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Green flocculant performance for wastewater treatment using cactus plant powder: A mini-review

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ABSTRACT
The use of reclaimed wastewater has emerged as one of the most effective strategies to address the global water scarcity issue. However, concerns arise due to the presence of various chemical residuals resulting from the diverse range of chemical products used during the treatment process. These residuals can pose significant threats to human health and the environment. As a solution to this problem, the utilization of cactus plant powder in water treatment has garnered increasing attention among researchers. This bio-material alternative offers several advantages, such as being biodegradable, non-toxic, and cost-effective. Chemical flocculants, though widely used, can lead to environmental problems due to their persistence and bioaccumulation in living organisms. In contrast, cactus-based bio-flocculants provide a more environmentally friendly approach to water treatment. The objective of this study is to investigate various methods of preparing cactus-based bio-flocculants and examine their performance in reducing turbidity, chemical oxygen demand, total suspended matter, total dissolved matter, and heavy metals in wastewater. Furthermore, the research delves into the impact of cactus preparation and application conditions on the efficiency of the treatment process.

1. Introduction:

In recent decades, the world has faced significant challenges resulting from population growth, industrialization, climate change, and pollution of aquatic systems, leading to a growing concern over water scarcity in countries worldwide **[1]**. In response to this pressing issue, the use of domestic and industrial reclaimed wastewater has emerged as a leading solution to combat water scarcity **[2]**. However, safeguarding human health and preventing persistent heavy metal contamination from toxic radicals demand careful attention to the various water treatment processes **[3]**. Researchers are exploring the use of natural products as an alternative to chemical compounds in different treatment steps, as this area presents a fascinating research opportunity **[4-5]**.

Biomaterials, with their numerous advantages such as biodegradability, non-toxicity, and non-corrosive qualities, have gained widespread attention for use in the laboratory-scale coagulation-flocculation process **[6]**. Bio-coagulants/bio-flocculants derived from bacteria, algae, fungi, animals, and plants are being increasingly studied as they produce limited sewage compared to synthetic flocculants **[7]**. Among the natural plant-based coagulants, there is a growing focus on cactus,

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particularly *Opuntia ficus indica*. Numerous studies have confirmed the remarkable flocculating activity of cactus extracts, especially in efficiently removing colloidal particles. The primary mechanisms driving floc formation involve adsorption and interparticle bridging, leading to effective particle agglomeration and precipitation **[8-10]**.

While existing reviews mainly concentrate on the liquid form of cactus-based flocculants due to their proven high efficiency, this mini-review presents the methods of preparation of the solid form of cactus powder, as well as its application performance investigated in the literature **[11-12]**.

Utilizing cactus-based bio-flocculants in water treatment presents a sustainable and environmentally friendly solution to combat water scarcity and pollution. Cactus materials possess biodegradability, resulting in minimal environmental impact, and are non-toxic and non-corrosive, ensuring the protection of human health. Researchers are especially intrigued by investigating the use of cactus powder as a solid form of bio-flocculant, providing practicality and ease of application in water treatment processes. The mini-review at hand encompasses the preparation methods of the solid form and explores the performance of cactus powder in various applications, as documented in the existing literature.

2. Coagulation-flocculation process:

The coagulation-flocculation process is among the most commonly used techniques in water and wastewater treatment plants. Its primary objective is to eliminate suspended and colloidal materials of very small sizes by destabilizing and agglomerating them into larger flocs that can be easily separated from the water through settling tanks **[13]**. This process plays a critical role in water treatment, particularly due to the strict regulatory limits on turbidity in treated water, which have gradually decreased in the United States from 1.0 NTU in 1989 to 0.3 NTU at present **[14]**.

Controlling the coagulation-flocculation process involves various parameters that significantly impact its efficiency. Therefore, optimizing these parameters is of utmost importance for effective water treatment. Figure 1 illustrates the different parameters involved in the coagulation-flocculation treatment.

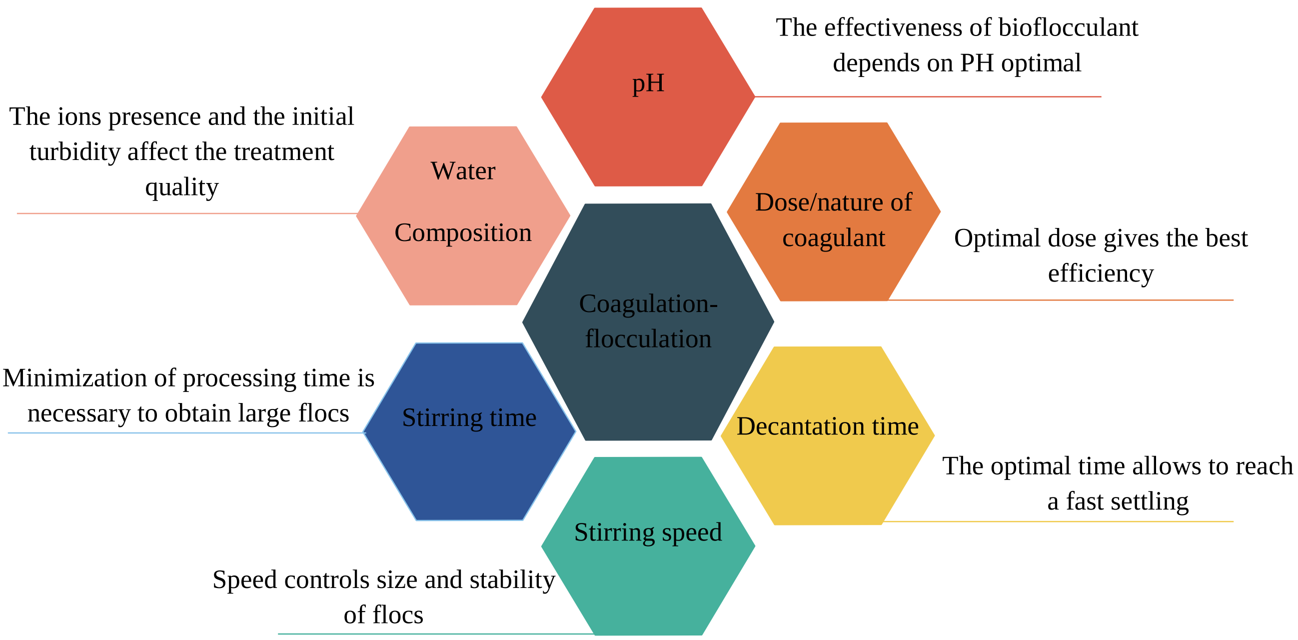

Figure 1. Schematic illustration of factors that control coagulation-flocculation processes.

3. Organic coagulants/flocculants extracted from the cactus:

Opuntia ficus-indica, a plant belonging to the Cactaceae family and the Opuntia genus, has garnered significant interest in the field of water treatment. This medicinal plant exhibits a remarkable flocculation ability comparable to synthetic products, making it an effective agent for removing colloidal particles from water, particularly in alkaline conditions with a pH of approximately 10.0 **[15]**.

The coagulation-flocculation processes involving *Opuntia ficus-indica* are driven by two key molecules: quercetin, a flavonoid with polyphenolic groups, and starch, a branched polymer of glucose. The presence of these compounds synergistically enhances the flocculating power of the plant material **[16]**. The mechanism behind the flocculation process primarily involves adsorption and the formation of a bridge between the biomaterial and suspended particles **[17]**.

4. The solid form of bio-flocculant:

Bio-flocculants exist in two forms: liquid and solid **[18]**. Both forms can be utilized in various ways, either directly without modification or after extraction. While there are alternative approaches, three methods, as depicted in Figure 2, are the most commonly used. However, despite the versatility of both powder and liquid bio-flocculants, the current research and literature reviews predominantly concentrate on the liquid form due to its higher effectiveness compared to the solid form. The solid shape possesses several characteristics that make its utilization more reliable, especially in terms of industrial applications, as it has a long lifecycle. The powder can be stored for several months while maintaining acceptable efficacy. On the other hand, the mucilage form degrades rapidly and loses its flocculating activity after approximately one month of use **[19-20]**.

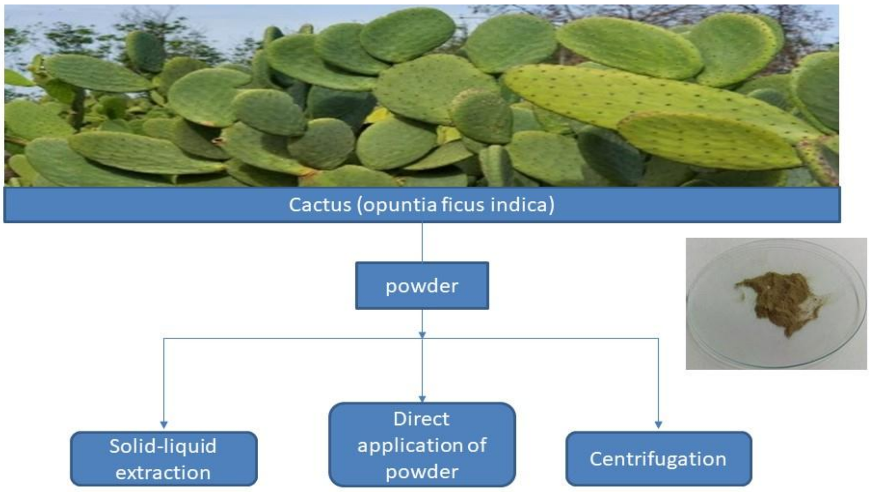

Figure 2. Methods of bio-flocculants use in solid form.

5. Solid bio-flocculant use in water treatment:

Several studies have utilized the solid form of cactus-based flocculant for treating synthetic, surface, and industrial waters, demonstrating its efficacy as a bio-flocculant. Bouaouine *et al.* (2018) **[21]** conducted laboratory tests and found that *Opuntia ficus-indica* powder could remove 90% of the turbidity from Kaolin-laden synthetic water at a pH of 10, achieved through adsorption and bridging mechanisms between particles. Similarly, Shilpa *et al.* (2012) **[22]**. treated surface water with cactus-based bio-flocculant, resulting in a turbidity removal of 89.03%. In the case of severe industrial waters containing a complex mixture of contaminants in the tannery sector, Kazi *et al.* (2013) **[23]**. reported a 78.54% reduction in water turbidity using cactus-based bio-flocculant. The efficiency of contaminant removal in water is influenced by various factors, including pH, initial turbidity, type of bio-flocculant, form of bio-flocculant (solid or liquid), and the method of bio-flocculant preparation. Table 1 presents the different values obtained for the same raw material, cactus (specifically *Opuntia ficus-indica*), highlighting variations in preparation techniques, application dose, and the type of water treated.

Table 1. Research summaries of the powder of cactus used as a bio coagulant.

Effluent	Preparations	Optimal dose	Efficiency	Reference
Synthetic water (Kaolin): pH was equal to 6.5 0.4 The absorbance was 1.2 Turbidity was 300 to 350 NTU	Drying at 80°C for 24 hours - grinding - sieving (0.5 to 1.0 mm) - storage (4°C) - extraction under alkaline conditions - filtration	Optimal flocculation ph is equal to 10.0 Optimal dose is 35 mg/L	the efficiency was 90%	**[21]**
Synthetic water Turbidity: 500 NTU Surface water : Turbidity: 83 NTU	Snowshoe cutting- drying at 60°C (24 hours)-grinding - sieving (300 µm	The optimal dose 20 mg/L;	Synthetic Water: Efficiency was 99.74% Residual turbidity:1.3 NTU Surface water: The efficiency was 89.03% Residual turbidity:9,1 NTU	**[22]**

Used water from the tannery industry: pH-5.5 Dark brown colour, COD-28 000 mg/l, BOD-8000 mg/L, Total solids: 15 200 mg/l, Dissolved solids: 6550 mg/L,	Snowshoe cutting -drying at 60°C for 24 hours - grinding - sifting	Optimal dose is 0.2gm/500ml pH = 5.5	Efficiency: 78.54% Reduction of COD = 80.65%	**[23]**
10 L of cloudy water : Turbidity = 41.38 NTU Conductivity is 725 µs/cm; pH equal to 7.81; Salinity is 0.35%; OD is 6.94 mg/l; TDS is 354 mg/l; Chlorophyll concentration (a) is 70.62 mg/l;	washed with distilled water- stored in polyethylene plastic bags- drying (70 and 90°C)- spraying - storage (ambient T)	Optimal dose = 3,50 g	Turbidity = 17.3 NTU The conductivity = 1885 µs/cm; pH = 4.18 Salinity = 0.98% OD = 5.39 mg/l TDS = 948 mg/l Chlorophyll concentration (a) = 102.3 mg/l;	**[24]**
For MB : pH = 7.2 turdidy = 65.6 NTU For MO : pH = 6.2 turdidy = 80.2 NTU	Repeated cleaning and washing of snowshoes with distilled water - disinfection with sodium hypochlorite - sample cutting - oven drying at 60 C for 24 hours - grinding - powder sifting	Optimal dose = 1,46 g/L	Color abatement and turbidity efficiency is 62%	**[19]**
pH = 7.6 Color : 0.4583 COD: 7693 mg/L Turbidity : 7760 NTU	drying of Cactus snowshoes (O. ficus indiça) at 100°C for 2 hours - grinding - sifting the powder obtained through a sieve of 0.2 mm diameter - coagulant extraction using 3N Na Cl.	Optimal dose = 3 g/L pH = 7.2–7.8	Color = 88.37 COD = 78.20 Turbidity = 82.60%	**[25]**
DCO : 16700 mg/L. Turbidité 3390 NTU. pH : 5,6.	Washing the collected cactus snowshoes with distilled water - the mucilages are obtained by boiling small pieces of cladodes	Optimal dose = 21.1 mg PH = 5,6	Turbidity : 67.8 % COD : 38.6%	**[26]**
COD : between 8000-180000 mg/L pH = 5.5	Dry Opuntia drying at 60°C for 24 hours - Grinding -and sifting to obtain 600 µm particle size	Optimal dose = 0.2mg cactus/500 mL pH = 5.5	Turbidity : 8.54% COD : 80.65%	**[27]**
DCO : 2350 mg/L Turbidity : 38 UTN Absorbance at 630 nm is 10.67	washing of O. ficus indiça mucilage with distilled water - sun drying for 3 hours- cutting into small pieces - drying powder at 60°C for 24 hours- combination of mucilage with coagulant (Al2(SO4)3	Optimal dose = 40 mg/L	Color : 99,84% COD : 88,76% Turbidity: 91,66%	**[28]**
Polluted river water	washing samples with tap water - cutting samples into small pieces - sun drying for 4 weeks - oven drying at 60 ºC for 24 hours - storing the powder in an airtight polyethylene bag.	Optimal dose = 10 mg/L	Pb :100 % Zn : 85.74 % Cd : 84.16 % Cu : 93.02 %	**[29]**
Synthetic wastewater (clay) : Turbidity = 55 NTU pH = 7.4 DCO = 376.23 mg/l Tannery effluent : Turbidity = 74.43 NTU pH = 7.8 DCO = 502.6 mg/l	washing of cactus snowshoes - removal of external parts and spines - drying of mucilage in the oven at 65°C for 24 hours- grinding	Optimal dose = 40 g/ml pH = 7	Synthetic water treat: Turbidity = 50.5 % pH = 7 DCO = 63.6 % Tannery water treat: Turbidity = 51.5% pH = 7 DCO = 59.35 %	**[30]**

The results presented in Table 1 highlight that cactus-based bio-flocculants offer a compelling alternative to synthetic products. Besides their demonstrated efficiency in water treatment, cacti possess several valuable advantages. One such advantage is their local availability and abundance, making them accessible resources for bio-flocculant production. Additionally, cacti have low irrigation needs, making them environmentally friendly in terms of water consumption, and they exhibit remarkable adaptability to extreme environmental conditions.

The solid form of cactus-based bio-coagulant proves highly effective in treating effluents containing various types of pollutants, including heavy metals and dyes, among others. Its extended shelf life, exceeding that of the liquid form, is attributed to the absence of water content. The powder retains its high efficacy even after several months of preparation, without the need for additional processing, chemical additives, or specific storage conditions. This stability and convenience make cactus-based bio-flocculants an attractive and sustainable choice for water treatment applications.

4. Conclusion:

In conclusion, the solid form of cactus-based bio-flocculants exhibits a highly effective flocculating and coagulant power. Numerous laboratory-scale experiments have demonstrated significant success in removing various types of pollutants from water, including suspended solids, turbidity, COD, BOD, dyes, and heavy metals. The efficiency of pollutant removal often exceeds 90%, and it is dependent on treatment conditions, types of pollutants, and operating parameters, such as bio-product dose, pH, temperature, and contact time. The use of *Opuntia ficus-indica* in wastewater treatment has garnered considerable attention from researchers, with laboratory-scale trials consistently yielding promising results, especially when using the powder form with its extended shelf life compared to the liquid form. The impressive efficacy and sustainable nature of cactus-based bio-flocculants make them an attractive option for water treatment applications. However, to fully harness the potential of cactus-based bio-flocculants and encourage commercialization, further large-scale experiments are essential to develop more efficient and cost-effective treatment processes. These efforts would not only enhance the attractiveness of this technology to potential investors but also contribute to the advancement of sustainable and eco-friendly water treatment practices. Overall, the solid form of cactus-based bio-flocculants shows great promise as a green and effective solution for water treatment, offering a viable alternative to synthetic products and contributing to a more sustainable and environmentally conscious approach to water management.

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