

Use of Chitosan for Enhancing the Process of Surface Water Purification in Egypt

Rania S. M. A. Hamdon, Ahmed Salem, Hany G. I. Ahmed, Medhat M. H. ElZahar

Abstract—Natural Organic Matter (NOM) is found in all surface waters. An increase in the amount of NOM over the past 10-20 years has been observed in raw water supply in many areas in Egypt, which has had a significant impact on drinking water treatment. Water scarcity and the increased contamination of drinking water has led to increased doses of coagulants and disinfectants used in water treatment, which has led to increased sludge volume and the production of harmful residual byproducts. In this paper, the results of experiments using an experimental model carried out to investigate improving the removal efficacy of NOM using a natural coagulant, such as chitosan, along with alum, are presented. The results show the use of chitosan is effective in removing NOM and reducing algae and turbidity. In addition, a dose of chitosan added to alum successfully reduced the amount of alum needed in the purification process.

Index Terms—Alum, chitosan, coagulation, flocculation, NOM, water purification.

I. INTRODUCTION

Water pollution is one of the greatest concerns in developed and underdeveloped countries. The substantial pollution of water bodies is standard of developing countries affected by the maximum serious effects of this resource degradation, the spreading of water-related illnesses [1], [2]. Waterborne illnesses that launch parasitic and diseased microorganisms into water bodies are a result of the lack of expertise and resources to build and maintain a healthy sanitation apparatus [3], [4].

In 2017, about 2.72 billion and 2.38 billion rural residents were still lacking basic drinking water and sanitation services (UNICEF and WHO, 2020) [5]. The vast majority of these people are positioned in rural regions of Africa, South Asia, and East Asia [4]. Around five million lives are lost annually due to the consumption and use of infected water [4]-[6]. Many pollutants can be found in surface water streams, one of them is the natural organic matter (NOM) [7], [8].

Chitosan is a linear copolymer that is produced by deacetylation of chitin, which is the second-most abundant biopolymer in the world after cellulose. Due to its unique

properties, chitosan is used in many industrial applications [8]. Chitosan has also attracted significant amount of research attention as a promising coagulant and flocculant, owing to its environment friendly properties [8], [9].

A. Natural Organic Matter in Water

NOM is a complicated organic component of natural surface water [10]. The term Natural Organic Matter refers to a large spectrum of chemical substances that result from natural processes inside the environment, consisting of the decomposition of natural and algal metabolic reactions [11]. Proteins, amino acids, polysaccharides, hemic, and folic acids are all examples of NOM [11]. The presence of NOM poses problems at specific stages in water purification, most notably the formation of poisonous residual byproducts [12], [13].

B. Chitosan As a Coagulant

Chitosan-based materials have also been recommended in laboratory studies as potentially eco-friendly coagulants and flocculants for water and wastewater treatment because of their natural biological characteristics and biodegradability [14].

Chitosan has been reported to perform well as a coagulant by removing chlorella in algae turbid water, removing turbidity from sea water, and for harvesting microalgae [15], [16]. It has several industrial and commercial utilities, can be recycled, and is an excellent chelating agent for many metals such as arsenic, molybdenum, cadmium, chromium, lead, and cobalt [17]. The use of chitosan as a drinking water coagulant has been the focus of several studies. The chemical modification methods used to prepare chitosan-based flocculants and the impact of auxiliary elements on flocculation properties and mechanisms have been recently reviewed [3], [7].

This study will examine the effectiveness of using chitosan as an environmental-friendly coagulant with and without alum to purify Nile River water in Egypt, focusing on reducing turbidity, TOC, and algae by removing NOM in the stages of water purification [18], [19].

II. LITERATURE REVIEW

There is extensive research concerned with water pollution and methods of purifying water using many chemicals. Due to the negative impact of alum on human health, a natural coagulant such as chitosan was highlighted as it does not negatively affect human health [7], [8].

Ample research on water purification by chitosan was carried out as illustrated by Goss and Gorczyca [15]. They recorded that the optimum pH for coagulation to remove water turbidity was 6.0, 5.5, and 5.5 when using alum,

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chitosan, and ferric chloride, respectively. The aggregate of coagulation at the optimum dose, sedimentation, and paper filtration lowered treated water turbidity by 98.8, 96.9, and 98.9 percentages using alum, chitosan, and ferric chloride as coagulants respectively. They also studied the removal of BOD₅ by chitosan, finding it was reduced as the pH increased. Treated water COD levels were recorded to be better using chitosan rather than alum or ferric chloride as coagulants [13], [14], [15].

Björnar Eikebrokk *et al.* [1], found that:

Chitosan is able to remove color and organic carbon from NOM-containing raw water. At doses up to 7.5 mg/liter—about 80% of the color is removed. However, the removal of organic carbon is only 35–40%. 2. The production of sludge solids using chitosan is less than 50% compared with using alum. 3. Both chitosan and alum are capable of removing biodegradable organic carbon more efficiently than dissolved organic carbon. The dominating molecular weight fractions within the raw waters used were within the range of 5,000–20,000. 4. Although the best TOC removal with algae by chitosan is achieved in the molecular weight range of 5,000–20,000, TOC is removed to some extent over a huge variety of molecular weight.

III. EXPERIMENTAL WORK

Experiments focusing on improving the removal efficacy of NOM using natural coagulants such as chitosan to decrease the negative impacts of using alum were carried out. The performance of chitosan for coagulation was investigated through jar testing using a lab design. A series of three jar tests were performed, using six jars per test (Fig. 1).



Fig. 1. Jar tester.

The laboratory experiments were divided into three groups, changing the coagulation material in each. The first group used alum as a chemical coagulant, finding the optimal dose to be 23mg/L, which was the dosage used in Gezeret El-Dahab Water Plant located in Giza (Fig. 2). In the second group of the experiments, the natural coagulant chitosan was used, finding the optimum dose of 8 mg/L. The third group of the experiments used a mixture of the two coagulants chitosan and alum, finding the optimum doses to be 5 and 15mg/L respectively [8], [18], [19].

A. Water Samples

The water samples were taken from the Nile River at

Gezeret El-Dahab Water Plant located in Giza, Egypt, shown in Fig. 2. This location was selected because this plant serves a huge population and has a large amount of NOM. Three water samples were taken from the plant location. Each sample volume was around 12 liters. Jar tester was used to record the optimum dose of each coagulant used. The coagulants used were alum only (current coagulant used), chitosan only, and chitosan mixed with alum. An experimental model was set up consisting of mixing, sedimentation, and filtration to purify the water samples, Fig. 3.

B. Water Characteristics

The raw water characteristics are shown in Table I.

RAW WATER CHARACTERISTICS	VALUE
PH	8.00
TDS MG/L	231
DO MG/L	6.26
SALINITY Δ	0.00
CONDUCTIVITY US/CM	360
TEMPERATURE C ^o	25.9
TOC PPM	6
COD PPM	18.18
BOD PPM	16.20
TURBIDITY NTU	4.5
TOTAL ALGAE UNIT/ML	4000
CAC ₃ MG/L	138

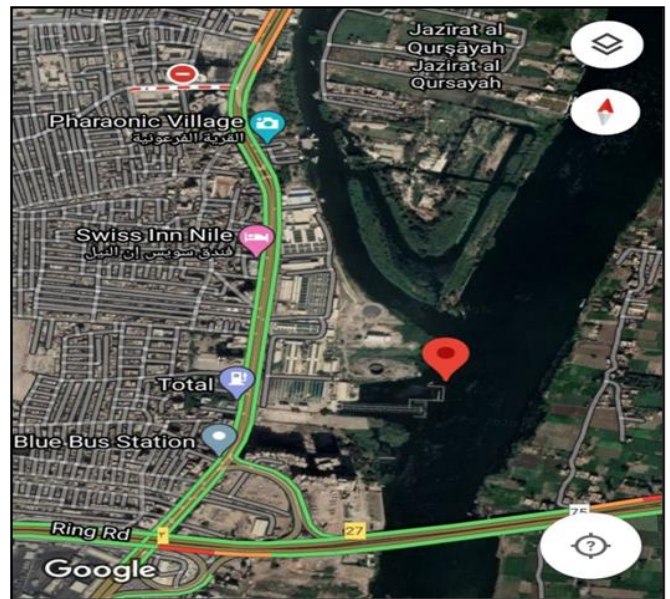


Fig. 2. Intake location (Google map image).

C. Experiments

Each group of experiments used different doses of coagulant. The first group used alum in doses of 19, 21, 23, 25, 27 and 29 mg/L. The second group added chitosan doses in doses of 2, 4, 6, 8, 10, and 12 mg/L. The third group added a mixture of alum and chitosan at doses of 10/4, 20/4, 10/5, 15/5, 10/6, and 5/6 mg/L respectively. A chlorine solution with a dose 7 mg/liter was added to all experiments. Finally, all experiments were carried out again without adding chlorine to compare the results [20].

The experimental laboratory model consisted of two stages: mixing/sedimentation stage and filtration stage. In the first stage, raw water was mixed with coagulant to produce flocks to settle. In the second stage, filtration was used to complete

water purification, as shown in Fig. 4 [20], [21].

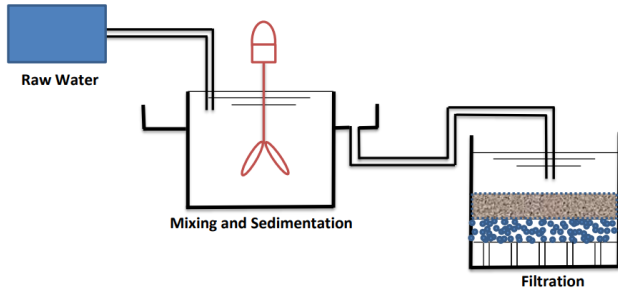


Fig. 3. Experimental model setup [13], [22], [23].

The typical run of one experiment was as follows: -A flash mixing was executed in jar beaker with mixing speed 130rpm for two minutes, then, gentle mixing was used with speed 30rpm for 20 minutes, and then paddles stopped and sedimentation of solids occurred within four minutes. Water was filtered for about 25 minutes using the sand filter mentioned in the filtration stage below. The water samples were measured before mixing and after filtration for the following: turbidity, conductivity, pH, TDS, DO, salinity, conductivity us/cm, BOD₅, COD, TOC and temperature °C. The initial value of turbidity was almost the same for all samples because experiments were done in the same month.

It was noticed that in the group using chitosan, the flocks were heavy and settled down easily. But, in the group using alum, the formed flocks were light, and part of these flocks did not settle down.

The experimental model was used to simulate the water treatment plant through several variables: [24], [25]

- 1) Appropriate doses of coagulants used, i.e., alum, chitosan, and alum/chitosan mixture.
- 2) Sedimentation time which is calculated by Sedimentation time=Sedimentation tank volume/flow rate, i.e., $T=(W*H*L)/Q=V/Q$.
- 3) Filtration process which will be designed in next section according to according to SDI laboratory as shown in Table II [26].

IV. EXPERIMENTAL STAGES

A. Coagulation/Sedimentation Stage

In this stage, we added the coagulants alum, chitosan, and alum/chitosan to the raw water at the doses mentioned above. In each stage, the jar test was used to record the optimum coagulant dose. The optimum dose recorded was 23, 8, and 15/5 mg/L for alum, chitosan, and alum/chitosan, respectively. Furthermore, pH, turbidity, algae, BOD₅, COD, and TOC were measured or determined. The results were summarized in Tables III, IV, and V and in Figs. 5-16.

The goal of this stage was to minimize the time of sedimentation and to improve the removal efficacy of NOM using chitosan alone or mixed with alum. These merits can result in operation improvement by increasing the capacity of the plant and design improvement by decreasing the size of tanks. These merits could save time for the purification process with better quality of purified water. For example, if 10cm of sediment occurred in 60 seconds using alum, 40 seconds would be enough to complete sedimentation using chitosan. Thus, the use of chitosan can increase the efficiency

of the water purification process.

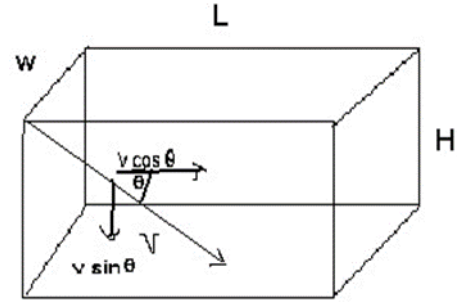


Fig. 4. Sedimentation kinetics.

B. Filtration Stage

In this stage, a sand filter was designed to purify water after decreasing turbidity in the first stage. The sand filter consists of a circular box 5cm in diameter. The filter media consist of an upper layer of 25cm thickness of clean, granulated and homogeneous sand. The sand particles diameter is 1.7-2.0 mm. Under that, there is a layer of clean and spherical gravel. The thickness of the gravel layer is 15 cm, made up of an upper part of 5cm thickness with gravel diameter equal to 2-6 mm, and the lower gravel layer with a thickness of 10cm and gravel diameter equal to 5-15 mm.

C. Filtration Process Design

Consider the productivity flow rate equals 0.002m³/hour, equivalent to 0.0088gpm, referring to Table II, if the effluent turbidity=2NTU, then the filtration rate should be 6gpm/ft². The dimensions of the filter are shown below.

$$A = \frac{1.47 \times 10^{-3}}{3.28} = 4.48 \times 10^{-4} \text{ m}^2$$

$$D = 0.055 \text{ m}$$

$$D = 5 \text{ cm}$$

$$V = 0.9817 \text{ Lit}$$

$$V_{\text{sand}} = \frac{2}{3} * 0.9817 = 0.654 \text{ Lit}$$

$$V_{\text{gravel}} = \frac{1}{3} * 0.9817 = 0.327 \text{ Lit}$$

$$V_{\text{sand}} = 0.654 * 1.6 = 1.04 \text{ Kg}$$

$$V_{\text{gravel}} = 0.52 * 1.6 = 0.52 \text{ Kg [11, 17].}$$

TABLE II: FILTRATION RATE ACCORDING TO SDI LABORATORY

FILTRATION RATE (GPM/FT ²)	TURBIDITY	NOTES
4	10-20	HIGH TURBIDITY
5	5-10	AVERAGE TURBIDITY
6	1-5	LITTLE TURBIDITY
7	<1	NON-TURBID

V. MATERIALS AND METHODS

Three types of coagulants, which are available in Egypt, were applied. The first one was a chemical coagulant, aluminum sulfate, (alum, Al₂(SO₄)₃ 16H₂O). The second one was the natural coagulant chitosan. The third coagulant used was mixture of alum and chitosan. Chlorine was used in the purification plant for disinfection, i.e., it was important to use chlorine during our experiments to have the same conditions as in the plant. Pre-chlorination was carried out by the same values applied in the water plant, which was 7 mg/L.

Moreover, the percentage of pollutant removal was recorded as shown in the tables and figures below. The materials used in the experiments were prepared as follows:

A. Chlorine

Chlorine, used in the water purification process, has an important role in sterilizing water. It is widely available in the market in a solid form in the form of colorless crystals, which are not used in this form in water purification. Instead, a chlorine solution was prepared by using the hydroxide chloride 65%, which means that the chlorine percentage is 65% with existing 35% impurities. The chloride hydroxide was chosen because it contains enough chlorine percentage [13], [14]. Volume to be prepared is one-liter, initial residual chlorine concentration is 0.0mg/L, final residual chlorine concentration is 100mg/L. Weight of calcium hypochlorite with 65% chlorine which was available for use is 0.1538g.

B. Alum

Alum is a chemical compound made of alum stone. This stone contains two types of salt, potassium sulfate and hydrothermal aluminum. Alum consists of a mixture of these two salts, dissolving in water or liquid glycerin [23]. Alum could be dissolved in water for a period of 5-10 minutes [24]. There is also potassium and sodium aluminum, used to sterilize and disinfect water treated with a solution concentration of 1%. In order to prepare 1% of alum solution, i.e., 10mg/1000ml, thus, each liter of this solution contains 10mg of alum [23], [24].

C. Chitosan

Chitosan is a biomaterial, primarily produced from the alkaline deacetylation (40-50% NaOH) of chitin where this N-deacetylation is almost never complete. The chitosan is considered as a partially N-deacetylated derivative of chitin [21]. It is an abundant natural biopolymer obtained from the exoskeletons of crustaceans and arthropods which is a non-toxic copolymer consisting of b-(1,4)-2-amino-2-deoxy-D-glucose units. Glucosamine unit contains a free amino group, and these groups can take on a positive charge which gives amazing properties of chitosan [21]. These biopolymers offer a wide range of unique applications including bioconversion for the production of value-added food products, preservation of foods from microbial deterioration, formation of biodegradable films, recovery of waste material from food processing discards, purification of water, and clarification and de-acidification of fruit juices [21].

Chitosan exists in the form of solid crystals, and in this case, it cannot react or dissolve in water, so three types of salts were evaluated to dissolve chitosan: chitosan hydrochloride HCL, chitosan acetate CH_3COO , and chitosan lactate $\text{OH CO}_2 \text{CH}_3\text{CH}$.

Chitosan acetate was chosen because it was the fastest of the three salts in dissolving chitosan with a dissolution time of 15 minutes. After dissolving chitosan, it is mixed with water to be ready for reaction and use for water purification.

The choice of dissolving chitosan in acetate CH_3COO for a period of 30 minutes was chosen based on previous studies of chemically different treated chitosan, in which the most effective chitosan was determined as a substance [16]. When chitosan is dissolved in acetate solution, it loses 2% of its

concentration [21], [27], [28].

The effectiveness of chitosan for improving the quality of drinking water by the removal of metal contents and microbial contaminants was confirmed. Increasing concentration of chitosan in drinking water led to decrease in turbidity, TDS, electrical conductivity and pH. In addition, the chitosan had sedimented all the salts and improved water quality [21]. The relationship between chitosan concentration and each of turbidity, TDS, electrical conductivity and pH is linear. The determination coefficient ranged between 0.916 and 0.965. Moreover, the effect of chitosan on the G- bacteria was higher than that on G+ bacteria. The unique properties of chitosan made it an exciting and promising agent for using it in the purifying water [17].

Chitosan salts were purchased from "Medical Chitosan Egypt."

VI. RESULTS

Experimental work was executed in the National Research Center. Jar tester which is in the main laboratory of National Research Center, was used in bench-scale simulating processes of coagulation and flocculation to determine the different values of water turbidity. It consists of six flasks of total volume two liters per each flask as revealed clearly in Fig. 1.

A series of tests were carried out to determine the different values of turbidity, pH, TDS, DO, salinity, conductivity, and temperature. Three jar tests were carried out for each coagulant, (alum, chitosan, and mix of alum/chitosan).

In the following tables, results obtained by conducting the previously mentioned experiments are summarized. In these tables, values of turbidity, conductivity, pH, TDS, DO, salinity, conductivity, BOD₅, COD, TOC, and temperature after filtration were recorded.

TABLE III: PH, TURBIDITY, RESIDUAL ALUMINUM, ALGAE, BOD₅, COD AND TOC USING ALUM ONLY, (CHITOSAN = ZERO)

Alum Dose mg/L	pH	Turbidity NTU	Residual Aluminum m	Algae unit/ml	COD ppm	BOD ₅ ppm	TOC Ppm
19	7.41	1.8	0.21	240	10.6	7.6	3.49
21	7.35	1.6	0.23	220	10.3	7.16	3.39
23	7.31	1.4	0.25	200	10.15	6.9	3.34
25	7.28	1.3	0.28	180	12.12	8.2	3.9
27	7.27	1.6	0.30	150	12.72	8.9	4.19
29	7.26	1.6	0.32	120	12.60	8.6	4.15

TABLE IV: PH, TURBIDITY, ALGAE, COD, BOD₅ AND TOC USING CHITOSAN ONLY, (ALUM = ZERO)

Chitosan Doses mg/L	pH	Turbidity NTU	Algae unit/ml	COD ppm	BOD ₅ ppm	TOC ppm
2	6.92	2.7	230	12	10	3.96
4	7.48	2	215	13	11	4.29
6	7.19	2.15	200	13	11	4.29
8	7	2	200	10	8	3.30
10	6.89	2.11	180	14	12	4.62
12	6.85	2.14	150	14	12	4.62

TABLE V: pH, TURBIDITY, RESIDUAL ALUMINUM, ALGAE, COD, BOD5 AND TOC USING MIXTURE OF ALUM/CHITOSAN

Chitosan Doses mg/L	Alum Doses mg/L	pH	Turbidity NTU	Residual Aluminum	Algae unit/ml	COD ppm	BOD ₅ Ppm	TOC Ppm
4	10	7.25	0.8	0.143	137	10	6.66	3.30
4	20	7.96	0.8	0.201	63	11	6.67	3.63
5	10	7.32	1.2	0.145	196	11	6.67	3.63
5	15	7.46	0.85	0.166	148	7	5	2.31
6	10	7.39	0.7	0.145	240	10	7.15	3.95
6	5	7.07	2	0.033	165	10	7.15	3.30

A. pH, Turbidity, and Residual Aluminum

The results obtained from experiments using the jar tester were recorded in Tables III, IV, V, and Figs. 5-16. The pH of water affects the natural organic matter in water [15], [16]. The higher the pH, the more organic matter is removed. The pH value decreases as the dose of alum, chitosan, and alum/chitosan increases. The best pH value was recorded when using 23, 8 and 15/5 mg/L of alum, chitosan and alum/chitosan, respectively. Moreover, the TOC value was acceptable. To evaluate the effectiveness of the overall turbidity removal, the water was filtered after completion of the jar test by passing water over a sand filter. The combination of coagulation with optimum dose, sedimentation and sand filter reduced the turbidity of the treated water by 98.5, 98.5 and 99.5 percent when using alum, chitosan, or alum/chitosan, respectively.

It is clear from reports of the World Health Organization (WHO) over the past decade [5], that there is a problem about the relationship between aluminum residue in treated water and the spread of Alzheimer's disease. As a result, the research focused on the use of natural coagulants such as chitosan in water purification in an attempt to limit the spread of this disease [17].

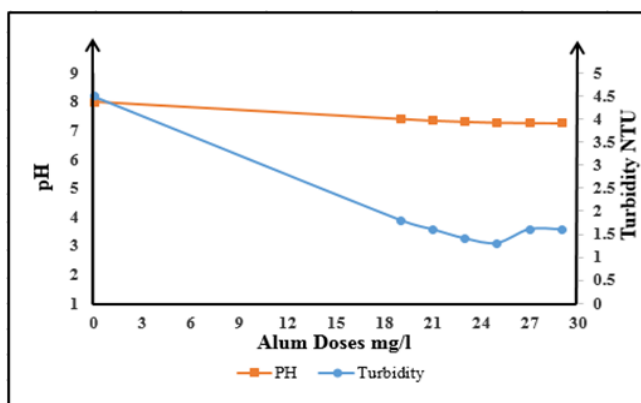


Fig. 5. Turbidity and pH in water versus alum doses.

Figs. 5, 6, 7, show the results we obtained for turbidity, pH, and residual aluminum. Fig. 5 shows the use of alum and its effect on pH and turbidity. The results showed that the higher the alum dose, the lower the turbidity value to about 1.4. This value resulted when using a dose of 23mg/L of alum, and also the pH decreases slightly to the value 7.31 using that dose of alum, i.e., 23 mg/L alum. Thus, we find that the best dose of alum to give the lowest turbidity is 23mg/L and corresponding pH were recorded.

Fig. 6 shows the results we obtained when using chitosan as a coagulant and its effect on turbidity and pH. The

turbidity decreased with the increase in the dose of chitosan. The lowest value for turbidity was 2 when using a dose of 8mg/L of chitosan, and the corresponding pH also decreased significantly. The pH value was 7 when using the dose of 8mg/L of chitosan. Thus, from these results, the dose of 8mg/L of chitosan as a coagulant is the optimum value recorded.

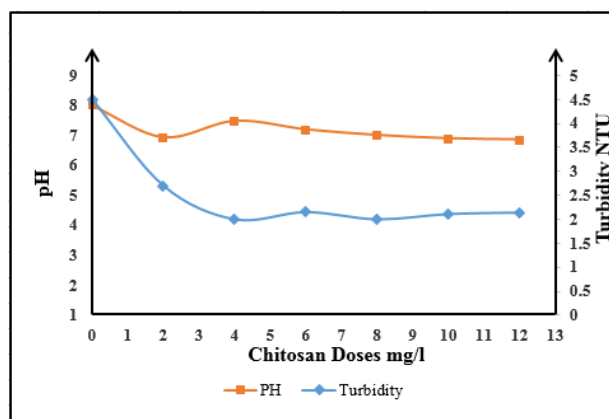


Fig. 6. Turbidity and pH in water versus chitosan doses.

Fig. 7 shows the value of the residual aluminum in the water after completion of the purification process when using alum in the plant as a coagulant, as the higher the dose of alum, the more aluminum remains in the water. Looking at the dose of 23 mg/L of alum, we find that the value of the residual aluminum is 0.25, which is less than 0.5, i.e., less than the permissible value in drinking water in Egypt. Thus, 23mg/L is the dose of alum used in the purification plant.

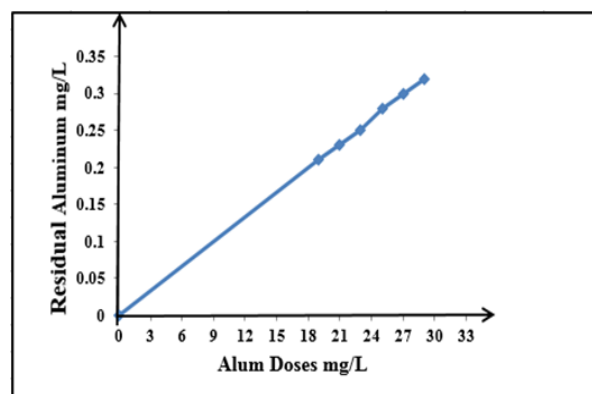


Fig. 7. Residual aluminum in water versus alum doses.

Figs. 8, 9, and 10 show the values of pH, turbidity, and residual aluminum when using a mixture of alum/chitosan as a coagulant. Fig. 8 shows the pH values when using alum/chitosan together, where the pH value changes slightly

as the doses increase. Fig. 9 shows the turbidity values when using different combination of doses of alum/chitosan coagulants.

The following doses resulted in acceptable results for turbidity and were recorded as best values obtained. The turbidity is 0.85 at a dose of 15/5 of alum/chitosan, which is a good turbidity value, and the corresponding pH is 7.46, which is an acceptable value. Therefore, the optimum doses that give the lowest turbidity is 15/5mg/L of alum/chitosan.

Fig. 10 shows the values of residual aluminum in the water when using alum/chitosan together as a coagulant, as the remaining aluminum in water decreased when using alum/chitosan due to the use of lower doses of alum. This means that our aim succeeded by purifying water with less residual aluminum.

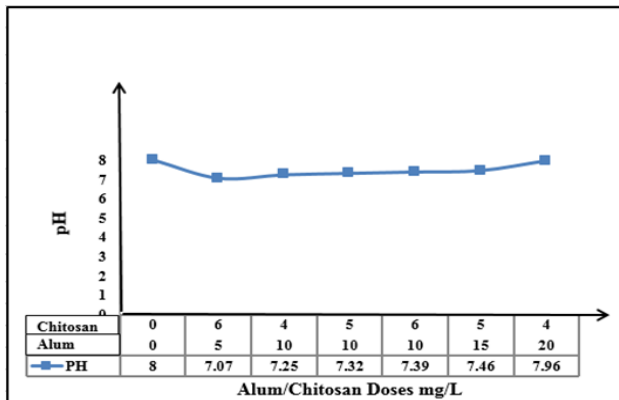


Fig. 8. pH in water versus alum/chitosan mixture doses.

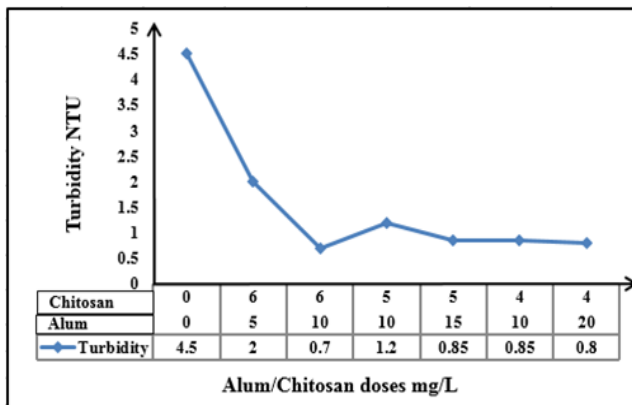


Fig. 9. Turbidity in water versus (alum/chitosan) doses.

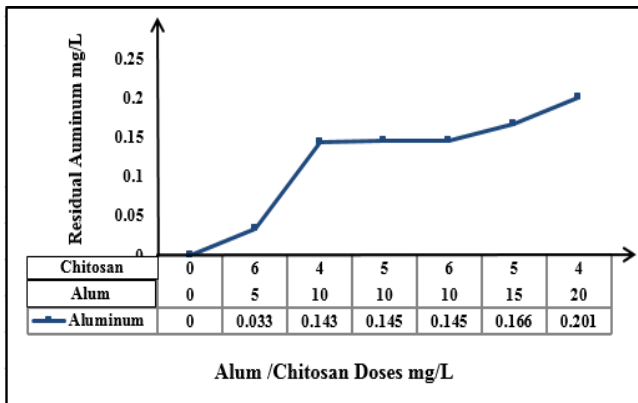


Fig. 10. Residual aluminum in water versus (alum/chitosan) doses.

B. Removal of Algae

Figs. 11,12, and 13 show the amount of algae present in the

water after the purification process when using different materials such as alum, chitosan, and alum/chitosan together. Fig. 11 shows the amount of algae when using different doses of alum. The values demonstrate the amount of algae decreased when the dose of alum increased. The amount of 200 unit/mL of algae was recorded at the dose of 23mg/L of alum in the purification plant. Fig. 12 shows the amount of algae when using different doses of chitosan. Using chitosan gave similar algae results that were obtained when using alum. The amount of algae decreased when using higher dose of chitosan. Fig. 13 shows the amount of algae when using a mixture of alum/chitosan together. The amount of algae decreased remarkably. In fact, the results were better than the results when using alum only or chitosan only. The amount of 148 unit/mL of algae was recorded when using the determined optimum dose 15/5 mg/L of alum/chitosan. When using the alum/chitosan mixture, it was found to be effective in coagulation, as the removal rate reached 93%, at the optimum coagulant dosage and the corresponding pH value. It was also found that chitosan was more effective for removing algae from water with a 96% removal rate. From the previous results that were shown in the Figs. 11, 12, 13, when using a mixture of alum/chitosan as coagulant, the amount of algae decreased significantly. Therefore, it is preferable to mix alum with chitosan to get the lowest amount of algae in the water.

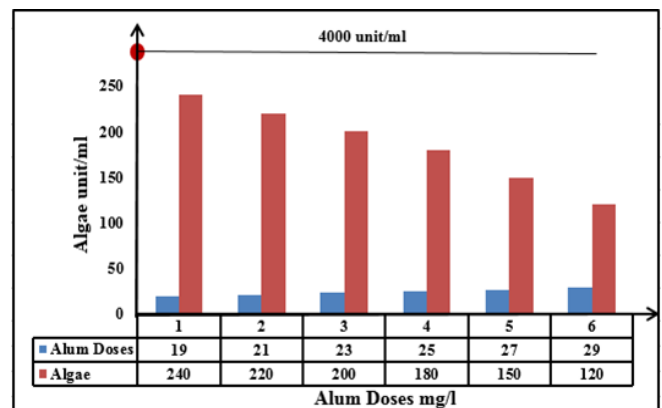


Fig. 11. Algae in water versus alum doses.

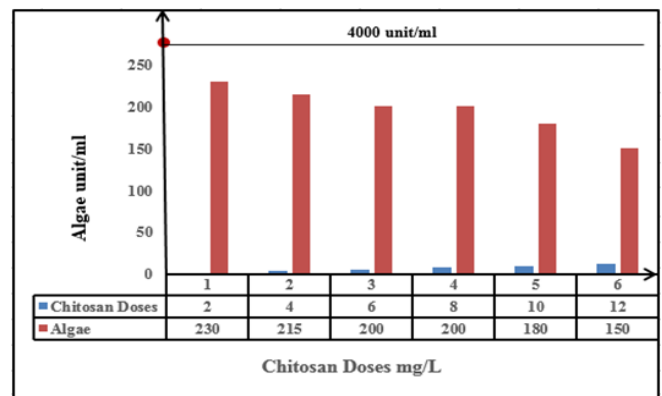


Fig. 12. Algae in water versus chitosan doses.

C. NOM Removal

Fig. 14, 15, and 16 show the values of the organic matter when using different coagulants in different doses for each coagulant: alum, chitosan, and alum/chitosan together. Organic matters are expressed by measuring BOD₅, COD, and TOC.

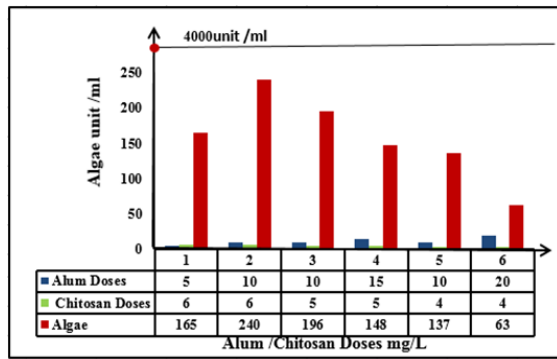


Fig. 13. Algae in water versus (alum/chitosan) doses.

Fig. 14 shows the results of BOD₅, COD, and TOC when using alum only as coagulant as it is taking place in the water purification plant. The values of BOD₅, COD, and TOC decrease as the dose of alum increases, so alum is effective in removing organic matter from water. The pH value ranged between 7.26-7.41 (average of 7.31). The BOD₅ value decreased to 6.9. The COD value reached approximately 10.15ppm (44% removal rate). The TOC value reached 3.34 ppm (removal rate up to 44%).

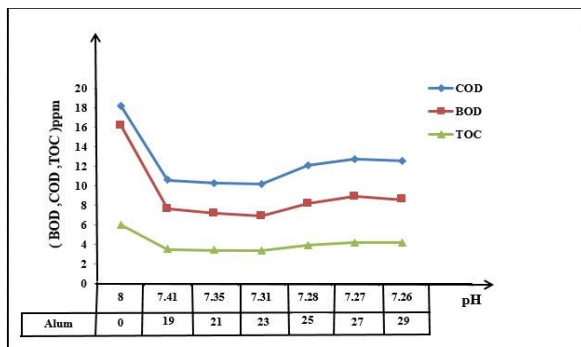
Fig. 14. Effect of pH on BOD₅, COD, and TOC using alum.

Fig. 15 shows the results of BOD₅, COD, and TOC when using chitosan coagulant only. It was found when using the selected dose of 8mg/L that the pH value ranged between 6.85-7.48 (average 7.06). The BOD₅ value reached 8.0, and the COD value reached approximately 10.00ppm (45% removal rate). The TOC reached 3.3ppm (removal rate reached 45%). Thus, from these results we find that using chitosan alone had no significant effect in removing natural organic matters as the results were almost the same as when using alum alone.

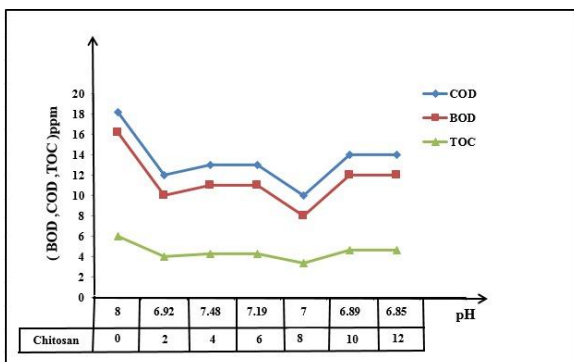
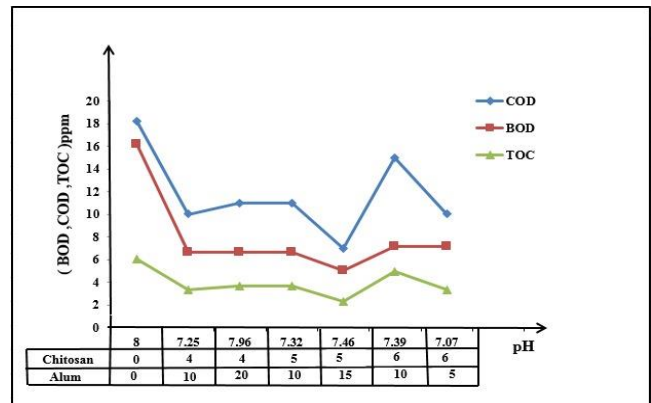
Fig. 15. Effect of pH on BOD₅, COD, and TOC using chitosan.

Fig. 16 shows the results of BOD₅, COD, and TOC when using alum/chitosan together. The mixture gave better results. It was found when using the selected dose 15/5mg/L that the

pH value ranged between 7.07-7.96 (average 7.4). The value of BOD₅ decreased to 5.0 and the value of COD reached approximately 7.00ppm (removal rate of 61.5%), and TOC decreased to 2.31ppm (removal rate of 61.5%). Therefore, we find that the effect of chitosan alone was not noticeable in removing natural organic matter, as almost the same results were obtained as using alum alone. However, the mixture gave good results as (BOD₅, COD, TOC) were significantly reduced, and the results of a combination of alum/chitosan were the best.

Fig. 16. Effect of pH on BOD₅, COD, and TOC using (alum/chitosan).

VII. CONCLUSION

The results of the research can be summarized as follows. The possibility of using a natural coagulant such as chitosan to purify the Nile River water and remove the natural organic matter effectively was confirmed. It was also confirmed that a dose of chitosan could be added to a dose of alum to reduce the percentage of alum used in purification plants and thus reduce the negative effects of using a high dose of alum, which leads to aluminum residuals in water. This in turn causes diseases such as Alzheimer's.

In addition, an experimental model was set up and experiments were carried out to investigate improving the removal efficacy of NOM, BOD₅, COD, and TOC. Removal of BOD₅ by chitosan was reduced as the pH was increased. Treated water COD levels were higher for chitosan than for alum. After using alum, chitosan, and alum/chitosan as coagulants, the turbidity of water became 1.4, 2, and 0.85 with removal efficiency 98.5, 96.5, and 99.5 percent respectively. The optimum value of pH was 7.31, 7, and 7.49 using coagulants, alum, chitosan, and alum/chitosan, respectively.

Removing algae using chitosan or alum/chitosan is better than using alum only. One of the advantages of using chitosan only or alum/chitosan is that it reduces the sedimentation time because the flocs formed are cohesive and large in size. Finally, the optimum coagulant dose used based on steady water turbidity was 8, and 15/5 mg/L using chitosan and alum/chitosan as coagulants respectively. More future research is needed to start applying using environmentally friendly coagulants for water and wastewater treatment.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

R SMAH, conducted the experiments and wrote the initial paper; AS, supervised, co-wrote the paper; HGIA, guided, reviewed and co-wrote the paper; MMHE, supervised, guided, co-wrote, and revised the paper; all authors approved the final version.

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