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The removal of suspended matter by natural coagulants for low brackish water

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ABSTRACT

Natural coagulants have been the focus of research of many investigators through the last decade. In general, these coagulants are used as a point-of-use technology in less-developed communities as they are relatively cost-effective, compared to chemical coagulants; they can easily be processed in usable form and are biodegradable. Chitosan and *Cactus* were used as natural coagulants in this study to reduce the turbidity in brackish water. Some jar tests were conducted in order to optimize the coagulant dose, speed, rapid mixing time, and pH of the medium. The initial turbidity values, measured at 53.5 NTU, were reduced by as much as 97.08% (chitosan) and 93.35% (*cactus*). The turbidity removal capacity determined in this study indicated that chitosan and *cactus Opuntia* have the potential to be used in brackish water treatment applications.

Keywords: Brackish water; Turbidity; Jar test; Chitosan; *Cactus*

1. Introduction

Water is considered as a national resource of the utmost importance. Water is vital to ensure the population's well-being and quality of life, and preserve agricultural productivity. The increase in water demand for domestic uses, due to population growth and to the rising standard of living, combined with growing environmental pollution problems have led to over-utilization of renewable drinking water sources, which resulted in the decrease in water quality. Currently, 91% of the world's population, approximately 6.6 billion people, uses improved sources of drinking water [1]. Beyond these demographic and environmental considerations, desalination is now an economically viable solution in industrialized countries, as well as in other regions, that lack water resources. In many regions around the world, the high demand for fresh drinking water has pushed decision makers and administrators to think about treating brackish water to produce drinking water [2].

Brackish water contains less TDS (Total Dissolved Solids) than seawater but more than freshwater. Brackish water contains total dissolved solids (TDS) with concentrations that can range from 1000 mg/L to 15000 mg/L; it is typically characterized by low organic carbon content and low particulate or colloidal contaminants [3]. The desalination processes used in brackish water treatment are generally based on reverse osmosis (RO) [2]. Pretreatment is an essential step in reverse osmosis (RO); it is mainly intended to reduce the clogging potential during wastewater treatment and also to provide water with satisfactory quality, as it is required for the successful implementation of desalination processes.

Conventional pretreatment, widely and currently used in desalination plants operated worldwide, is based on a number of physicochemical separation procedures (coagulation/flocculation, decantation, depth filtration, etc.) [4]. Coagulation and flocculation are commonly used methods for water turbidity removal, and are usually conducted by adding chemicals, such as aluminum and iron salts as well as polyelectrolytes [5]. The coagulation-flocculation efficiency may be affected by various factors such as the type and dosage of coagulant/flocculant [6], pH [7,8], speed and time of mixing [9], temperature, retention time, etc. [10].

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Many researchers have worked on the elimination of water turbidity by chemical coagulants. Mirzaiy et al. evaluated the removal of turbidity, by poly aluminum chloride from the water of the Karoun river in Iran. The results showed that the most optimal conditions for turbidity removal efficiency by poly aluminum chloride were pH = 8, flash mixing = 120 rpm and the optimal doses of poly aluminum chloride were obtained as 10 and 30 ppm. The turbidity removal efficiency, under optimum condition of poly aluminum chloride application for doses 10 ppm, 30 ppm were 96.59%, 99%, respectively [11]. In the study of Mirzaie et al., at the dose of 10 ppm and 10 ml of injected sludge, turbidity removal with poly aluminium chloride was 98.31%. Also, at the dose of 30 ppm and 4 ml of injected sludge, maximum turbidity removal was 98.92% [12].

While the effectiveness of the above mentioned chemicals as coagulants is well-recognized, it is worth mentioning some drawbacks that are associated with the usage of these coagulants, such as their ineffectiveness in low-temperature water, relatively high procurement costs, detrimental effects on human health, production of large volumes of sludge, and the fact that they significantly affect the pH of treated water. There is also strong evidence linking aluminum-based coagulants to the development of Alzheimer's disease in human beings. Thus it is desirable to replace these chemical coagulants for products that do not generate such drawbacks, such as natural polymers and coagulants [13]. Using natural coagulants could help make considerable savings in chemicals and sludge handling cost [14].

In recent years, chitosan has been utilized as a coagulant in water treatment [15]. Chitosan has received limited study as a drinking water coagulant. The chemical modification methods used to prepare chitosan based flocculants and the influence of structural elements on flocculation properties and mechanisms have been recently reviewed [16]. Chitosan, a natural linear biopoly amino saccharide, is obtained by alkaline deacetylation of chitin, which is the main component of protective cuticles of crustaceans, such as crabs, shrimps, prawns, lobsters, as well as the cell walls of some fungi like aspergillus and mucor. Chitosan is a weak base that is insoluble in water and in organic solvents. However, it is soluble in dilute aqueous acidic solutions (pH < 6.5), which can convert glucosamine units into a soluble form $R–NH_3^+$. Chitosan is inexpensive, biodegradable and nontoxic to mammals [17]. In addition, chitosan has been studied for use as a nontoxic coagulant or flocculant for a wide variety of suspensions, including silt and microorganisms encountered in river water. The effective coagulation for turbidity removal was achieved in tap water when using much lower doses of chitosan than would be required for complete charge neutralization of bentonite [18].

Cactus is another coagulant that has widely been used in water treatment. *Cactus*, a member of the plant family *Cactaceae*, is well adapted to arid and hot dry lands, where plants have a marked capacity to withstand prolonged drought. The ability of *Cactus* species to retain water, under unfavorable climatic conditions is due, in part, to the water-binding capacity of mucilage [19]. *Cactus* belongs to the genus *Opuntia*, a succulent xerophytic plant which can store large amounts of water and has no bad impact on the human health [20]. Furthermore, it possesses considerable benefits in various domains such as cosmetics, medicine and food [21,22]. It was determined, via two separate studies, that standalone long bean extract [23] was ineffective in removing turbidity while *cactus Opuntia* [24] exhibited high turbidity removal efficiency. Natural coagulants have a bright future and have attracted a great number of researchers because they are abundant in nature, not expensive, environment friendly, multifunction, and biodegradable.

The objective of the present experimental study was to remove turbidity from brackish water using chitosan and *cactus*. Jar test experiments were performed on brackish water samples with a low salt concentration (C_{NaCl} = 3 g/L), and different reaction parameters, such as pH and coagulant dose, were varied.

2. Materials and methods

2.1. Preparation of synthetic water

The waters to be treated were prepared in the laboratory using distilled water and sodium chloride (NaCl = 3 g/l). The sodium chloride used is of the mark: Sigma-Aldrich; Assay: ≥ 99.5% (AT); Form: crystalline (fine); pH = 5.0–8.0 (25°C, 50 mg/mL in H_2O).

Turbidity was created by adding industrial bentonite, and the suspension was stirred slowly to reach 20 rpm for 1 h, in order to obtain a uniform dispersion of bentonite particles. The suspension was then allowed to stand for 24 h, and to get complete hydration of bentonite.

2.2. Preparation of natural coagulants

In this study chitosan and *cactus* were used as natural coagulants. Chitosan powder, accurately weighed (100 mg) and placed into a glass beaker, was mixed with 10 mL of

Table 1
Characteristics of synthetic water

Turbidity (NTU)	53.5
TDS (mg/l)	3000
pH	7.4
Electrical conductivity (µs/cm)	5760
Temperature (°C)	21–22

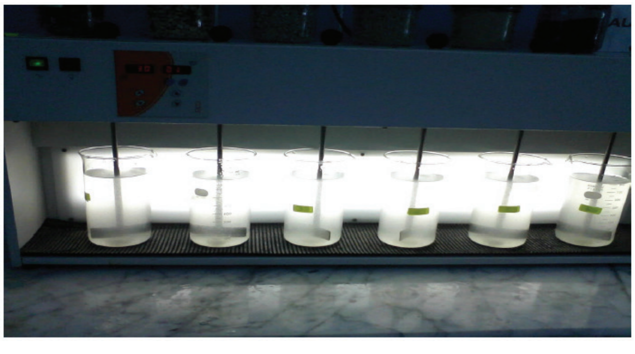

Fig. 1. Jar test (ISCO IDH3A000) (Laboratory of the Treatment Plant "Sekkak dam at tlemcen, in Algeria").

0.1 M HCl solution, and was then kept aside for about one hour to dissolve. It was then diluted to 100 mL by adding distilled water to obtain a solution containing 1.0 mg of chitosan per ml of solution.

As observed earlier, chitosan in acid solutions undergo some change in its properties over a period of time. The solutions were freshly prepared before each set of experiments [25]. HCl was considered to be a better choice for chitosan preparation from the view point of organic inputs [26].

Dry *cactus* powder was obtained by cutting fresh *cactus* into 1 cm wide strips, and then by drying them at the temperature of 60°C, for 24 h. These dry *cactus* strips were then ground in a grinder and sieved to get particles of size 600 µm [27]. The *cactus* used was brought from Tlemcen, a northwestern town in Algeria.

2.3. Description of flocculation tests

The jar test was carried out, using flocculator mark ISCO IDH3A000 which is equipped with 6 agitators and propeller blades. Its rotational speed can vary between 0 and 300 rpm. The volume of the beakers is 1 L.

The jar test would be performed as follows:

- Preparation of 1 L of sample,
- Fast stirring at the speed of 200 rpm for 2 min while introducing the coagulant,
- Slow stirring at 30 rpm for 20 min,
- Stopping the stirring, raising the stirring blades, and decantation for 15 min,
- A sample of 30 ml of decanted water is taken from each beaker.

The results are expressed in terms of turbidity reduction percentage (yield) in order to prevent its variation.

$$\%\text{ Reduction} = \frac{\text{Initial turbidity} - \text{Residual turbidity}}{\text{Initial turbidity}} \times 100 \quad (1)$$

All results are the average of the 3 series of tests. One calculates the arithmetic mean and the standard deviation:

$$\bar{x} = \frac{\sum_{i=1}^{n} xi}{n} \quad (2)$$

$\bar{x}$: the median value of residual turbidity

$$\Delta X = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(xi-\bar{x})^2} \quad (3)$$

ΔX: the standard deviation.

2.4. Methods of physicochemical analysis

Experimental study and analyses were performed using equipments, a 2100N turbidimeter and a PHM220 pH meter.

The turbidity was measured by Naphelometric method using turbidimeter Model 2100 as described in Turbidimeter Instruction Manual Laboratory (HACH, 2000).

The pH is measured for the concentration in H^+ ions of water. It translates the balance between acid and bases on a scale from 0 to 14 (7 being pH of neutrality). This parameter characterizes a great number of physicochemical balances and depends on multiple factors, where it belongs to the origin of water. We measured the potential hydrogenates pH by the pH meter measures (PHM220). This measuring device made up of an electrode of pH which we plunge in the solution and where we want to know acidity, then its pH posts on the screen. The electrode must be rinsed well with tap water, then in the distilled water, after with the analyzed water before each measurement, and the apparatus must be regularly calibrated so that these measurements will be right.

3. Results and discussion

3.1. Optimization of temperature

Tables 2 and 3 show the results obtained for turbidity measurements at different temperatures (10°C, 15°C, 20°C, 25°C, 30°C and 35°C), Depending on the concentration of the coagulant. We have tried to determine the influence of temperature on coagulation flocculation.

From Figs. 2 and 3 it can be seen that the best turbidity elimination is for a chitosan concentration of 1.5 mg/l and a *cactus* of 22 mg/l; Representing the optimum doses for all measurements. Especially for a temperature of 20°C the turbidity values are minimal this indicates that a low temperature disadvantage the coagulation.

Water temperature is important water quality parameter for coagulant and dosage selection. Temperature affects turbidity and particle counts during coagulation [28].

3.2. Optimization of dosage

The coagulation–flocculation assays were conducted on the synthetic solution already prepared (with unadjusted pH; T = 20°C). The first step consisted in testing the efficiency of the coagulants in removing turbidity. The coagulation dosage is one of the most important factors that must be considered in determining the optimum performance conditions of coagulants in coagulation and flocculation. The poor flocculation performance may be caused by either the insufficient coagulant dosage or overdosing. For that reason, determining of the optimum dosage is important to reduce the chemical cost and sludge formation.

When sweep flocculation dominates the coagulate mechanism, almost all the particles will trap positive charge, while only a small portion of particles trap few positive charges and remain negative charged. These two species of particles can coagulate sufficiently with each other [11].

The results from this stage of study encouraged us to proceed further to the second stage, with an optimized coagulant dosage ranging from 10 to 35 mg/l for *cactus*, and 0.5 to 10 mg/l for chitosan (Table 4). From Fig. 6 it can be seen that the highest turbidity removal rate was observed in initial chitosan amount of 1.5 mg/L, which residual turbidity reaches to 1.94 NTU. From Fig. 4 the turbidity removal rate decreased gradually until residual turbidity rate reaches to 5.37 NTU at 22 mg/L of *cactus*.

A very good percentage of turbidity removal was observed with low doses of chitosan. This optimum chitosan dose is higher than that reported by Frederick for

Table 2
Optimization of temperature (fast stirring at 200 rpm for 2 min and slow stirring at 30 rpm for 20 min) (coagulation by chitosan)

Cc (chitosan) (mg/L)	Turbidity (NTU)						
	Before	After					
		T1 = 10°C	T2 = 15°C	T3 = 20°C	T4 = 25°C	T5 = 30°C	T6 = 35°C
0.5	53.5	7.37	4.89	3.67	3.93	5.61	9.79
1	53.5	6.7	4.22	2.97	3.26	4.94	9.12
1.5	53.5	5.76	3.28	2.06	2.32	4	8.18
2	53.5	5.89	3.41	2.19	2.45	4.13	8.31
2.5	53.5	6.47	3.99	2.77	3.03	4.71	8.89
3	53.5	6.75	4.27	3.05	3.31	4.99	9.16
3.5	53.5	7.2	4.72	3.61	3.87	5.55	9.81
4	53.5	7.55	5.07	3.96	4.22	5.87	10.13
4.5	53.5	7.67	5.19	4.05	4.34	5.99	10.27
5	53.5	8.01	5.53	4.39	4.95	6.6	10.92
5.5	53.5	8.82	6.02	4.88	5.44	7.08	11.39
6	53.5	9.42	6.62	5.34	5.9	7.52	11.85
8	53.5	13.4	10.6	9.35	9.48	10.96	15.03
10	53.5	17.38	14.58	13.33	13.46	14.58	18.65
12	53.5	20.2	17.47	17.31	17.19	18.26	20.93
15	53.5	24.18	21.45	21.29	21.17	22.24	24.91
18	53.5	28.11	25.43	25.27	25.39	26.46	29.47
20	53.5	32.15	29.42	29.22	29.34	30.11	33.12
22	53.5	35.96	33.39	33.23	33.35	34.39	37.4
24	53.5	39.97	37.4	37.16	37.04	37.81	40.53
26	53.5	43.89	41.32	41.19	41.09	42.11	44.83
30	53.5	48.92	46.24	46.14	46.05	47.12	49.84
35	53.5	52.04	49.31	49.15	49.03	50.1	52.86

turbidity removal [29] and Yoosofi et al. reported that the optimum dosages of chitosan for removing the turbidities 1000, 500, 50 and 10 NTU were 10, 6.5, 1.5 and 1 mg/L, respectively [30].

At the optimum dose, charges at the surface are all neutralized. In fact, large amounts of bentonite particles at the surface become positively charged due to their coverage by chitosan, and this leads to destabilization (repulsion) of the suspension [31]. Chitosan did not change pH in water treatment process [32]. It was also found that chitosan does not affect the alkalinity. The high content of amine groups in chitosan provides cationic charges at acidic pH, and can destabilize the colloidal suspension to promote the growth of large, rapid-settling flocs that can then flocculate [19]. Because chitosan is a long-chain polymer with positive charges at natural water pH, it can effectively coagulate natural particulates and colloidal materials, which are negatively charged, through adsorption, charge neutralization, inter-particle bridging as well as hydrophobic flocculation [33]. The cationic groups of chitosan neutralize the negatively charged surface of bentonite particles, which results in bridging a polymer of chitosan with several particles of the solids. This bridging allows bringing together the particles of the suspension, which leads to its destabilization.

Results indicated good performance of chitosan as a coagulant for the removal of the turbidity from water. Similarly, Ahmad et al. reported that the initial amount of chitosan has a significant effect on the turbidity removal rate in which, by increasing the chitosan from 0.3 to 10 g/L, the turbidity of treated solution increase from 10 to 12 NTU [34]. Also, Orooji et al. showed that the chitosan as a coagulant aid for the improvement of a polyaluminum chloride coagulant in removing the turbidity from drinking water [35].

Thus, from the results obtained, one can say that the optimum dosage for *cactus* was 22 mg/l. It was also noted that large flocs were formed with impurities in the sample, and this facilitated its settling. As a result, a clear supernatant was produced. This outcome was then compared with the findings from a study conducted by Zhang et al. who indicated that the optimum dosage of *cactus Opuntia* used for turbidity removal of seawater (980 NTU) was 60 mg/L [24]. The high coagulation capacity of *cactus* is probably attributed to the presence of mucilage which is a viscous and complex carbohydrate stored in *cactus* inner and outer pads that have good water retention capacity [36].

Maximum turbidity reduction equal to 89.96% was obtained; comparable results on maximum turbidity reduction equal to 98% and 70%, were a reported by Yang et al. [37], for estuarine and river waters, respectively. Similarly, Shilpa et al. [27] found a maximum turbidity removal efficiency of 89.03% for lake water when treated with *Cactus*.

Table 3
Optimization of temperature (fast stirring at 200 rpm for 2 min and slow stirring at 30 rpm for 20 min) (coagulation by *cactus*)

Cc (*Cactus*) (mg/L)	Turbidity (NTU)						
	Before	After					
		T1 = 10°C	T2 = 15°C	T3 = 20°C	T4 = 25°C	T5 = 30°C	T6 = 35°C
0.5	53.5	21.83	18.48	18.25	18.29	20.87	22.12
1	53.5	21.27	17.92	17.69	17.73	20.31	21.56
1.5	53.5	21.05	17.7	17.52	17.56	20.14	21.39
2	53.5	22.92	17.57	17.39	17.43	20.01	21.26
2.5	53.5	22.32	16.97	16.79	16.91	19.49	20.74
3	53.5	22.06	1671	16.53	16.65	19.58	20.7
3.5	53.5	21.37	16.02	15.84	15.96	18.89	20.01
4	53.5	21.38	16.03	15.78	15.9	18.83	19.95
4.5	53.5	21.25	15.9	15.65	15.74	18.67	19.79
5	53.5	12.71	15.84	15.59	15.68	19.69	19.73
5.5	53.5	18.82	13.47	13.24	13.33	17.34	17.38
6	53.5	17.81	12.46	12.23	12.27	15.28	16.45
8	53.5	15.22	9.75	9.49	9.64	12.61	13.5
10	53.5	14	8.53	8.27	8.42	11.39	12.28
12	53.5	13.78	8.31	8.05	8.2	11.17	12.06
15	53.5	11.96	6.49	6.23	6.27	9.24	10.13
18	53.5	11.52	6.05	5.79	5.83	8.8	9.69
20	53.5	11.82	6.15	5.89	5.93	8.98	9.87
22	53.5	11.39	5.72	5.46	5.49	8.54	9.41
24	53.5	12.25	6.58	6.32	6.35	9.4	10.27
26	53.5	12.7	6.93	6.66	6.82	9.87	10.69
30	53.5	13.51	7.74	7.47	7.63	10.81	11.63
35	53.5	15.15	9.38	9.11	9.27	12.45	13.27

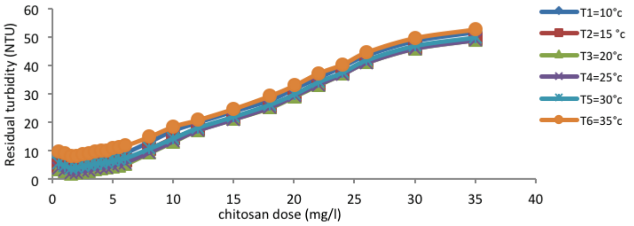

Fig. 2. Optimization of temperature (coagulation by the chitosan).

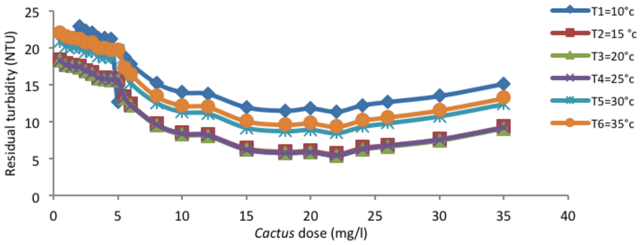

Fig. 3. Optimization of temperature (coagulation by the *cactus*).

Cactus powder is a natural coagulant which is effective in the reduction of water turbidity which is comparable with chitosan's work [38] and can compete with Alum in the water treatment process.

3.3. Optimization of mixing time

Taking into account mainly the optimum coagulant concentrations, as previously determined, a study was conducted to optimize the speed for rapid mixing, while the slow mixing speed was set to 30 rpm, for a time period of 20 min. Table 5 shows the final results.

In the coagulation process, rapid mixing is used to spread out the coagulant throughout the turbid water. In the flocculation process, slow mixing is an essential opera-

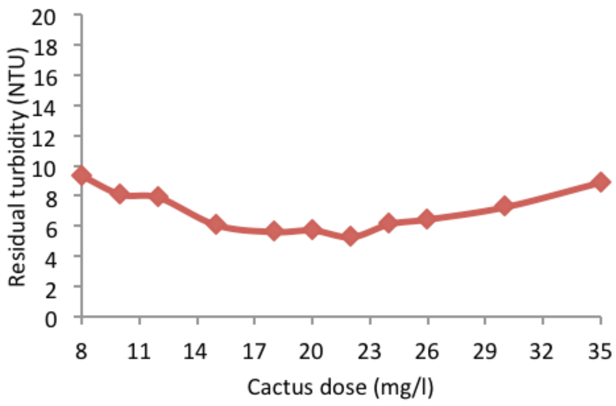

Fig. 4. Effect of cactus dose on bentonite removal.

Table 4
Optimization of coagulant dosage (*cactus* and chitosan) (fast stirring at 200 rpm for 2 min and slow stirring at 30 rpm for 20 min) [T = 20°C]

Cc (chitosan) (mg/L)	Turbidity (NTU)		R (%)	ΔX	Cc (*Cactus*) (mg/L)	Turbidity (NTU)		R (%)	ΔX
	Before	After				Before	After		
0.5	53.5	3.55	93.36	0.62	8	53.5	9.41	82.41	1.64
1	53.5	2.88	94.61	0.5	10	53.5	8.19	84.69	1.42
1.5	53.5	1.94	96.37	0.34	12	53.5	7.97	85.10	1.38
2	53.5	2.07	96.13	0.36	15	53.5	6.15	88.50	1.06
2.5	53.5	2.65	95.04	0.46	18	53.5	5.71	89.32	0.99
3	53.5	2.93	94.52	0.51	20	53.5	5.81	89.14	1.00
3.5	53.5	3.49	93.47	0.6	22	53.5	5.37	89.96	0.94
4	53.5	3.84	92.82	0.67	24	53.5	6.23	88.35	1.09
4.5	53.5	3.96	92.59	0.69	26	53.5	6.54	87.77	1.14
5	53.5	4.3	91.96	0.75	30	53.5	7.35	86.26	1.28
5.5	53.5	4.79	91.04	0.84	35	53.5	8.99	83.19	1.55
6	53.5	5.25	90.18	0.91		–	–	–	–
8	53.5	9.23	82.74	0.33	–	–	–	–	–
10	53.5	13.21	75.30	0.46	–	–	–	–	–

Cc = coagulant concentration (mg/L).
Δ*X*: the standard deviation

Table 5
Optimization of mixing time (slow mixing is set at 30 rpm for 20 min) at 20°C

Rapid mixing (rpm) for 2 min	Chitosan Cc = 1.5 (mg/l) Turbidity (NTU)		R(%)	ΔX	*Cactus* Cc = 22 (mg/l) Turbidity (NTU)		R(%)	ΔX
	Before	After			Before	After		
80	53.5	5.1	90.46	0,966	53.5	8.37	84.35	0,951
100	53.5	3.94	92.63	0,725	53.5	7.51	85.96	0,861
150	53.5	2.44	95.43	0,469	53.5	5.67	89.40	2,059
200	53.5	1.94	96.37	0,375	53.5	5.37	89.96	2,336
250	53.5	2.67	95.00	0,473	53.5	6.89	87.12	1,244
300	53.5	4.12	92.29	0,927	53.5	8.04	84.97	0,787

Cc = coagulant concentration (mg/L).

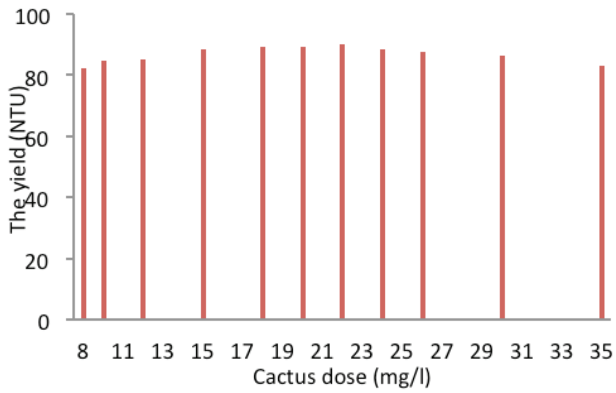

Fig. 5. Effect of *cactus* dose on bentonite removal.

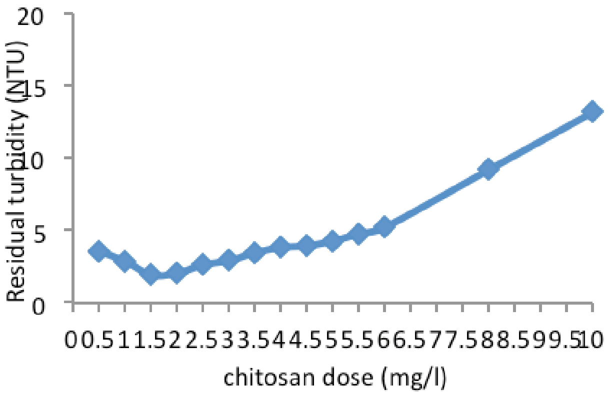

Fig. 6. Effect of chitosan dose on bentonite removal.

Table 6
Optimization of rapid mixing time (slow mixing is set at 30 rpm for 20 min) (rapid mixing is set at 200 rpm) at 20°C

Rapid mixing time	Chitosan Cc = 1.5 mg/l Turbidity (NTU)		R(%)	ΔX	*Cactus* Cc = 22 mg/l Turbidity (NTU)		R(%)	ΔX
	Before	After			Before	After		
0.5	53.5	3.34	93.75	0,781	53.5	5.87	89.02	0,986
1	53.5	2.09	96.09	0,556	53.5	5.79	89.17	0,666
1.5	53.5	2.24	95.81	0,335	53.5	5.34	90.01	0,625
2	53.5	2.97	94.44	0,468	53.5	4.67	91.27	1,115
2.5	53.5	4.42	91.73	0,884	53.5	4.97	90.71	0,581
3	53.5	4.92	90.80	0,734	53.5	5.27	90.14	0,838

Cc = coagulant concentration (mg/L).

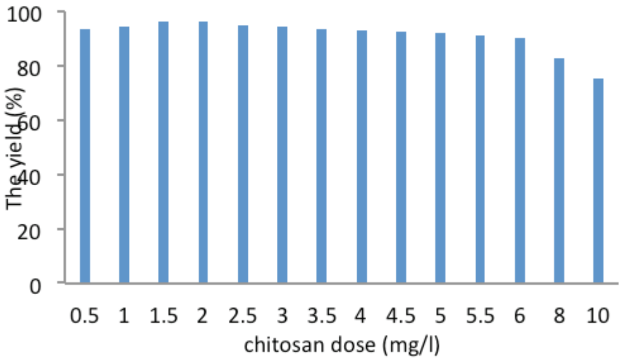

Fig. 7. Effect of chitosan dose on bentonite removal.

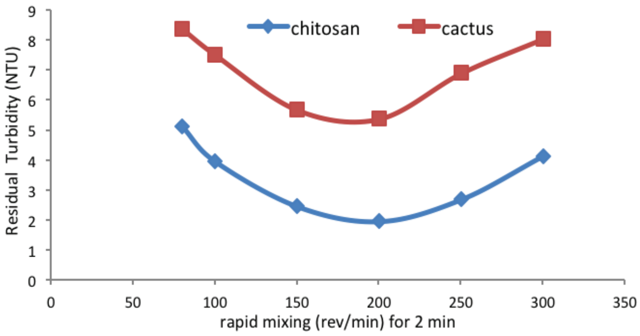

Fig. 8. Optimization of rapid mixing time.

tion in getting the best performance. Appropriate time must be provided to allow the production of sufficiently large particles so they can be efficiently removed during the sedimentation process [39].

It can be noted from Fig. 8 that the optimum mixing time for coagulation, with both chitosan and *cactus*, is 200 rpm for 2 min. At that speed, an optimal amount of energy is dissipated to ensure efficient coagulation through the instantaneous and uniform distribution of the coagulant.

It may seem appropriate to use high speed values to maximize the efficiency in using the chitosan and *cactus*; however, there is an upper limit. Once the speed values exceed that limit, the formation of flocs is delayed and their size gets smaller. It can be expected that higher energy dissipation increases the number of particle collisions, and consequently the rate of floc break-up will increase [40].

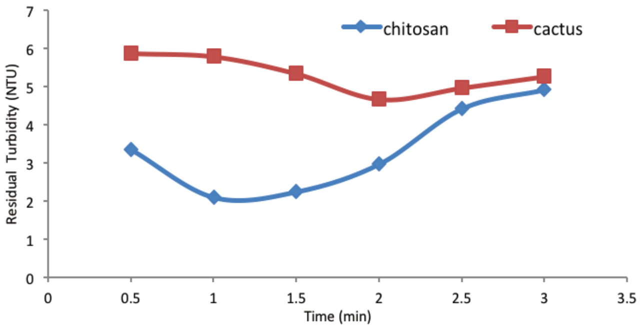

Fig. 9. Optimization of rapid mixing time.

3.4. Optimization of rapid mixing time

Based on the results of optimal coagulant concentrations and rapid mixing obtained before, a study was performed to determine the optimal time of the coagulation / rapid mixing step.

Fig. 9 shows that the lowest residual turbidity was obtained when a rapid mixing time equal to 1 min was applied for chitosan and 2 min for *cactus*. The mixing time has a great impact on floc formation during the slow mix phase. In general, fast mixing for a period shorter than the optimum yields higher residual turbidity and larger flocs [41]. As such, each application has an optimal rapid mixing time which is dependent on the rapid mixing speed and coagulant concentration. The negative effect of prolonged rapid mixing time can be seen in Fig. 9, as higher residual turbidity was obtained for longer rapid mixing times. According to Bratby, extended periods of rapid mixing may give rise to deleterious effects in the coagulation-flocculation process [42].

Yu et al. reported that 10 s fast mix time at 200 rpm fast mixing speed (10 min slow mix time at 50 rpm slow mixing speed) was not sufficient for complete adsorption to take place when applied to 50 mg/L kaolin clay suspension treated with alum as a coagulant [43].

Table 7
Optimization of pH in coagulation-flocculation at 20°C (slow mixing is set at 30 rpm for 20 min). (Rapid mixing is set at 200 rpm, for 1 min (for chitosan) and 2 min (for *cactus*))

pH	Chitosan Cc = 1.5 mg/l Turbidity (NTU)		R(%)	ΔX	*Cactus* Cc = 22 mg/l Turbidity (NTU)		R(%)	ΔX
	Before	After			Before	After		
4	53.5	3.85	92.80	0,792	53.5	6.85	87.19	0,801
5	53.5	3.68	93.12	0,889	53.5	6.68	87.51	0,849
6	53.5	3.51	93.43	0,236	53.5	5.51	89.70	0,781
7	53.5	1.56	97.08	0,496	53.5	3.56	93.34	0,400
8	53.5	6.25	88.31	0,475	53.5	4.78	91.06	0,532
9	53.5	6.45	87.94	0,256	53.5	6.23	88.35	0,705

Cc = coagulant concentration (mg/L).

3.5. Optimization of pH in coagulation-flocculation

Since the pH of the aqueous solution has a key role in the coagulation-flocculation processes and its influence on forming different metal hydroxide species [44,45], the effect of initial pH value of the suspension on the removal efficiency of turbidity was studied in a range of (4 to 9) in coagulation process with chitosan (1.5 mg/L), *cactus* (22 mg/L). The pH was adjusted, in the range, during the fast phase of agitation, using the solutions of HCl and NaOH (2N). Fig. 10 displays the evolution of the outputs of bentonite removal as a function of the initial pH of the solution.

The results from Fig. 10 indicated that in coagulation with *cactus*, when the pH amounts of solution elevates from 4 to 7, the removal efficiency of turbidity increased from 87.19% to a maximum of 93.34% and then the removal efficiency decreased to 88.35%, as the pH 9.

Therefore, through the use of *cactus* as a coagulant, our results confirm that the optimum pH is 7. These results indicate that the turbidity removal efficiency of *cactus* is not dependent strictly upon the pH of water. It was observed that there is no significant change in the pH during the coagulation process. Insignificant change in the final pH has been reported for *Opuntia ficus-indica* [46].

As Fig. 10 shows, in coagulation with chitosan, the highest turbidity removal rate was observed in the solution pH of 7 and the removal rate was decreased with increases and decreases beyond pH 9 and 4, respectively. The reactivity of chitosan for coagulation and flocculation of suspended particles results from several mechanisms, i.e. electrostatic attraction, biosorption (correlated to protonation of the amine group of chitosan and chelating capacity due to the high content of hydroxyl groups) and bridging (correlated to the high molecular weight of chitosan). The contribution of each mechanism depends on the pH of the suspension [47].

The results obtained confirm that the mechanism implied in the coagulation-flocculation process of the system bentonite-chitosan is mainly due to adsorption, with the formation of connections between the amino groupings (NH_2) of chitosan and the inter-foliaceous metal cations of bentonite [48,49]. This is due to the fact that at pH = 7, the group (NH_3) is transformed by deprotonation into the amino group (NH_2); the pKa of chitosan is equal to 6.14.

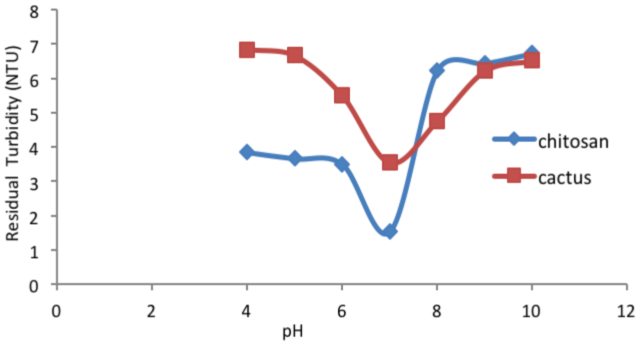

Fig. 10. Influence of pH on coagulation-flocculation.

Thereby, this phenomenon can be attributed to the increase in number of protonated amine groups on chitin at lower pH [44]. The results of the recent studies showed that the chitosan, as a primary coagulant, has better performance in acidic solution and needs to be adjusted to the pH values of the solutions [34,50].

Similar results were obtained when chitosan was used as a coagulant by Jill et al. [51]; in their experiments, they stated that destabilization of the particles was enhanced by the increase in the amount of charged groups followed by charge neutralization, hence resulting in a decrease in the optimum dosage. Turbidity removal was observed at lower pH. The resulting floc diameter was smaller, and the settling velocity was slower. This may be explained by the variation in the configuration of chitosan. In neutral solutions, because of the more coiled structure, the chitosan polymer is able to produce larger and denser flocs. In acidic solutions, it becomes a more extended chain (more charged), and, therefore, produces smaller and looser flocs. Moreover, the effect of pH on the coagulation efficiency of chitosan is insignificant. The evidence infers that charge neutralization is not a major mechanism controlling the formation of flocs for chitosan coagulation [52].

3.6. Comparison of efficiency of natural coagulants

Table 8 displays comparative results of two natural coagulants, i.e. chitosan and *cactus*, in reducing turbid-

Table 8
Comparison of efficiency of natural coagulants

Initial turbidity = 53.5 NTU	Chitosan	*Cactus*
Optimum dose	1.5 mg/l	22 mg/l
Optimum pH	7	7
Slow mixing	30 rpm for 20 min	30 rpm for 20 min
Rapid mixing	200 rpm for 1 min	200 rpm for 2 min
The yield	97.08%	93.35%

ity, with their optimum dosage at an optimum pH value. From Table 8 it can clearly be noted that, out of the two coagulants, chitosan is more efficient in reducing turbidity (97.08 %).

4. Conclusions

In the present study, a batch jar test experiments were done to assess the coagulation efficiency of chitosan and *cactus* for removing of turbidity from brackish water.

The optimum coagulant dose for the water tested in this study based on settled water turbidity was 1.5 and 22 mg/l for chitosan and *cactus*, respectively. The optimum pH found for coagulation to remove settled water turbidity was 7.0 for chitosan and *cactus*. The maximum coagulation of turbidity were achieved by chitosan (97.08%) compared with *cactus* (93.35%). From our results, one can conclude that the powders of *cactus* and chitosan are very effective for removing turbidity from brackish water.

Natural coagulants hold a promising future; they are being investigated by many researchers because they are abundant in nature, cheap, environmentally friendly, multifunction, and are biodegradable in water purification. Today, the use of natural coagulants is not regarded as suitable due to health and economic considerations; it could be more cost effective for the treatment of water in general, and brackish water in particular, especially in the African countries where the economic situation is bleak.

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