Wastewater Treatment using Bio-Coagulant as Cactus Opuntia Ficus Indica – A Review

Saurabh O. Deshmukh[1] Dr. M. N. Hedaoo[2]
[1]PG Student [2]Associate Professor
[1]Department of Environmental Engineering [2]Department of Civil Engineering
[1,2]Government College of Engineering, Amravati, India

Abstract— Reusing wastewater by effective treatment can contribute to counter the water scarcity. Conventional metal based coagulant treatment methods may prove inadequate to apply in aspects such as non-biodegradability and altered pH in post-treatment. There has been an extensive research on the use of biological plant material such as Agricultural waste, Chitosan, Moringa Oleifera, Eichhornia crassipes, Bark of acacia, Surjana seed, Maize seed, Tannin, Cicer aretinum, Cactus plant etc. as a coagulant. The present paper review to explore the use of cactus species in the bio-coagulation process and also it aims about investigation on effectiveness of cactus species Opuntia Ficus Indica as bio-coagulant which involve pH implication in post-treatment. In addition, the cactus had no significant effect on pH of treated water. This review highlights about optimum dosage and optimum pH at which turbidity removal is maximum. Some studies show the effectiveness of cactus in removing chemical oxygen demand (COD) and coloration in wastewater. Plant-based coagulants have the potential are effective in wastewater treatment which is sustainable and environmentally appropriate. The bio-coagulant proved to be efficient in turbidity and colour removal.

Key words: Bio-Coagulation, Cactus Opuntia Ficus Indica, Natural Coagulant, pH Implication, Wastewater Treatment

I. INTRODUCTION

The rapid increase of industrialization, urbanization, and population increase in the last few decades had caused a dramatic increase in the demanded surface water, as well as significant deteriorations in water quality throughout the world. The coagulation/flocculation process offers various advantages for the treatment of both industrial and municipal wastewaters including the lowered sensitivity to toxic loadings and to higher amounts of organics, the easy operation, the energy saving, etc. However, it had been demonstrated in various studies that chemicals (such as aluminum salts, acrylamides, etc.) used in the coagulation-flocculation process remain in treated water and may induce health problems. As indicated higher than, various health effects such as neurotoxic, carcinogenic, genotoxic and cancerogenic properties were reported [1]. Moreover, artificial polymers and undesirable substances related to them could react with others additional materials throughout the treatment and make by-products with unknown health effects [3]. For example, alum, the most widely used coagulant, was reported to be related to Alzheimer's disease [22].

II. PREPARATION OF COAGULANT

A. Amira, a. Ali, et al. (2017) deals with the preparation and application of a new biodegradable, non-polluting and the main biofocculant as cactus cladodes for water clarification. The Main objective of work was to replace conventional commercial products such as chemical coagulants ($FeCl_3$, $Al_2(SO_4)_3$ by natural coagulants [7].

A. Dry Extract

The cactus cladodes were peeled off the outer part. The inner part mucilage was sliced and oven dried at different temperature for different time laboratory. The dried cactus was milled into powder form, sieved and later used for coagulation purposes [1, 5, 7, 10,]. The following Table 1 shows that the various author quoted different temperature and time for drying mucilage.

Sr. No.	Temp.	Time	Ref.
1	80° C	24 hours	[1]
2	65° C	24 hours	[5]
3	100° C	2 hours	[7]
4	60° C	24 hours	[10]
5	85° C	20 min	[11]
6	60° C	24 hours	[13]
7	80° C	8 hours	[14]
8	80° C	6 hours	[15]
9	60° C	3 days	[19]
10	65 ° C	24 hours	[27]
11	105° C	4 hours	[30]
12	100° C	2 hours	[41]
13	60° C	24 hours	[44]
14	60° C	24 hours	[45]

Table 1: Temperature & Time Used For Drying Cactus Mucilage

A. Belayneh and w. Batu (2015) reported that the powdered cactus formed large flocs with impurities in the sample which facilitated setting and cleared supernatant was produced [8].

B. Aqueous Form

Peeled mucilage extract and different method used for perpetration of liquid coagulant shown in Table 2.

Sr. No.	Method	Ref.
1	10 gm of cactus powder was added to 100 mL distilled water followed by agitation for homogenization..	[4]
2	Mucilage was boiled in demonized water for 30 °C. pH is altered to 7 -7.5 with 1.0 M NaOH mixture was centrifuged at rpm 4000 for 10 minutes.	[6]
3	Dry powder heated in water at 85° C for 20 min	[12]
4	1 gm of powder mucilage mixed by magnetic stirrer in 1 Litre distilled water	[22]
5	10 gm coagutant added in saline sodium chloride 1.0% mixed with magnetic stirrer	[24]

	for 1 hour, centrifuged at 3500 rpm for 10 min	
6	Cladodes Cuts in small pieces and boiling 2L water for 20 min.	[28]
7	1.0 g of Opuntia ficus indica added to 100 mL of extraction solution (sodium chloride, potassium chloride and sodium nitrate (1 mol/L)) and agitated for 10 min. in magnetic stirrer	[31]
8	Cladodes mucilage cuts in small pieces ground with grinder and filters the extract using filtration viscous liquid found.	[38]
9	Known amount of Opuntia ficus indica added to 100 mL eluent (NaCl, $Bacl_2$)	[41]

Table 2: Method Used In Preparation of Coagulant

A. Amira, a. Ali, et al. (2017) recovered 1liter of gel from 500 gm of raw material and also cactus gel had a lifetime of 18 days where it had maintained at 4 °c for constant coagulant power. Also, 500 gm of cactus make it possible to treat 12. 5 m^3 of water which was similar to 500 gm of alum [7].

III. MATERIAL USED

Cactus was an abundant natural product, cost effective, safe for human health and biodegradable, offering various options (coagulant/flocculant, biosorbent, etc.) for the treatment of wastewater.

A. Cactus Mucilage

The Opuntia species in the cacti family had been known for its large production of mucilage, a complex used by the cactus to store water. The mucilage from the Opuntia ficus-indica had been previously studied as a natural flocculant [25, 42, 47]. Mucilaginous cells containing mucilage were identified to exist in both the peel and pulp of the cathodes, particularly the pads.

Different methods are developed to extract the mucilage from the cactus cladodes.

B. Chemical Composition and Properties of Cactus Mucilage

A. Belayneh and W. Batu compared chemical composition of Cactus and Moringa olifera. Following Table 3 shows Chemical composition of cactus and moringa olifera. The Carbon percentages of both shelled and non-shelled Moringa olifera were almost twice the percentage of cactus [8].

Content	Cactus	Moringa Olifera	
		Shelled Seeds	Non - Shelled Seeds
Nitrogen	2.30	6.10	5.0
Carbon	29.40	54.80	53.30
Hydrogen	1.7.	8.50	7.70

Table 3: Chemical Composition of Natural Coagulants

C. Nirmala Rani and Jadhav M. V. found that Cactus Opuntia contains carbohydrates such as L-arabinose, D galactose, L-rhamnose, D-xylose and galacturonic acid. Also report that galacturonic acid was possibly the active ingredient that affords the coagulation capability of Opuntia species through it should be noted that it only accounts for only 50% of turbidity removal. [14].

Luis G. Torres, Carlos Orozco, et al. reported that Opuntia mucilage contains polygalacturonic acid and five sugars. Cactus was use in the treatment of waters, using either the mucilage or the whole cladode powder. Water treatment without Fe/Al + synthetic polymers would yield water with less toxicity [28] [43].

IV. JAR TEST

Jar test equipment with multiple spindle stirrers and 1000 ml beakers was used in experiment. Sample were mixed thoroughly and agitated for a rapid mixing speed for different quantity of coagulant dosage for each beaker then lowered to slow mixing for flocculation after which sample were allowed to settle. The supernatant sample was collected and tested for turbidity and pH using turbidity meter presented in Nephelometric units (NTU) and pH meter respectively [1].
For Coagulation and flocculation jar testing apparatus used with rapid mixing and slow mixing speed with various timing with known coagulation quantity and determining the optimum dosage of coagulant shown in table 4.

Sr. No.	Rapid Mixing	Slow Mixing	Settling time	Ref.
1	150 rpm for 5 min	50 rpm for 15 min	30 min	[1]
2	150 rpm for 2 min	40 rpm for 15 min	30 min	[7]
3	100 rpm for 1 min	30 rpm for 10 min	20 min	[10]
4	100 rpm for 1 min	30 rpm for 10 min	20 min	[21]
5	200 rpm for 1 min	40 rpm for 20 min	20 min	[22]
6	200 rpm for 1 min	40 rpm for 20 min	20 min	[24]
8	150 rpm for 2 min	35 rpm for 20 min	30 min	[27]
9	200 rpm for 1 min	45 rpm for 30 min	60 min	[34]

Table 4: Jar Test- Mixing Speed, Time and Settling Time

Specification Effect of Coagulant Dosage On pH

A. W. Mumbi et al. reported that the pH depending on the coagulant dosage. PAC and Alum used water treatment was reduced the pH 8.2 to 8.1 and 8.2 to 7.4 with maximum dosage of 30 mg/L and 40 mg/L respectively. But it is reported that cactus + PAC does not change pH after treatment at dosage of 35 mg/L. This means there was no need to use other chemicals to alter the pH range [1].

H. D. Beyene, T. D. Hailerebrial et al. reported that cactus powder did not have a significant effect on final pH [21].

J. Diaz, J. Arguello, et al. reported that chemical coagulants lead to high aluminium concentration in water after treatment, which interferes with water disinfection, which poses some distribution problems, decreases transmission capacity, and generates corrosion problems. The study concludes that natural coagulants are equally effective in treating water and are also unlikely to alter the pH of treated water [24].

T. kannadasan, M. Thirumarimurugan, et al. reported that that increased cactus dosages correlated with

decreased pH. Powdered and dried cactus Opuntia was very effective in removing turbidity from effluent water than water hyacinth. It is proven that it has an effect on final pH of water as compared to chemical based coagulants [15].

H. D. Beyene, T. D. Hailerebrial et al. reported that cactus powder is more effective in pH upholding, TDS maintenance, and salinity removal than Alum. But combination of Alum and cactus powder was good coagulant for turbidity removal, salinity removal, pH and conductivity upholding [21].

A. M Inas, and L.Q Hashim suggested that high reduction in water turbidity is achieved, does not changed pH, little volume with biodegradable sludge is produced, as well as it is used for cold water treatment [22].

L. Muruganandam, M P Saravana Kumar, et al. reported that initial studies were done on the synthetic waste water to determine the optimal pH and dosage, the activity of natural coagulant, followed by the real effluent from tannery waste. The raw tannery effluent have high COD 4000mg/l and turbidity in the range 700NTU was diluted and dosed with organic coagulants, Aloe Vera, Moringa Oleifera and Cactus. The study observed that coagulant Moringa Oleifera of 15 mg/L dose at pH 6 gave the best reduction efficiencies for major physicochemical parameters followed by Aloe Vera at pH 5 and Cactus has optimal dosage and pH of 40mg/l and 7 respectively. [27].

V. EFFECT OF COAGULANT DOSAGE ON TURBIDITY

A.W. Mumbi, et al. had taken sample from Mwagu outfall. The initial turbidity of water samples were 150 NTU, 415 NTU and 510 NTU. Coagulants used were Polyaluminium chloride (PAC), Alum and Cactus + PAC. The use of PAC in water coagulation resulted in turbidity removal efficiency of 95% at an optimum dosage of 30 mg/L. Alum had been found removal efficiency of 95% and combined with Cactus + PAC had been found removal efficiency of 98%. By comparing their turbidity removal efficiencies Cactus + PAC performed better than alum and PAC was used alone [1].

A. Sangeetha, E. Tamilarasan, et al. reported that when compared to Alum gives turbidity removal 36%, Cactus gives best result in turbidity removal 49% in treatment of Textile effluent [2].

A. Mukhtar, W. Ali, et al. reported that initial turbidity of 150 NTU of synthetic water lies between pH 9-10 reduce turbidity between 18 – 63 NTU for different coagulant doses. Also it was observed that there was no significant change in the pH during coagulation process [5].

A. Balakrishnan and A. Neera, used two different plant materials as Cactus and barks of acacia as natural coagulants tested using synthetic water. Cactus is found to be more effective in the neutral pH with more than 95% turbidity removal. Acacia is more effective in the acidic pH with 98% turbidity removal [6].

A. Amira, A. Ali, et al. reported that initial turbidity of sample was 120 NTU at pH 8.20 after using the cactus as coagulant optimum pH found to be 8 and percentage turbidity reduction was equal to 99.53% [7].

B. S. Shilpa, Akanksha, et al. used two different natural coagulant was opuntia ficus indica species of cactus and Hyacinth Bean peels. The optimum pH of cactus and Hyacinth Bean peels was found to be 9.0 and 9.5 for 20 mg/L. Also initial turbidity of 500 NTU the turbidity removal was 89.03% and 77.10% respectively. The use of natural coagulants like cactus and Hyacinth bean are receiving attention for their effectiveness in water treatment [10].

B. Mounir, A. Abdellah, et al. reported that evaluation of fives extracts from cladodes of Opuntia Ficus Indica extracted by different solvents at high temperature was investigated, as coagulant aids with lime as coagulant. The turbidity of 1000 NTU removal efficiency for two extracted was greater than 95% and can achieve 99% at optimal condition of dosage and pH [11].

Bouatay F. and Mhenni F. reported that an optimization and modelling analysis using cactus mucilage combined with aluminium sulphate showed that best condition for flocculation process were given for pH equal to 7.25, flocculants dose of about 40 mg/L with mixing speed of about 30 rpm for 11 min. The result of decolourization equal to 99.84%, COD removal of about 88.76% and turbidity removal of about 91.66% [13].

C. Nirmala Rani and Jadhav M. V. conducted coagulation process using Strychnos potatorum, Cactus and Coccinia indica as coagulant. Optimum dosage found to 1.5 mg/L, 30 mg/L and 0.5 mg/L respectively [14].

J. Zhang, F. Zhang et al. reported that the cactus coagulation attained comparatively high turbidity removal efficiency and water with turbidity less than 5NTU could be obtained with initial turbidities from 20 to 200. When cactus was used with $AlCl_3.6H_2O$ synchronously to treat sewage water, the removal efficiency of turbidity 94% and COD were higher than that of cactus or $AlCl_3.6H_2O$ was used solely [25].

M. Neffa, H. Hanine, et al. reported that use of cactus was decrease of 75% of COD is achieved, 90% for suspended solids with an optimal dose of 150 ml/L of Olive mill waste waters [30].

M. T. F. de Souza, E. Ambrosio, et al. reported that use of cactus in jeans washing laundry effluent optimum conditions determined for $FeCl_3$ 160 mg/L, cactus dosage 2.60 mg/L at pH 5.0. For fabric dyeing effluent optimum condition determined for $FeCl_3$ 640 mg/L, cactus dosage 160 mg/L at pH 6.0 [31].

N. fedala, H. Lounici, et al. reported the effectiveness of different solution of Opuntia with best removal of 0.5 NTU for the most turbid water by using 0.2 mg/L of cactus concentration. This natural coagulant functions by means of adsorption mechanisms followed by charge neutralization or polymeric bridging effect [34].

R. Rachdi, F. Srarfi, et al. reported that treatment conducted by aluminium sulphate followed by cactus juice had significantly better turbidity removal efficiency 93.65%, low residual COD 64.30% and suspended solid 82.75% [38].

R. Daza, J. M. Epalza, et al. reported that % turbidity and % colour removal using various desertic plants shown in table V [39].

Plant species	% Turbidity Removal	% Colour Removal
Opuntia species	88.56	97.67
Stenocereus	88.56	94.67
Cereus forbesii	88.31	92.27

Melocactus species	97.15	96.80
Aloe arborecens	92.74	95.73
Aloe vera	92.74	95.73

Table 5: Percentage & Colour Removal Using Desertic Plant

S. Miller, E. Fugate, et al. (2008) explored the use of Cactus Opuntia together with Moringa Oleifera in turbidity removal in synthetic clay solutions. Coagulation activity was found present in most parts of OFI plant which varied according to treatment. There was no coagulation activity in the skin of Opuntia species. The maceration and/or drying of whole pad at 120 °C resulted in loss of coagulation activity. The natural coagulant was found to reduce turbidity in the range 92 to 99% with residual turbidity falling between 5 and 7 in basic waters [42].

T. Kazi, A. Virupakshi, et al. reported that Cicer arietinum, Moringa Oleifera and cactus were used as locally available natural coagulants for study to reduce turbidity and COD of tannery wastewater [45].

Natural Coagulants	Dosage	pH	Turbidity Removal	COD Removal
Cicer arietinum	0.1	5.5	81.20%	90%
Moringa Oleifera	0.3	4.5	82.02%	83.33%
Cactus	0.2	5.5	78.54%	75%

Table 6: Result of Wastewater Treatment Using Natural Coagulant

VI. Effect of Cactus on Sludge Volume

N.H. Al-Saati, E. H. Hwaidi, et al. studied comparative performance between cactus and alum as coagulant. Also reported that Natural coagulant produce less sludge volume compared to alum and they do not require pH adjustment [35].

VII. Effect of Cactus Dosage on Dissolved Oxygen

H. D. Beyene, T. D. Hailerebrial et al. reported that the initial concentration of DO in the collected water sample was 6.9 mg/L. When the dose of cactus powder increased from 0.50 g to 3.50 g, the concentration of DO decreased from 6.49 mg/L to 4.32 mg/L. In a similar condition, when the dose of Alum increased from 0.50 g to 3.50 g, the concentration of DO decreased from 6.65 g/L to 5.39 mg/L. In both natural and chemical coagulants, the value of DO is decreased. [21].

VIII. Cactus Used in Different Treatment Methods

A. Cactus used as Adsorbent

A. Gebrekindan studied that analytical grade chemicals were used during the experiment as Aldrin, Dieldrin, DDT, Trifluralin, methanol, dichloromethane and anhydrous sodium sulphate. It was found that pesticides adsorption on dried Opuntia ficus-indica. Cactus has potential for the development of an economically viable, effective, inexpensive natural adsorbent for treatment of polluted surface waters. The removal of pesticides takes place due to surface adsorption and the adsorptive capability of mucilage [3].

B. Cactus Used In Electrocoagulation

A. Nawel, D. Farid, et al. study that optimization of the effect of Opuntia Ficus-Indica pad juice on electrocoagulation water treatment process by response surface methodology. Electrocoagulation with cactus juice shows 71.90% of turbidity removal [4].

C. Cactus used in Sludge Conditioning

H.betatache, A. Aouabed et al. compared north Algerian prickly pear cactus juice with polyelectrolytes (Chimfloc C4346, Sedipur NF 102, a cationic polymer, and Sedipu AF 400) and inorganic conditioners ($FeCl_3$ and $Al_2(SO_4)_3$) in coagulating wastewater sludge. Also chemical characterization of the cactus juice alongside conditioning of the sludge with the juice and comparison chemicals, with analysis involving Fourier Transform Infrared spectral analysis and photometry. Also it was demonstrated that the juice from the cactus promoted the coagulation of almost all of sludge, enabling liquid and solid separating and easing filtration process [19, 20].

P. Jelena, S. Marina, et al. reported that the most common coagulant is alum, but presence of large quantities of aluminum salts in sludge has a harmful impact on digestion and digested sludge application. Organic nature, the biogas yield can be enhanced by presence of cactus [23].

Q. Abdulazeez, Md. S. Jami, et al. reported that natural polycoagulant can be selected for sludge dewatering with high efficiency and eco-friendly nature [37].

D. Cactus used for Heavy Metal Removal

P. C. Mane, A. B Bhosle, et al. studied that the removal of Chromium and Nickel ions by Opuntia, a natural polyelectrolyte was investigated. The working concentration of metals used in this study was 10 mg/L. The equilibrium time needed for maximum metal removal was 18 hour. 10%(v/v) Opuntia ficus indica polyelectrolyte and 150 rpm at 30 °C are optimum conditions for removal of Cr and Ni ions from aqueous solution. The maximum removal of Cr and Ni by Opuntia polyelectrolyte after 18 h of equilibrium was 68% and 88.4% respectively [32].

S. Asha, C Tabitha, et al. studied to determine the efficiency of prickly pear mucilage in removal of chromium 98.75% from wastewater [40].

T. Nharingo, M. Zivurawa, et al. reported that Cactus Opuntia ficus indica was investigated on its potential to remove Pb(II) ions from wastewaters. FTIR characterization confirmed the involvement of –C–O–C, –OH, –C=O, N–H and –CH groups of the carboxylic acids, amino acids and polysaccharides in the removal of Pb(II) ions [44].

IX. Conclusion

It is concluded that the Cactus family species used for various purposes like treatment of wastewater, conditioning of sewage, heavy metal removal, adsorbent to remove pesticides and medicinal use also. Due to use of metal based coagulants causes diseases like Alzheimer's etc. and also there is change in pH of water after treatment occurs. To overcome these problems, cactus coagulant is the best replacing material. Biodegradability of cactus helps in sludge separation as well

as degradation of organic material. But after use of cactus as coagulant, in treatment, there is decrease in dissolved oxygen level in water.

REFERENCES

[1] W. Mumbi, L. Fengting, A. Karanja, "Sustainable treatment of drinking water using natural coagulants in developing countries: A case of informal settlements in Kenya", Water Utility Journal 18: 1-11, 2018
[2] A.Sangeetha, E. Tamilarasan, T. Tamilmani, M. Yuvasri, P.Shankar, "Treatment of textile waste water by natural coagulant", International Journal of Intellectual Advancements and Research in Engineering Computations Vol. –06(02) 2018 [1137-1139] ISSN: 2348-2079
[3] Gebrekidan, H. Nicolai, L. Vincken, M. Teferi, T. Asmelash, T. Dejenie, S. Zerabruk, K. Gebrehiwet, H. Bauer, J. Deckers, P. Luis, L. De Meester, B. Bruggen, "Pesticides Removal by Filtration over Cactus Pear Leaves: A Cheap and Natural Method for Small Scale Water Purification in Semi-Arid Regions", https://doi.org/10.1002/clen.201200042
[4] Nawel, D. Farid, M. Belkacem, L. Jean-Pierre, M. Khodir, "Improvement of electrocoagulation–electroflotation treatment of effluent by addition of Opuntia ficus indica pad juice", Separation and Purification Technology 144 (2015) 168–176 journal homepage: www.elsevier.com/locate/seppur
[5] Mukhtar, W. Ali, G. Hussain, "A Preliminary Study of Opuntia stricta as a Coagulant for Turbidity Removal in Surface Waters", Proceedings of the Pakistan Academy of Sciences 52 (2): 117–124 (2015), ISSN: 0377 - 2969 (print), 2306 - 1448 (online)
[6] Balakrishnan, A. Neera, "Assessment Of Turbidity Removal Efficiency of Natural Coagulants", International Journal of Advance Research in Science and Engineering, Vol. No.6, Issue No.06,June 2017 www.ijarse.com
[7] Amira, A. Ali, B. Omar, "Synthesis and application of a new biomaterial based on Opuntia Ficus Indica (cactus) in water treatment", Algerian Journal of Engineering Research AJER, N°1, June 2017. https://ajer.univ-constantine3.dz/wp-content/uploads/2018/03/AJER-01-02-2017-.pdf
[8] Belayneh, W. Batu, "Application of Biosorbent Derived from Cactus Peel for Removal of Colorful Manganese ions from Ground Water", Journal of Water Resources and Ocean Science 2015; 4(1): 18-23 Published online February 9, 2015 (http://www.sciencepublishinggroup.com/j/wros) doi: 10.11648/j.wros.20150401.13 ISSN: 2328-7969 (Print); ISSN: 2328-7993 (Online)
[9] Karanja, Li Fengting, W. Ng'ang'a, "Use Of Cactus Opuntia As A Natural Coagulant: Water Treatment In Developing Countries", Int. J. Adv. Res. 5(3), 884-894, ISSN: 2320-5407 DOI:10.21474/IJAR01/3586
[10] S. Shilpa, Akanksha, Kavita, P. Girish, "Evaluation of Cactus and Hyacinth Bean Peels as Natural Coagulants", International Journal of Chemical and Environmental Engineering June 2012, Volume 3, No.3
[11] Mounir, A. Abdellah, Z. Abdeljalil, "Low Technology Water Treatment: Investigation of the Performance of Cactus Extracts as a Natural Flocculant for Flocculation of Local Clay Suspensions", International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Vol. 3 Issue3, March-2014
[12] Mounir, Z. Abdeljalil, A. Abdellah, "Comparison of the Efficacy of Two Bioflocculants in Water Treatment", International Journal of Scientific Engineering and Technology Volume No.3 Issue No.6, pp : 734-737 (ISSN : 2277-1581) 1 June 2014
[13] Bouatay F, Mhenni F, "Use of the Cactus Cladodes Mucilage (Opuntia Ficus Indica) As an Eco-Friendly Flocculants: Process Development and Optimization using Stastical Analysis", Int. J. Environ. Res., 8(4):1295-1308, Autumn 2014 ISSN: 1735-6865
[14] Nirmala Rani, Jadhav M. V., "Enhancing Filtrate Quality Of Turbid Water Incorporating Seeds Of Strychnos Potatorum, Pads Of Cactus Opuntia And Mucilage Extracted From The Fruits Of Coccinia Indica As Coagulants", Journal of Environmental Research And Development Vol. 7 No. 2, October-December 2012
[15] Dr. T. Kannadasan, M. Thirumarimurugan, K. S. Sowmya, S. karuppannan, M. Vijayashanthi, "Dye Industry Effluent Treatment Using Cactus (Opuntia) And Water Hyacinth (Eichhornia Crassipes)", IOSR Journal Of Environmental Science, Toxicology And Food Technology (IOSR-JESTFT) e-ISSN: 2319-2402,p-ISSN: 2319-2399.Volume 3, Issue 4 (Mar. - Apr. 2013), PP 41-43 www.Iosrjournals.Org
[16] Elizabeth R. da Costa, K. Silva, A. Marques, "Plant-based polymeric coagulants for water and wastewater treatment: a green technology approach", http://www.aidisnet.org/PDF_mem/35INT/ID%201667_ed.pdf
[17] F. Ben Rebah, S.M. Siddeeg, "Cactus an eco-friendly material for wastewater treatment: A review", JMES, 2017 Volume 8, Issue 5, Page 1770-1782 http://www.jmaterenvironsci.com/
[18] G. Vijayaraghavan, T. Sivakumar, A. Vimal Kumar, "Application of Plant Based Coagulants for Waste Water Treatment", IJAERS/Vol. I/ Issue I/October-December, 2011/88-92
[19] G. Jayalakshmi, V. Saritha, B. Dwarapureddi, "A Review on Native Plant Based Coagulants for Water Purification", International Journal of Applied Environmental Sciences ISSN 0973-6077 Volume 12, Number 3 (2017), pp. 469-487
[20] H. Betatachea, A. Aouabed, N. Drouiche, H. Lounici, "Conditioning of sewage sludge by prickly pear cactus (Opuntia ficus Indica) juice", Ecological Engineering 70 (2014) 465–469 https://doi.org/10.1016/j.ecoleng.2014.06.031
[21] H. Betatache, Ali Aouabed, "Sewage Sludge Conditioning Using Opuntia Ficus Indicajuice", Revue des Sciences de l'Eau 28(1) (2015) 67-72 ISSN : 1718-8598
[22] H. D. Beyene, T. D. Hailegebrial, W. Batu , "Investigation of Coagulation Activity of Cactus Powder in Water Treatment", Journal of Applied Chemistry

Volume 2016, Article ID 7815903,9 pages http://dx.doi.org/10.1155/2016/7815903

[23] M. Al-aubadi, L. Q. Hashim, "Application of Cactus Cladodes Mucilage (Opuntia ficus-indica) as an Eco-Friendly Natural Coagulant and Flocculent Aid with Alum for Potable Water Treatment", International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

[24] Prodanović, M. Šćiban, M. Antov, "Improvement of wastewater treatment by use of natural coagulants", Journal of Economic Development, Environment and People Volume 2, Issue 2, 2013 ISSN-L = 2285 – 3642

[25] Díaz, J. Arguello, G. Ribon, "Behavior of turbidity, pH, alkalinity and color in Sinú River raw water treated by natural coagulants" Revista Facultad de Ingeniería, Universidad de Antioquia, No. 78, pp. 119-128, 2016

[26] J. Zhang, F. Zhang, Y. Luo, H. Yang, "A preliminary study on cactus as coagulant in water treatment", Process Biochemistry 41 (2006) 730–733, doi:10.1016/j.procbio.2005.08.016

[27] J. Idris, A. Som, M. Musa, Hamid, R. Husen, M. Rodhi, "Dragon Fruit Foliage Plant-Based Coagulant for Treatment of Concentrated Latex Effluent: Comparison of Treatment with Ferric Sulfate", Journal of Chemistry Volume 2013, Article ID 230860, 7 pages http://dx.doi.org/10.1155/2013/230860

[28] L Muruganandam, M P Saravana, A. Jena, S. Gulla, B. Godhwani, "Treatment of waste water by coagulation and flocculation using biomaterials", Materials Science and Engineering 263(2017) 032006 doi:10.1088/1757-899X/263/3/032006

[29] G. Torres Bustillos, Sandra Carpinteyro-Urban, Carlos Orozco, "Production and characterization of Opuntia ficus-indica mucilage and its use as coagulant-flocculant aid for industrial wastewaters", International Journal of Biotechnology Research Vol. 1(3), pp. 038-045, April 2013 ISSN 2328-3505 Available online at http://academeresearchjournals.org/journal/ijbr

[30] G. Torres, S. L. Carpinteyro, "Use of Prosopis laevigataSeed Gum and Opuntia ficus-indica Mucilage for the Treatment of Municipal Wastewaters by Coagulation-Flocculation", Natural Resources, 2012, 3, 35-41 http://dx.doi.org/10.4236/nr.2012.32006 Published Online June 2012 (http://www.SciRP.org/journal/nr)

[31] Neffa, H. Hanine, M. Taouir, A. Yacine, Lekhlif B, "Cactus Prickly Pears Extract For Coagulation/Flocculation Processes To Ameliore The Treatement Of Olive Mill Waste Waters Mill Olive (Omww)", Linnaeus ECO-TECH ´10 Kalmar, Sweden, November 22-24, 2010 https://doi.org/10.15626/Eco-Tech.2010.024

[32] M. de Souza, E. Ambrosio, C. Almeida, T. de Souza Freitas, L. Santos, V. Almeida, J. Garcia, "The use of a natural coagulant (Opuntia ficus-indica) in the removal for organic materials of textile effluents", Environ Monit Assess DOI 10.1007/s10661-014-3775-9

[33] Mane P. C, Bhosle A. B, Jangam C. M and Mukate S. V., "Heavy Metal Removal from Aqueous Solution by Opuntia: A Natural Polyelectrolyte", Scholars Research Library J. Nat. Prod. Plant Resour., 2011, 1 (1): 75-80 http://scholarsresearchlibrary.com/archive.html

[34] M. A. Oliveira, "Production of Fungal Protein by Solid Substrate Fermentation of Cactus Cereus Peruvianus and Opuntia Ficus Indica", Quim. Nova,Vol. 24, No. 3, 307-310, 2001.

[35] Fedala, H. Lounici, N. Drouiche, N. Mameria, M. Drouiche, "Physical parameters affecting

[36] coagulation of turbid water with Opuntia ficus-indica cactus", Ecological Engineering 77 (2015) 33–36 journal homepage: www.elsevier.com/locate/ecoleng

[37] N. H. A. Al-Saati, E. H. Hwaidi, S. H. Jassam, "Comparing cactus (Opuntia spp.) and alum as coagulants for water treatment at Al-Mashroo Canal: a case study", Int. J. Environ. Sci. Technol. DOI 10.1007/s13762-016-1114-0

[38] Guedes Paiva, I. Andrade Costa de Souza, M. Vicalvi Costa, A. Silva Santos, L. Barroso Coelho, "Opuntia sp. Cactus: Biological Characteristics, Cultivation and Applications", Advances in Research 7(3): 1-14, 2016, Article no.AIR.26125 ISSN: 2348-0394, NLM ID: 101666096

[39] Abdulazeez, Mohd S. Jami, Md. Z. Alam, M. Iwata, "Analysis of the Efficiency of Sludge Dewatering Using Moringa oleifera as Natural Phytocoagulant", Int'l Journal of Research in Chemical, Metallurgical and Civil Engg. (IJRCMCE) Vol. 2, Issue 2 (2015) ISSN 2349-1442 EISSN 2349-1450

[40] Rachdi, F. Srarfi, N. Shimi, "Cactus Opuntia as natural flocculant for urban wastewater treatment", Water Sci Technol. 2017 Oct;76(7-8):1875-1883. doi: 10.2166/wst.2017.370.

[41] Daza, A. F. Barajas-Solano, J. M. Epalza, "Evaluation of the Efficiency of Bio-Polymers Derived from Desertic Plants as Flocculation Agents", CHEMICAL ENGINEERING TRANSACTIONS VOL. 49, 2016 ISBN978-88-95608-40-2; ISSN2283-921 DOI: 10.3303/CET1649061

[42] S Asha, Tabitha C, Himabindu N, and R Bharath, "Efficiency of Opuntia ficus-indica (L) Mill. in Removal of Chromium from Synthetic Solution", Research Journal of Pharmaceutical, Biological and Chemical Sciences 5(3):1244-1251 · May 2014

[43] Vishali, R. Karthikeyan, "Cactus opuntia (ficus-indica): an eco-friendly alternative coagulant in the treatment of paint effluent", Desalination and Water Treatment, DOI: 10.1080/19443994.2014.945487

[44] S. M. Miller, Ezekiel J. Fugate, V. Craver, J. A. Smith, Julie B. Zimmerman, "Toward Understanding the Efficacy and Mechanism of Opuntia spp. as a Natural Coagulant for Potential Application in Water Treatment", Environ. Sci. Technol.2008,42,4274–4279

[45] Y. Choy, K. Prasad, M. Raghunandan, R. Ramanan, "Utilization of plant-based natural coagulants as future alternatives towards sustainable water clarification", Journal Of Environmental Sciences 26 (2014) 2178–2189

[46] Nharingo, M. T. Zivurawa, U. Guyo, "Exploring the use of cactus Opuntia ficus indica in the biocoagulation–flocculation of Pb(II) ions from wastewaters", Int. J.

Environ. Sci. Technol. (2015) 12:3791–3802 DOI 10.1007/s13762-015-0815-0

[47] T. Kazi, A. Virupaksh, "Treatment of Tannery Wastewater Using Natural Coagulants", International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 8, August 2013 ISSN: 2319-8753

[48] Thamer J., E. Shakir, "Effect of settling time, velocity gradient, and camp number on turbidity removal for oilfield produced water", Egyptian Journal of Petroleum 27 (2018) 31–36

[49] T. Pichler, K. Young, N. Alcantar, "Eliminating turbidity in drinking water using the mucilage of a common cactus",https://www.geochemie.uni-bremen.de/pdf/pichler/WS%202012%20Mucilage.pdf

[50] T. Nharingo, M. Moyo, "Application of Opuntia ficus-indica in bioremediation of wastewaters. A critical review", Journal of Environmental Management 166 (2016) 55e72 http://dx.doi.org/10.1016/j.jenvman.2015.10.005

[51] Y. Alima , C. Agbangnan, A. Koudoro, C. A. Dèdjiho, M. Aïna, Daouda M., Dominique S., "Evaluation of the Opuntia dilleniias Natural Coagulant in Water Clarification: Case of Treatment of Highly Turbid Surface Water", Journal of Water Resource and Protection, 2013, 5, 1242-1246 http://dx.doi.org/10.4236/jwarp.2013.512133

[52] Y. Yang, S. A. Talib, L. Ying Pei, Mohd. S. Nizan , S. AbdRazak, A. Mohd. Mohtar, "Turbidity Remov Al From Surf Ace W A Ter And Landfill Leacha Te Using Cactus Opuntia", Journal - The Institution of Engineers, Malaysia (V ol. 68, No. 1, March 2007)

[53] Z. Abidin, N. Madehi, R. Yunus, "Coagulative Behaviour of Jatropha curcas and its Performance in Wastewater Treatment", American Institute Of Chemical Engineers Environ Prog, 36: 1709–1718, 2017

