Investigation of the potential of Opuntia Ficus-Indica powder for sewage treatment

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DOI: 10.29322/IJSRP.10.10.2020.p10626
http://dx.doi.org/10.29322/IJSRP.10.10.2020.p10626

Abstract- The world is facing scarcity in water resources due to various reasons. Irrigation consumes about 86% of the water withdrawal in Egypt which means less water for the domestic and other sectors usage. Thus, treatment of turbid wastewater as sewage water should be done to decrease the amount of the pure water used in irrigation. The presented project reviews a wastewater treatment technology that involves cactus of the species OFI (Opuntia ficus-indica). This adsorptive biomaterial is involved as coagulant/flocculent and hence collects all the pollutants, heavy metal ions and bacteria in the wastewater instead of using synthetic coagulants as Alum. The results obtained in the depollution of wastewater showed very high and promising pollutants-removal efficiency. Cactus significantly optimized many wastewater parameters (turbidity, COD, heavy metals ions, BOD, TSS etc.). The optimum dosage obtained was 1.5g/L of cactus powder. The pH was maintained near the normal level (7.5-8). The removal efficiencies for the Manganese, Iron, and Aluminum ions were 92%, 87.8%, and 83.6% respectively. The total coliform removal efficiency was 99.92%. For many special characteristics (surface composition, properties, abundance, non-toxicity, etc.), cactus powder is a useful material for wastewater treatment instead of chemical coagulants making it applicable.

Index Terms- cactus mucilage, polysaccharides, Bio-sorption, coagulation, Glucuronic acid, d-galactose, l-arabinose, carboxyl, hydroxyl, amino/amine, divalent ions.

I. Introduction

Water crisis is now approaching step by step to the whole world and it is one of the fundamental grand challenges facing humanity in this era. Irrigation is consuming about 86% of the water withdrawal in Egypt and 90% of the global water usage according the International Water Management Institute [9]. In this paper, water crisis challenge is discussed stressing on the irrigational consumption. Wastewater of several sorts is disposed into rivers and seas as a final stage of its drainage. The solution discussed in this paper is to treat the wastewater, like sewage water, and try to utilize it in irrigational purposes.

This thesis presents the flocculent, bio coagulant, and bio sorbent capabilities of a cactus species common to many dry arid climates throughout the world. Opuntia Ficus-Indica, the used cactus species, capabilities to remove sediments, heavy metal ions, and various types of bacteria from contaminated sewage water were investigated using different extracts: mucilage and powder. The species proved that it could be used as a bio sorbent or a bio coagulant/flocculent instead of the traditional means of water treatment by flocculation as: Alum and Ferric chloride.

Screening and sand filters are used in companion with the cactus-coagulation method to remove coagulated structures and relatively large sediments in water as well as dyes (Chlorophyll-A) introduced by the cactus. This novel treatment method presents an economic solution with minimal health hazards—compared to its counterparts. This treatment method could be applied to all the treatment stations for sewage and municipal water. To sum up, the treated water has the potential to replace a large portion of the pure water used in irrigation.

The tested water parameters are: TSS; TKN; NH3; BOD; COD; Turbidity; heavy metal ions including Al, Ba, Cu, Fe, Pb, Mn, Sr, Zn, and Cd; bacteria removal including Total Coliform, Fecal Coliform, B-cereus, and E-coli.

II. Methods

***Preparing the cactus (coagulant / flocculent / adsorbent / bio-sorbent)*:** Two types of fresh cactus were collected and processed with different ways, first way was taking the fresh viscous mucilage from sliced cactus. The second way was making cactus powder by peeling the cactus (shown in figure 1) and drying it for 10 minutes at oven's high temperature, 5 minutes at medium temperature, and finally 5 minutes at low temperature. the dried cactus was grained by mortar and pestle.

Figure 1: Opuntia Ficus-Indica species being peeled for drying and mucilage extraction.

Preparation of sand filters: The sand was collected and put in contact with water to remove the very small clay particles that stayed suspended in the water. Charcoal was brought and grained forming fine charcoal. Two filters were made, the first one had more sand content to reduce TSS. The second one had more active carbon content to filter out the "chlorophyll-A" and dyes of cactus powder.

Collection of turbid sewage water sample: 4 liters of non-treated sewage water samples were obtained from a village's sewage collecting plant.

(Coagulation/flocculation/adsorption/bio-sorbent) activity jar test: 400 ml of high-turbidity sewage water samples were put in each of the four 1-liter beakers after the sewage was passed through sand filter. Cactus extractions were put with water in 3 beakers and were exposed to different stirring speeds: 100rpm for 1 minute and 30rpm for 10minutes; the fourth beaker was left as a control.

After rotating, the one liter beakers were allowed to settle for 20 minutes then 40ml were taken 3 cm below surface of water from each beaker and parameters like TSS, TS, TDS, PH, DO, COD, BOD, TOC, DOC, conductivity, chlorophyll-A, turbidity and Transmittance were measured. The adsorption activity in the removal of heavy metals of the cactus as a bio-sorbent and coagulant/flocculent was determined by measuring the amount of heavy metal ions after and before the treatment. Finally, the water was passed again through second sand filter to filter out the dyes.

Investigation of cactus activity in bacterial flocs formation: Flocs of bacteria are shown in figure 2. The flocs formed after treating the water were taken and observed under microscope targeting the B-cereus and E coli, as shown in figure 4. At the right, E coli cells were gathered by cactus. Also at the left, the pretreated water showed the flocs made by cactus. Bacterial incubation test was performed to investigate the total and fecal coliform removal efficiencies. This was done by putting sample of non- treated and treated water in incubator different times with different conditions suitable for each bacterium and the samples were compared.

III. Results

Test 1: A jar test was made to determine the turbidity, TSS and "chlorophyll-A" after processing it in coagulation / flocculation processes, OFI (Opuntia ficus-indica) showed great results removing turbidity and TSS with efficiencies 97% and 92.8% respectively; the "chlorophyll-A" content increased dramatically but it was removed later with sand filter.

Test 2: After water samples were collected, some parameters were determined shown in table 2 .PH results were confirmed using a pH meter and compared to Alum for each dosage added as shown in figure 3.

***Test 3*:** After the water was put in contact with cactus powder, Cactus was determined to have relatively high capacity for heavy metals adsorption. The removal efficiencies are shown in table 1.

Test 4: Bacterial aggregation activity of cactus powder resulted in white flocs shown in figure (2) with concentration of 10^8 cells per ml; figure (2) illustrates the white flocs of bacteria formed after several hours of settling. The bacterial cells were observed by microscope. The incubation test showed a total coliform removal efficiency of 99.92% and fecal coliform removal efficiency of 99.94%.

Table 1: Metal ions removal efficiencies of the OFI powder.

Metal ion	Removal efficiency
Aluminum	83.6%
Barium	72.4%
Copper	50.8%
Iron	87.8%
Manganese	92%
Strontium	76.6%
Cadmium	89.8%
Zinc	85.2%
Lead	69.3%

Table 2: various water purity parameters removal efficiencies of the OFI powder.

Parameter	Removal efficiency
TSS	92.8%
TKN	66.1%
NH_3	97%
Turbidity	97%
BOD	99.4%
COD	99.6%

IV. Analysis

Characterization of mucilage and Factors making it an eco-friendly material for treatment: According to [7], the factor behind using cactus as a material for wastewater treatment is its biochemical composition without toxic effects. It was reported by many studies that cactus is composed of low-protein and lipid contents.

Polysaccharides are considered as the main ingredient. Interestingly, cactus species are known by the polysaccharide-rich mucilage production. The presence of minerals, such as $Ca^{+2}$and K^+, is necessary for the gelatinous properties of mucilage. The high flocculation/coagulation capacity of cactus is related to its polysaccharide structure that is composed of various carbohydrates, such as l-arabinose, d-galactose and galacturonic acid. Arabinose is the highest in turbidity removal. Galacturonic acid is significantly implicated as the main active coagulant agent, based on its polymeric structure as shown in figure 6. This polymeric structure provides a bridge for particles to adsorb.

http://dx.doi.org/10.29322/IJSRP.10.10.2020.p10626

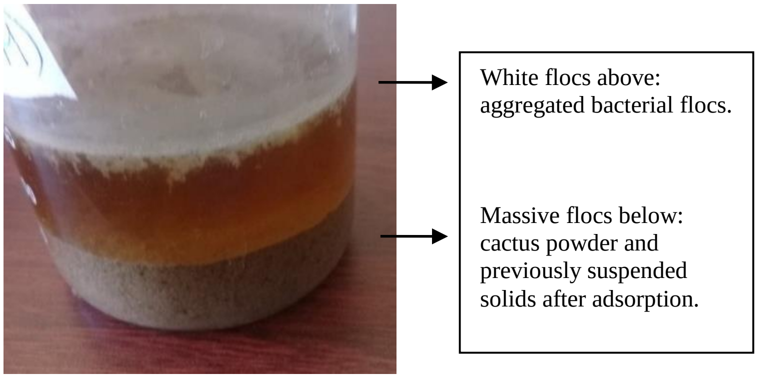

Figure 2: the collected flocs from ~3-liter sample of sewage water.

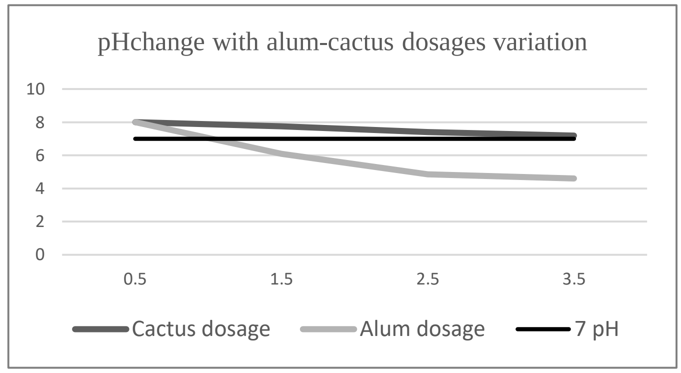

Figure 3: the effect of adding OFI powder on water pH vs

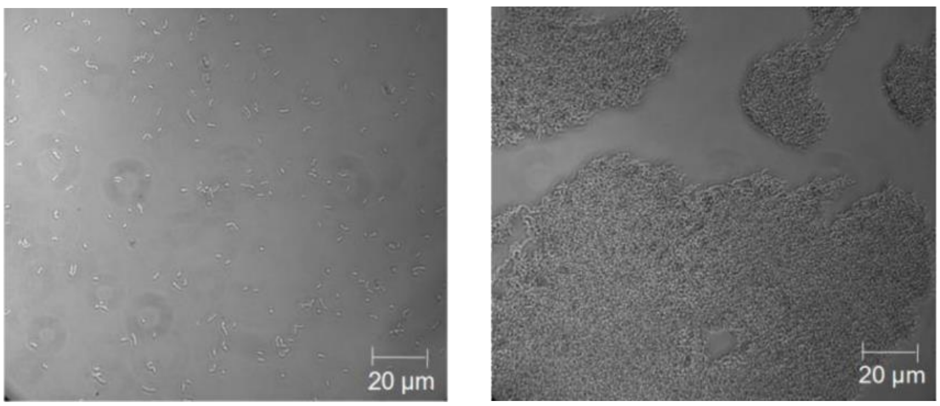

Figure 4: light microscope images of Bacillus cereus in control sewage water (Left) and bacterial flocs (Right).

Moreover, the functional groups of cactus polysaccharides included carboxyl (COOH—), hydroxyl (OH—) and amino or amine (NH_2—) groups, as well as hydrogen bonds. These functional groups are considered as preferred groups for the flocculation process.[1]

Bio-coagulant dosages effect: The increment in removal of turbidity by the increment of the dosage is due to increment of active site of the cactus powder. As the cactus powder dosage was increased, the final pH values of the water sample were relatively unaffected. This means that the cactus powder has no significant effect on the pH with the increment of the dosage unlike alum (as illustrated by figure 3).

Coagulation mechanism: Most of the plant-based organic coagulants predominantly function on adsorption and inter-particle bridging mechanism of coagulation. Our results have supported the hypothesis of adsorption facilitated by inter-particle bridging mechanism where particle destabilization takes place in the adsorption of colloidal particles onto the main chain and side chains of polysaccharides of OFI and forming the bridge in terms of complexes of particle-polysaccharide-particle[2]. Adsorption may take place through dipole-dipole interactions and hydrogen bonding. Due to high molecular weight of polysaccharides, their long chains may stretch into the medium and can adsorb the larger number of pollutants.

The natural electrolytes of mucilage of OFI, specifically divalent ions such as Ca^{+2} and Mg^{+2}, have a synergistic effect on coagulation by enhancing the complex formation. The full mechanism is illustrated in figure *5*.

Comparison between bio-coagulant and alum: As Alum is widely used as a chemical coagulant for water treatment, it was compared with cactus coagulant for treatment of wastewater. Although alum had relatively better turbidity-removal efficiency compared to cactus coagulant, the pH of treated water was much lower in case of Alum. The flocs formed using alum were nearly spherical in shape unlike the thread structured flocs formed by bio-coagulant. The floc size was small in case of alum generating the sludge of poor settling properties whereas the sludge formed by OFI was more compact with bigger flocs. It was also observed that in case of OFI, the sludge stayed compact even after creating the disturbance in water and separated from water easily.

Sand filters and the activated charcoal: The sand filter is used after the water is exposed to screening to get rid of some of the relatively large suspended solids. Activated charcoal is used in the sand filter since it has a large surface area and have tendency to adsorb heavy metal ions. The treated water by cactus is passed

[1] Credit of this hypothesis goes to [7].

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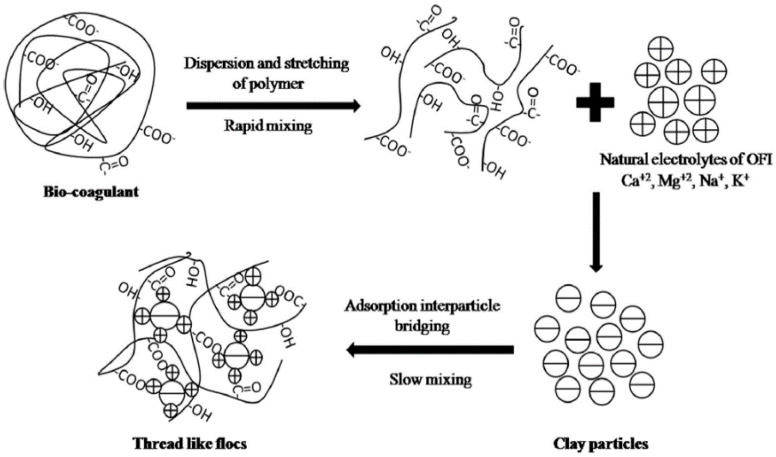

Figure 5: the supposed inter-particle bridging mechanism. Credit to [7]

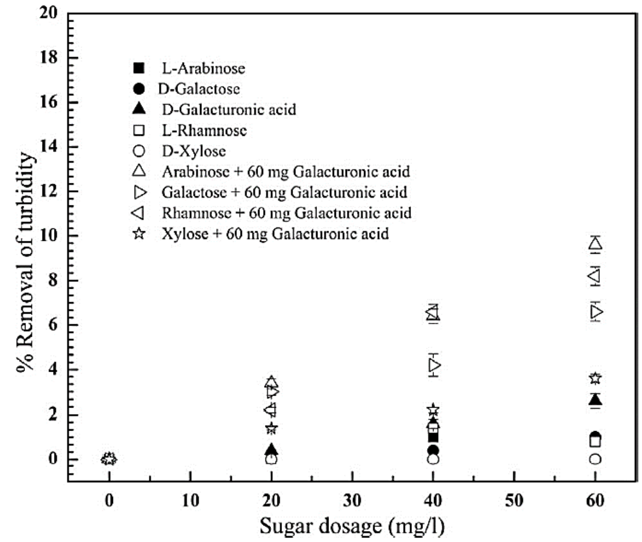

Figure 6: polysaccharides of mucilage with its anti-turbid effect. Credit to [7]

again over activated carbon to adsorb the chlorophyll-A dye present in the water.

V. Conclusion

Considering the discussed investigation, it is obvious that cactus has high potential for water treatment. It has high removal efficiencies for the contaminants of wastewater. It has no unfavourable effects on water during the treatment process. It has a negligible cost compared to the cost of chemical coagulants like Alum and Ferric Chloride; additionally, these chemical coagulants do not have the same potential as natural OFI powder. The first sand filter removed relatively large-sized particles and the second sand filter reduced "Chlorophyll-A" content. The cactus optimized the pH, COD, BOD, TSS, turbidity, heavy metal ions and bacteria presence in the water. Ultimately, clean sterile water suitable for agriculture was obtained.

VI. Recommendations

It is recommended for further investigation that:

1) Trying to combine other coagulants, instead of Alum, with cactus powder to obtain even better results in turbidity removal putting into consideration their effect on water characteristics and the pollutants removal.

2) When the project is applied on a large scale, it is preferred to dry the cactus to obtain the powder by subjecting the cactus (after peeling) to sunlight for about two weeks. This is much more cost-effective than drying cactus in the oven.

3) It is recommended to use pure cactus mucilage extracted with special type of centrifuge, the cactus will be peeled and mashed then it will be put in centrifuge machine which have very small pores that allows the mucilage liquid particles to pass without the other solid molecules, this mucilage should give better results as it will be pure extraction of polysaccharides and ions.

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