulation of turbid river water by means of alum and ferric chloride showed that dosage of 10 mg/L either chemical constituted pH increase by at least 0.4. It was therefore, anticipated that further increase in dosage of the chemicals would substantially increase the pH of treated water.

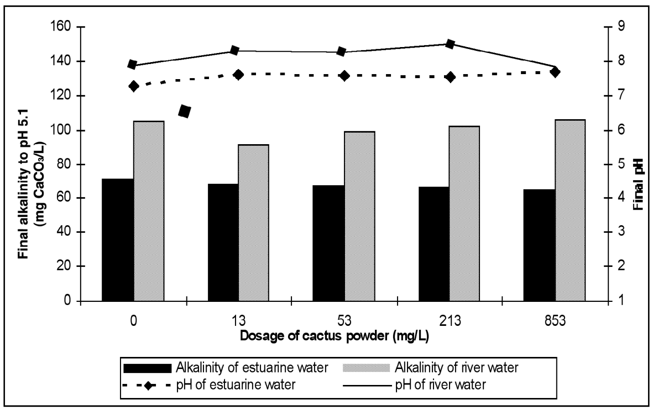

Figure 2: Effect of dosage of cactus powder on final alkalinity and PH of estuarine and river water

It can be seen that the amount of cactus added was well correlated with the final alkalinity to pH 5.1, albeit at contrasting trend for the two water. For estuarine water, increase of cactus dosage from 0 to 853 mg/L represented a decrease of alkalinity values from 71.2 to 64.8 mg $CaCO_3$/L. For river water, the initial dosage at 13 mg/L decreased alkalinity values from 104.8 to 91.2 mg $CaCO_3$/L while further increase of dosages increased alkalinity values from 98.8 mg $CaCO_3$/L (dosage 53mg/L) to 105.6 mg $CaCO_3$/L (dosage 853mg/L).

D. EFFECT OF CACTUS DOSAGE ON TURBIDITY REMOVAL OF LANDFILL LEACHATE

Initial pH and turbidity of landfill leachate prior to coagulation were 4.78 (acidic) and 924 NTU respectively. Figure 3 shows the effect of dosage of cactus powder on residual turbidity of leachate. The leachate pH fluctuated within the range of 4 - 5 with addition of varied dosages (not shown). Due to marginal changes in pH and high acidity of leachate, alkalinity was not determined for this case. Turbidity removal efficiencies after treatment at various dosages ranged from 35.0 to 41.9 %. As compared to turbidity removal from surface water, cactus powder was relatively less effective for leachate and exhibited a rather erratic trend where turbidity fluctuated slightly within the range from 500 to 600 NTU at cactus dosages of 0.8 to 6.7 g/L. Thus, the optimum cactus dosage for this case was comparatively ambiguous due to these fluctuations. The authors postulated that the ineffectiveness of cactus for leachate compared to surface water was due to two

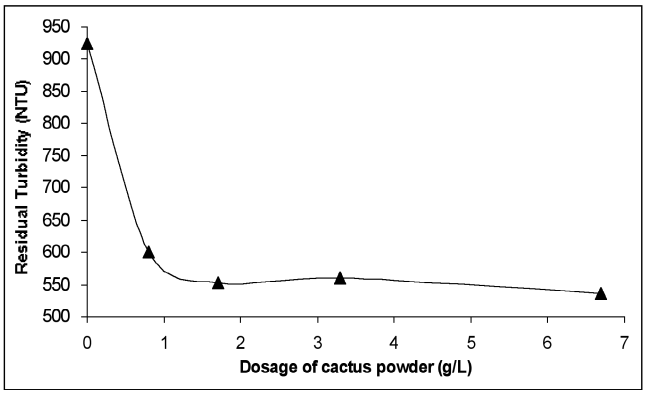

Figure 3: Effect of dosage of cactus powder on turbidity of landfill leachate

factors, namely, composition and initial pH of leachate. As landfill leachate from the Taman Beringin landfill was comprised of a spectrum of high-concentrated compounds such as suspended solids, heavy metals, dissolved organics and chlorine [12], it was therefore a much more complex mixture than surface water and these compounds may had significantly interfered with coagulation process. It was also postulated that the initial pH of leachate was not within the optimum range for coagulation process. At the time of the study, these postulates could not be verified due to limited laboratory resources.

E. COMPARISON BETWEEN TURBIDITY REMOVAL FROM SURFACE WATER AND LANDFILL LEACHATE

Figure 4 shows the comparison between turbidity removal from surface water and landfill leachate. Turbidity values were normalised for this case to offset the difference of initial turbidity so that all the samples would have the same initial normalised turbidity of 1 NTU/NTU. Significantly higher cactus powder dosages for landfill leachate were required for turbidity removal as compared to the surface water. Other dissimilarity between surface water and leachate was that the former achieved optimum removal at the smallest dosage before turbidity increased at increased dosages whereas turbidity removal for leachate increased gradually and reached constant removal percentage at about 40% for subsequent increased dosages.

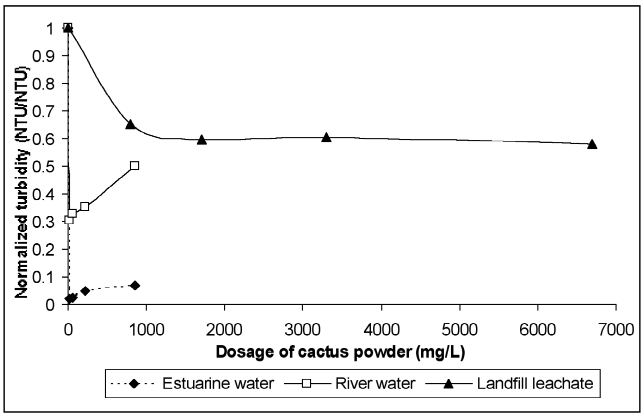

Figure 4: Comparison between turbidity removal from surface water and landfill leachate

F. EFFECT OF ADDITION OF MANGANESE (II) SULFATE FOR TURBIDITY REMOVAL FROM LEACHATE

In a study carried out by Okuda *et al.* [6], it was established that bivalent cations such as Ca^{2+} and Mg^{2+} significantly enhanced the coagulative effect of *Moringa oleifera* extracts in which the cations may have electrically adsorbed to the negatively-charged *Moringa* oleifera active components to form insoluble net-like structure to capture suspended kaolin particles. They further reported that monovalent cations could not form nets because the cations could not connect two active components together. Their findings indicated that other cations such as Mn^{2+} could perhaps be used to enhance turbidity removal effectiveness of cactus opuntia since it was established in Section 3.4 that cactus powder was

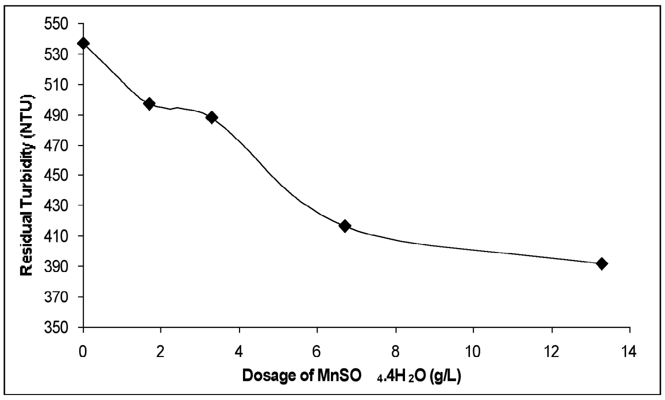

Figure 5: Effect of addition of $MnSO_4.4H_2O$ to enhance the effectiveness of cactus powder for turbidity removal from landfill leachate

relatively less effective for turbidity removal from leachate. Figure 5 shows the effect of addition of manganese (II) sulfate to enhance the effectiveness of cactus powder (dosage = 6.7 g/L) to remove residual turbidity from landfill leachate. Addition of manganese (II) sulfate evidently enhanced turbidity removal from the leachate. The highest increase of turbidity removal was 27% corresponding to addition of 13.3 g/L of manganese (II) sulfate. Results of this study suggested that the turbidity removal mechanism of cactus *opuntia* for treatment of leachate was possibly "enmeshment" by insoluble matters formed by active component in the cactus as initially suggested by Okuda *et al*. [6] for their *Moringa oleifera* study. This would require further research for verification.

4. CONCLUSION

Overall, results from this study indicated that powdered cactus opuntia was very effective in removing turbidity from surface water as evident by the high removal efficiencies (49.9 – 98.2%) while it was less effective for landfill leachate (31.6 - 41.9%). This suggested that cactus *opuntia* has good potential for surface water treatment applications. Increased cactus dosages correlated with decreased pH of surface water. For surface water, optimum removal was achieved at the smallest dosage before turbidity increased at increased dosages whereas turbidity removal for leachate increased gradually and reached constant removal percentage at about 40% for subsequent increased dosage. Addition of manganese (II) sulfate, a type of bivalent cation, enhanced the coagulative effect of cactus *opuntia* to remove turbidity from leachate. ■

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