# Synthesis and application of a new biomaterial based on Opuntia Ficus Indica (cactus) in water treatment.

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**Abstract**

***This present study deals with the preparation and application of a new biodegradable, non-polluting and economical bioflocculant based on available natural cactus cladodes (Opuntia Ficus Indica) for water clarification. The main objective of this work is to replace conventional commercial products such as chemical coagulants ($FeCl_3$, $Al_2(SO_4)_3$), synthetic organic polymers(anionic, cationic or non ionic) proving inadequate, unsuccessful or expensive to apply and to be able to meet increasingly stringent standards. The use of this new generation of biomaterials should reduce the cost of water treatment in a health, environmental and sustainable development context.***

***The efficiency of this new gelled product is evaluated through several Jar Test tests, both for synthetic and real water samples, by examining some parameters deemed useful in eliminating turbidity. These parameters are turbidity, pH, bioflocculant concentration and conductivity of water.***

***The present results showed overall and clearly that the maximum reduction in the turbidity of synthetic water is obtained for a very low volumetric ratio (gelled flocculant / water sample) .Throughout all the pH range studied, very high reduction rates were obtained with a residual turbidity meeting the standards and without affecting the pH and conductivity of treated samples.***

***The application of this biomaterial towards some surface water samples from the river of Hammam Melouan (Oued El Harrach) has given encouraging results where the obtained turbidity abatement rate seems to be important for all the pH range studied.***

***The Flocculation studies proved the cactus gel to be the most effective flocculating agent when compared to conventional commercial products and to other bioflocculants. According to the results obtained this Ecofriendly biomaterial can be attributed as an alternative solution to problems associated with the environmental performance of chemical coagulants.***

**Keywords**: *bioflocculant, biomaterial, cactus, clarification, coagulation-flocculation*.

## I. Introduction

Several studies have been carried out to remove suspended matter present in water by physicochemical ways. To remove these particles we have recourse to coagulation-flocculation processes. The purpose of coagulation is based onto the destabilization of the suspended particles by injection and dispersion of chemicals products. Thereafter, the flocculation promotes by means of a mixture the contacts between the destabilized particles to form a floc which can easily be removed by decantation. These chemical products called coagulants may have harmful effects on both human health and the environment. Aluminum sulfate is the most widely used coagulant because of its availability and price.

Nevertheless, the aluminum supplied by the coagulants represents a health and organoleptic drug such as Alzheimer's and other similar diseases [1, 2].

However looking for alternative products becomes a crucial necessity. In a health, environmental and sustainable development context; we will focus our studies on integrating biodegradable products into the water treatment process.

For this reason we have chosen to work on the valorization of cladodes of cactus produced locally (Blida, Algeria).

The objective of our study is to substitute the synthetic products used during the coagulation-flocculation by other natural products. In this framework and in the first place, we will cite the different materials and methods followed during the realization of this work.

Furthermore, we will use the biodegradable gel extracted from the cladodes of the cactus as a flocculating agent by varying the pH and bioflocculant concentration. In addition we will perform an FTIR characterization of the cactus gel to better understand the involved mechanisms. The different results will be interpreted.

## II. Materials and methods

### A. Origin and characteristics of chemical additive

The table below shows the additives used in this work and their origin. The sodium hydroxide and hydrochloric acid were used to modify the pH of the suspension.

**Table 1. Characteristics of chemical additives and their origin**

| Usuel nuons | Chemical forrmula | Physical proprety | Provider |
|---|---|---|---|
| hydrochloric acid | HCl | Density: $1.2 g.mL^{-1}$ at 25°C<br>Vapor pressure : 3.23psi (21.1°C)<br>Purity :37%<br>$M_w$ : $36.46 g.mol^{-1}$ | SIGMA-ALDRICH |
| Sodium hydroxide | NaOH | $M_w$: $40 g..mol^{-1}$<br>Vapor pressure:<18 mmHg (20°C)<br>Solubility :1260 $g.L^{-1}$ at 20°C<br>Purity :≥98% | SIGMA-ALDRICH |

In our study, pH, conductivity, temperature and TDS (total solids Dissolved) was carried out using a multi parameter model CRISON MM40.
The turbidity measurements were carried out using of a HANNA turbidimeter, models HI 93703.

### B. The jar test

The test was carried out using the flocculators (agitator) with 6 beakers with a volume of 1 L. This Apparatus has been programmed for two stirring speeds where the stirring speed of the Coagulation is estimated to be equal to 150 rpm for 2 minutes and that of flocculation is 40 rpm for 15 minutes. The time required for the decantation is equal to 30 minutes.

### C. Preliminary preparation of fresh raw material:

Cactus cladodes were collected during the month of March from the region of Sidi Aissa in the commune of Gourouaou, wilaya of Blida (Algeria), which has an average temperature of 22 ° C. In the warmest months it is of the order of 33 ° C, while it varies between 0 and 7 ° C during the colder months. The mean rainfall is about 600 mm.

### D. Extraction method

After removing the spines from the cactus, the cladodes were rinsed thoroughly with tap water and then with distilled water. They were then cut into small dice where the skin was peeled to increase the contact area of the inside part with the water. A quantity of 500g of the cut cladodes was introduced into a crystallizer with distilled water. The whole was placed in an oven at 100 ° C for 2 hours, after this period, the gel was recovered. The product obtained was stored in a refrigerator at 4 ° C and in the shelter.

### E. Fourier Transform Infrared Spectroscopy (F.T.I.R) Analysis

Our gel was analyzed by FTIR to identify functional groups of surface and localize the different absorption bands characteristic.

Analyzes by FTIR were performed using a JASCO FT / IR-4100 FTIR spectrometer over a range of frequencies between 400-4000 $cm^{-1}$.

The FTIR spectra were made from the lyophilized gel spread on a KBr pellet.

## III. Results and discussion

### A. Properties of cactus gel

**Tables 2: Properties of the bioflocculant**

| Characteristics | Value |
|---|---|
| pH | 4 |
| Conductivity ( $mS.cm^{-1}$) | 6.08 |
| Density | 1.26 |
| Percentage of moisture | 96% |

### B. Fourier Transform Infrared Spectroscopy (F.T.I.R) Analysis

Fig.1 shows the infrared spectrum of the gel extracted from cladodes of cactus.

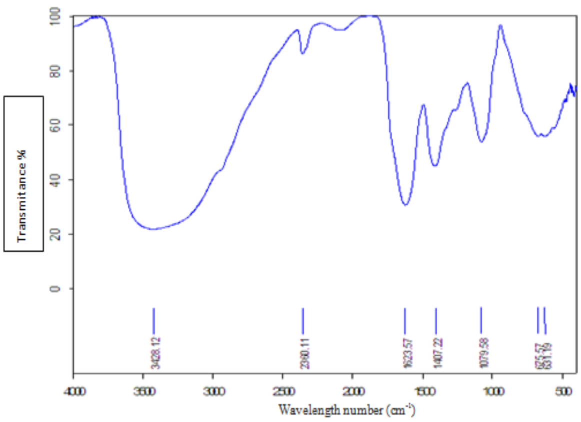


**Figure 1.** I.R spectrum of the cactus gel.

Table 3 lists the different absorption bands and functional groups properties.

**Table 3. Wavelengths of IR bands of constituents structure cactus gel**

| Wavelength Number ($cm^{-1}$) | Liaison Type |
|---|---|
| 3428.12 | O-H elongation/N-H elongation [3] |
| 2380.11 | Alcynes/ Nitriles |
| 1623.57 | –C=O (vibration)carboxylic acids /-NH 2 (deformation) Primary amides |
| 1407.22 | –C=O (elongation) carboxylates /elongation O-H [4] |
| 1079.58 | P-OH ( vibration ) phosphates /( -OH /– C–O- C–) Polysaccharides [5;6] |
| 675.57 | Aromatic groups [7] |
| 631.19 | Aromatic groups [7] |

### C. Removal of turbidity with cactus gel

**Optimal volume of bioflocculant**

Fig.2 shows the variation in water turbidity reduction rate in synthetic samples as a function of the volume of the added bioflocculant.

The initial samples are characterized by:
- Turbidity of 120 NTU.
- The conductivity is of the order of 790 $\mu S.cm^{-1}$.
- The TDS is equal to 506 $mg.L^{-1}$.
- The pH is equal to 8.20.

The gel volumes added ranged from 0.025 mL to 0.8 mL per liter of samples at a temperature of 25 °C.

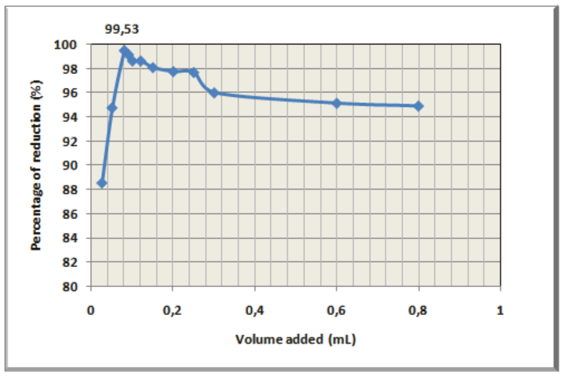


**Figure 2.** Evolution of the turbidity reduction power as a function of the volumes of bioflocculant added.

It can be seen from the figure that the coagulant power increases with the addition of the bioflocculant to reach a maximum value at a volume of 0.08 ml equivalent to 0.3 mg of dry matter (calculated from the results of Freeze-drying) with a percentage of turbidity reduction equal to 99.56% where residual turbidity is equal to 0.67 NTU.

Beyond this dose (over dosage), the reduction of turbidity decreases, this is justified by the steric restabilization of the colloidal particles (the increase in the polymer / particle ratio).
The final pH, conductivity and TDS values are 8.22, 793 µS.cm$^{-1}$, 508 mg.L$^{-1}$ respectively; these values are almost equal to the initial values. This method does not affect these parameters. [8]

By comparing these results with others obtained by several bioflocculant ,we find that this result is better than those obtained by different researchers who worked on mucilage and cactus powders and with biopolymers where we were able to have very high reduction rates at very low volumes.
[ 9;10;11].

## Optimum pH

In order to determine the optimum pH corresponding to the best reduction rates, we performed several Jar Test experiments where the pH of the samples was varied from 2 to 12 and we followed the reduction rate and the structure of the formed flocs At the optimum volume 0.08ml.

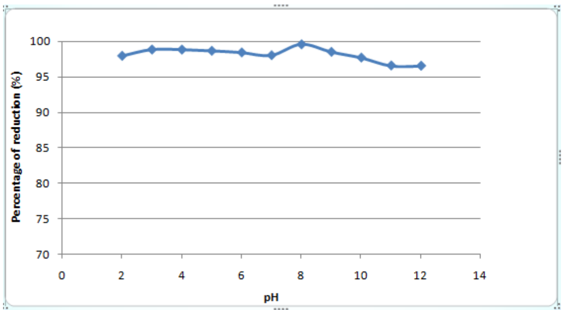


**Figure 3.** Evolution of the turbidity reduction power as a function of pH.

From fig.3 it can be seen that the reduction power is greater than 96% throughout the pH range studied, which shows that the pH does not influence, contrary to the results previously found, where they found an optimum pH of between 8 and 10.[12]

Nevertheless, at pH equal to 8 the percentage of turbidity reduction is equal to 99.53%.

By comparing these results with other studies carried out on the cactus, it can be seen that our gel offers a much wider pH range.[4;13;14;15;16;17]

However, it has been observed that the structure of the flocs changes as a function of the pH as shown in the fig.4.

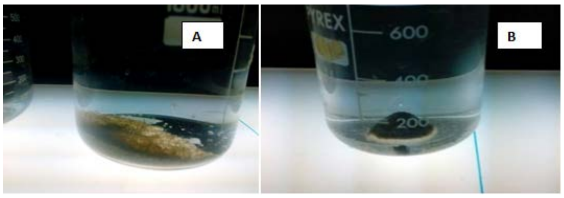


**Figure 4**. Flocs obtained at different pH : (A) flocs obtained at pH < 5; (B) flocs obtained at pH ≥5 **.**

At pH less than 5 there is the formation of macroflocks which decant in dispersed forms, contrary to the flocs formed at pH greater than 5 which are more compact, resistant, dense and broad forming a pad of a few centimeters in size.

At pH>10 we noticed the formation of the hydroxides which precipitate before the addition of the flocculant due to the excessive intake of [OH$^-$].

## Reduction rate according to storage time

In order to estimate the duration for which our product has an effectiveness with regard to the coagulating power, we carried out tests of Jar Test for one month under the same conditions of pH; conductivity; temperature and turbidity. The product was stored in the dark and at a temperature of 4 ° C. The volume of the added gel is equal to 0.08 ml and the pH of the samples is equal to 8 chosen according to the results of the optimum conditions. The follow-up of the reducing power during the time has resulted in the results presented in the following figure:

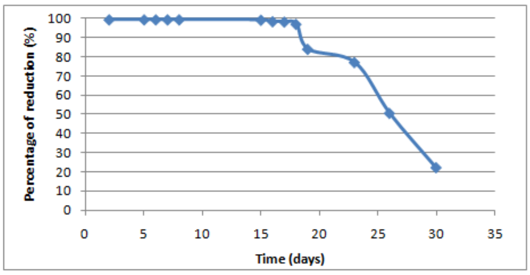


**Figure 5.**The rate of turbidity reduction as a function of storage time.

According to the fig.5, it is observed that the coagulating power is practically constant during the first 18 days with a reduction rate of more than 97%. From the 19th day, a significant decrease was observed until the 30th day when it reached 20%.

As a result, it can be seen that our product has a lifetime of 18 days where it shows a large and constant coagulant power.

The decrease of the coagulating capacity is probably due to the microbial degradation of the biopolymers which constitute the gel.

### D. Application of the cactus gel to surface water

To confirm the results obtained with the synthetic samples, the cactus gel was applied to a real sample (surface water).

**Table 4. Proprieties of surface water**

| propriety | value |
|---|---|
| pH | 8.25 |
| Conductivity (µS.cm$^{-1}$) | 560 |
| Turbidity (NTU) | 16 |
| TDS (mg.L$^{-1}$) | 359 |

### Optimal volume

Fig. 5 shows the variation in the rate of reduction of turbidity in the surface water as a function of the volume of bioflocculant added.

The gel volumes added ranged from 0.025 ml to 0.25 ml per liter of samples at a temperature of 25 ° C. The initial turbidity is of the order of 17 NTU.

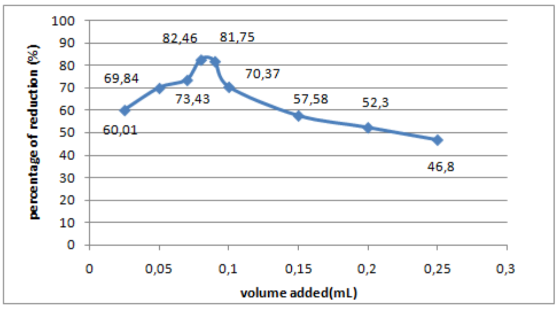


**Figure 5.** The rate of reduction of turbidity as a function of the volume of the gel added (application to surface water).

It can be seen from the figure 5 that the coagulating power increases with the addition of the flocculant to reach a maximum value at a volume of 0.08 mL with a percentage of turbidity reduction equal to 82.46%. Beyond this dose, that is to say overdose the reduction of turbidity decreases, which is justified by the steric restabilisation of the colloidal particles (the increase in the polymer / particle ratio). This result coincides with the result obtained previously with the synthetic samples.

### The effect of pH

In order to determine the optimum pH corresponding to the best reduction rates, we carried out several Jar Test experiments where the pH of the samples was varied from 4 to 10 and we followed the optimum volume reduction rate of 0.08 ml. Fig 6 shows the reduction rate as a function of pH.

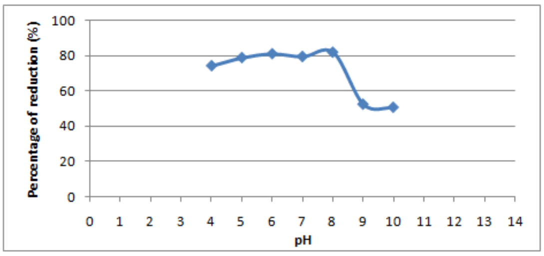


**Figure 6.** The rate of reduction of turbidity as a function of the pH (Application to surface water).

The fig.6 shows that the turbidity reduction rate is constant up to pH = 8 with 80%, above this pH value, a decrease of the reduction rate up to 52% is observed at pH> 8 where we assist to precipitation phenomena (formation of hydroxides).

## IV. General conclusion

The results presented in this study provide a clearer idea of the effectiveness and technical and environmental potential of a coagulation-flocculation process with cactus gel.

The extraction made it possible to recover 1 L of gel from 500 g of raw material.
The cactus gel has a lifetime of 18 days where it has maintained a high and constant coagulant power (under storage conditions at 4 ° C).

The best reduction rate is obtained at a volume of 0.08 ml per liter of sample (equivalent to 0.3 mg dry matter) with a reduction rate of more than 96% over the entire pH range without affecting the conductivity and pH of the treated sample.

The cactus gel produces large rigid, compact flocs with a volume of sludge much smaller, which makes it possible to reduce the required area of the settling ponds.

The application of our bioflocculant to surface water has given appreciable results at pH <8.

The effectiveness of the coagulation-flocculation process with the cactus is mentioned in the scientific literature and confirmed by the present experiments.

By being conservative, the bioflucculating agent makes it possible to remove more than 96% of turbidity when applied to synthetic water. Such a performance advantageously positions this technology among alternative solutions to the problems associated with the environmental performance of chemical coagulants without forgetting that this material Ecofriendly is produced locally and uses an Algerian workforce compared to the alum that is imported. In fact, 500 g of cactus makes it possible to treat 12.5 $m^3$ of water which coincides with about 500 g of alum. This observation makes it possible to believe that it will be able to attract the attention of the participants of the field.

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