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Application of Cactus Cladodes Mucilage (*Opuntia ficus-indica*) as an Eco-Friendly Natural Coagulant and Flocculent Aid with Alum for Potable Water Treatment

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Abstract: ***Turbid water has a significant harmful effect on water pollution which is included suspended solids and colloidal materials such as clay, silt and its contents of organic, inorganic materials and microorganism. Sedimentation method by coagulants is the best and least expensive process comparison to other methods, it is recommended for primary water treatment. Inorganic compounds such as aluminum sulfate (alum) are widely used as a coagulant, but it has caused many problems for human's health .Therefore many studies attempt to find eco-friendly natural coagulant as an alternative of chemical material for water treatment. This study comprised using cactus mucilage extract as a mainly coagulant as well as used a coagulant aid with alum by jar test apparatus to treat three levels of turbid water 53,100 and200 NTU at pH ranging between 4–10,varoius temperatures and several intervals of settle were examined in study. Results indicated that the optimum dosages of natural coagulant were 5,10 and30 ppm at pH 7 and the best period of sedimentation was 2 and 5 hours with significant turbidity removal 79.3%, 78.7%, 82% and 84.7%, 86.6%, 87.9% for two time and three levels of turbid water respectively, while there is non-significant difference between various temperatures in treatment. This study shows integrated natural coagulant with alum obtained maximum turbidity removal at ratio (0.5:0.5) (coagulant aid: alum) that were 74.1%, 84.7% and 89.8% for three levels of turbid water respectively.***

Keywords: River water, natural coagulant, purification, cactus, mucilage

1. Introduction

Water is a structure basic for all life aspects. Fresh water is a very little portion which is equal or less than 2% of total water on the globe, it is a very important substance for human's life as a source of drinking water and other purposes. there is a high percent of pathological cases were resulted from contaminated drinking water and 71% of world's population are still suffering due to consume contaminated water (Hamdani and Fathil, 2015). World health organization reported that more than 80% of world 's diseases occurred due to contaminated drinking water and 11% of world's population are lacking access to safe drinking water, especially in rural areas (WHO, 2011).

In recent years we have observed a significant deterioration in Iraqi natural environment, pollution extended from air to soil and water, especially in rural areas (Hadithi, 2013). Therefore, it is necessary to focus for water technology studies to seek appropriated methods for improving water quality to obtain human's requirements.

Turbid water has a significant harmful effect on water pollution, it is measurement of dissolved, suspended solids and colloidal materials such as clay, silt and its content of organic, inorganic materials, microorganisms and phytoplankton which are resulted from erosion of land and soils. Turbidity and particles size of water that are least than 0.01 mm still in suspension cause most of problems, but those are larger precipitated on bottom (Argullo *et al*., 2015; Obeidi and Neama, 2013; Sulaymon *et al*., 2013).

Sedimentation method by coagulants to remove turbidity water is the best and least expensive comparison to other methods and it is recommended for primary water treatment for drinking water treatment (Pichler *et al*., 2012).

Most coagulants are known inorganic compounds such as aluminum sulfate (alum), despite these coagulants are widely used, but they have caused many problems that affect on a human's health, decrease pH, increase sludge volume in treated water and it is non-biodegradable (Omer *et al*., 2013).

Many countries attempted to find eco-friendly natural coagulants that is consist of polysaccharide and proteins which contain ionic or non-ionic groups called natural polymers, one of them named cactus mucilage, it is added direct or assistant coagulant for water purification to reduce required concentration of inorganic coagulant for treatment (Arguello *et al*., 2015).

There are 400 species of cactuses are used in different purposes, one of them is called *Opuntia ficus-indica* of Opuntia genus and cactaceae family, it is growing in desert areas, aqueous extract of mucilage is thick substance and contains polysaccharide, monosaccharide and proteins focused in the outer and interior layer of plant's stem (Torres *et al*., 2012). Plant gum extraction could be produced by several methods, one of them use alcohol to precipitate mucilage, which is used in different purposes such as water purification (Arguello *et al*., 2015). This study aimed for using *Opuntia ficus-indica* mucilage in water purification to

reduce alum that required for water treatment to reduce harmful effects on human's health.

2. Materials and Methods

Preparation of cactus mucilage

Extraction process were carried out according to method of Bustillos *et al*., (2013) which was included, 2.5 kg of plant's stems was cut into small pieces, added 2 liter of distilled water then boiled for 20 minutes until color turned to green light and soft tissue, pieces separated from extract by using a sieve with large pores then amount of cool ethanol 96% was added to extract at ratio (1:1) (v/v) to precipitate mucilage, the mucilage was separated by cotton sieve and was dried by oven at 45 C° for 24 hours, dried gum was grind and kept into airtightly container.

Calculated yield of mucilage according to method of Shende and Marathe (2015) by following equation :

yield (%) = weight of dried mucilage(g) / weight plant(g) ×100

Preparation of alum solution

Aluminum sulfate solution (alum) AL2(SO4)3.14H2O was prepared according to method of Sulaymon *et al.*, (2013), dissolved 10 g of alum in 1 liter of distilled water to prepare concentration of 10,000 ppm. Kept into airtightly glass bottle for using in experimental work.

Preparation of natural coagulant solution

Natural coagulant was prepared according to method of Hamidawi and Al-obeidi (2014), dissolved 1 g of powder mucilage in little amount of distilled water then mixed by magnetic stirrer at room temperature, volume completed to 1 liter with distilled water to obtain concentration of 1000 ppm for using in experimental work.

Sampling of raw water

A water sample of tigris river was brought from Jadriya region near to baghdad university in September/2016.The sample was subjected to some analyses and preserved into plastic container at a temperature 5 C° according to method of United States environmental protection agency (2015).

Preparation of turbid water

The synthetic turbid water was prepared by socking 30g of pure natural clay after milling and sieving in 1 liter of distilled water, mixed for one hour by shaker at 100 rpm to homogenize and still for 24 hours to complete hydration. This suspension called stock solution. The filtrate was added to the sample for preparing different levels of turbid water 53, 100 and 200 NTU for experimental work (Renuka and Jadhav, 2013).

Experimental work by jar test

According to method of Arguello *et al*., (2015), water samples were used with three levels of turbid water 53,100 and 200 NTU at pH adjusted between 7.5-8 by adding volume of 0.1 M of NaOH or HCL at room temperature. The samples were subjected by using jar test which composed of 6 beakers. Coagulants were added to 1 liter of the sample into a specified glass beaker. Process included rapid mixing at 200 rpm for 1 minute, then slow mixing at 40 rpm for 20 minutes and allowed to settle for 20 minutes. The filtrate was withdrawn from the upper layer for examination, the measurements included pH, DOC, TOC, TSS, EC, TDS.

Turbidity removal and coagulant efficiency calculation

Coagulant efficiency and turbidity removal percentage were calculated according to the method of Arguello *et al*., (2015), as following equations:

Coagulant efficiency (%) = Residual turbidity of blank – Final turbidity/ Residual turbidity of blank ×100

Turbidity removal (%) = Initial turbidity - Final turbidity/ Initial turbidity ×100

3. Result and Discussion

Physicochemical properties of the raw water samples

Results of water samples analysis shown in table (1), there were rise values of all determinants according to increase water turbidity 53,100 and 200 NTU due to increase of organic and inorganic materials and salt concentration in water samples which were resulted by adding clay materials to water samples. This result agree with study of Zidane *et al*., (2009) who noted that the clay materials in water caused increase of dissolve organic, total organic compounds, pH, electric conductively and other determinates. As well as Hashim *et al*., (2015) indicated that the increment of pH and ionic compounds concentration in river water resulted by Flood and rock erosion.

Table 1: Physicochemical properties of the river water Samples

parameters	*Turbid water 53 (NTU)*	*Turbid water 100 (NTU)*	*Turbid water 200 (NTU)*
pH	7.4	7.8	8.2
DOC (ppm)	3.7	3.9	4
TOC (ppm)	14.3	19.5	26.1
EC (µs/cm)	899	1033	1064
TDS (ppm)	570	671	691
TSS (ppm)	37	55.7	129.6
Hardness (ppm)	379	384	393
Alkalinity (ppm)	133.8	148	157.9
Cu (ppm)	0.06	0.07	0.08
Pb (ppm)	0.01	0.02	0.03
Zn (ppm)	0.06	0.07	0.1
Co (ppm)	0.01	0.02	0.02
Cd (ppm)	0.02	0.02	0.03
Ni (ppm)	0.01	0.01	0.02

Optimum conditions for using cactus coagulant in water purification

Results comprised using various dosages of cactus coagulant for water purification as shown in fig (1,2). Optimum dosages of coagulant were 5,10,30 ppm with significant difference ($P<0.05$) of turbidity removal and coagulant efficiency were 67.6%,70%,76% and 57.8%,60.8%,68.8% for three levels of turbid water respectively. Study of Shilpa *et al*., (2012) supported current study which was carried out to use optimum dose of cactus and lablab extracts for wastewater treatment with turbidity removal reached to 89%,77% respectively. Other study of Jadhav and Mahajan

(2013) indicated that turbidity removal of cactus coagulant for fresh water treatment was between 49-89% .

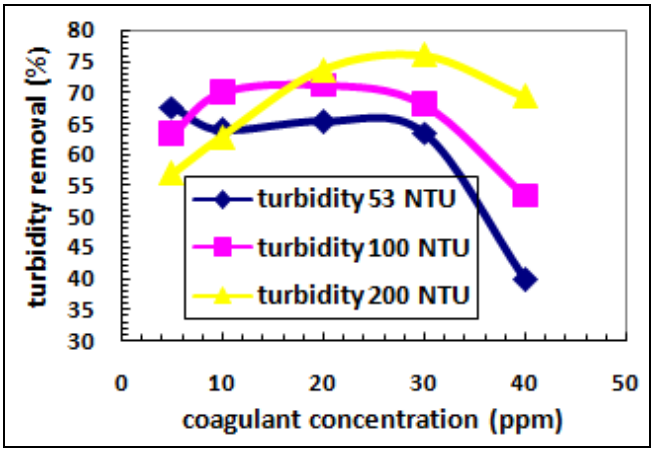

Figure 1: Effect of various doses of cactus coagulant on water turbidity removal for three levels of turbid water

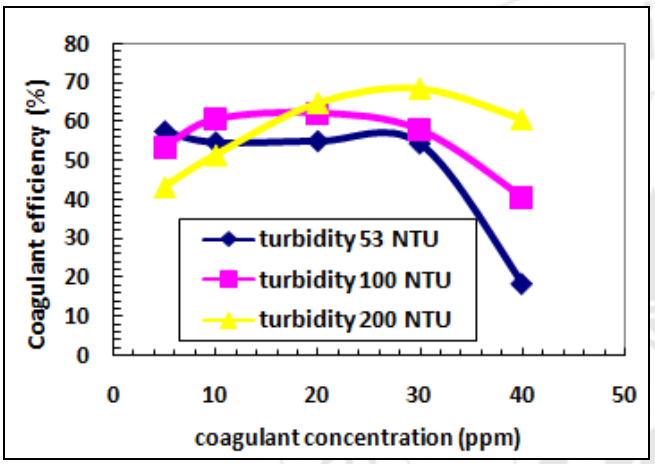

Figure 2: Coagulant efficiency in optimum doses of cactus coagulant to treat three levels of turbid water

Fig (3) showed decrease in total suspended solids from 37, 55.7 and 129.6 to 13.2, 19.9 and 28.4 ppm at optimum dose for three levels of turbid water respectively. Reduction in suspended solids means reduction of total organic carbon and microorganism and other compounds. Reduction of contaminated materials could be obtained by attachment active group of natural polymer to external layer of contaminated particles by opposite charging between them to obtain neutralization point, this process called adsorption. It is also obtained by polymer bridge formation to bind particles together to form floc that consisted of aggregated particles in little volume, high density and easily to precipitate in bottom basin.

In addition, there is increase in concentration of dissolve organic carbon which was resulted due to added natural coagulant in water but did not excess of 1 ppm in treated water, world health organization carried out that the high concentration of these compounds exceed than 5 ppm in drink water cause decrease in efficiency of sterilization due to it's interaction with chlorine and prevents UV- radiation passage through water during sterilization process (WHO, 2011).

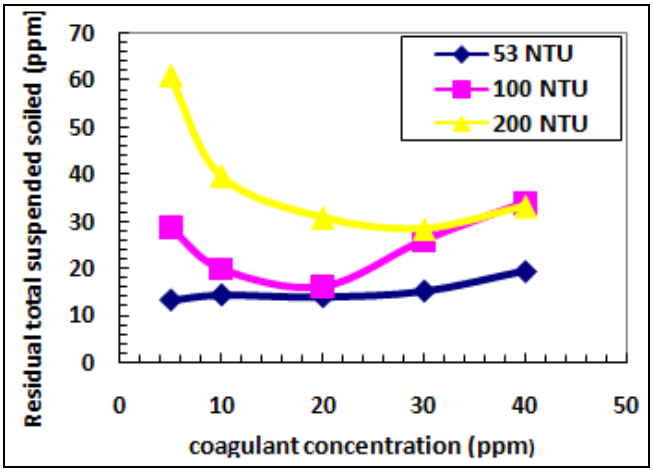

Figure 3: Residual total suspended solid in treated water by use cactus coagulant to treat three levels of turbid water

there is a slight decrease in electric conductivity by using 10,20 ppm of cactus mucilage ,while alum solution at same concentrations caused slight increase in electric conductivity, this increase due to high concentration of sulfate ion in treated water that was resulted from decomposition of alum, natural coagulant did not add ionic compounds in treated water as shown in fig (4).

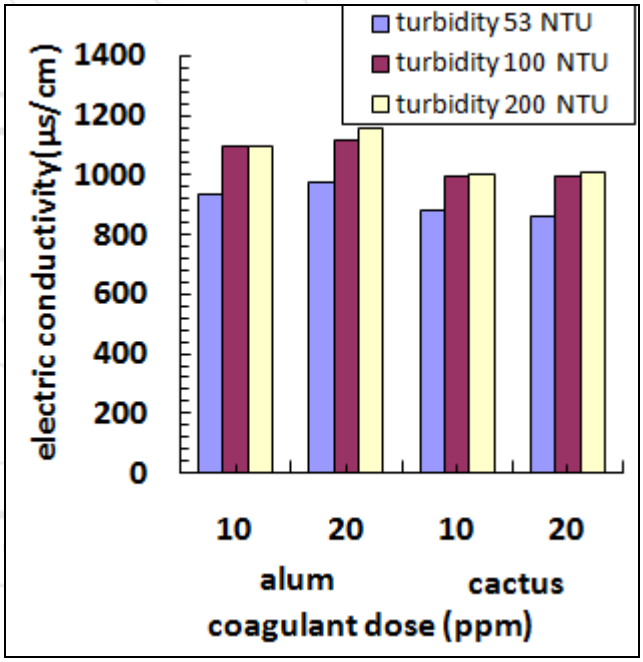

Figure 4: Concentration of alum, cactus solutions at 10,20 ppm and it's effects on electric conductivity of treated water

Influence of pH on water turbidity removal shown in fig (5) that pH 7 gave maximum significant difference ($P<0.05$) of turbidity removal which were 66.9%, 71% and 75.2% for three levels of turbid water respectively. Most studies have indicated that the typical pH of most natural coagulants to remove water turbidity is between 6.5-7.5 and pH has an important role for changing electrical charge of active groups such as acid galacturonic in cactus mucilage and it's effect include attachment between coagulant active groups and suspended particles (Jadhav and Mahajan, 2013; Omer *at el*., 2013). Bouatay and Mhenni (2014) noted that the pH of the water between 7-8 is suitable for water purification by using cactus coagulant.

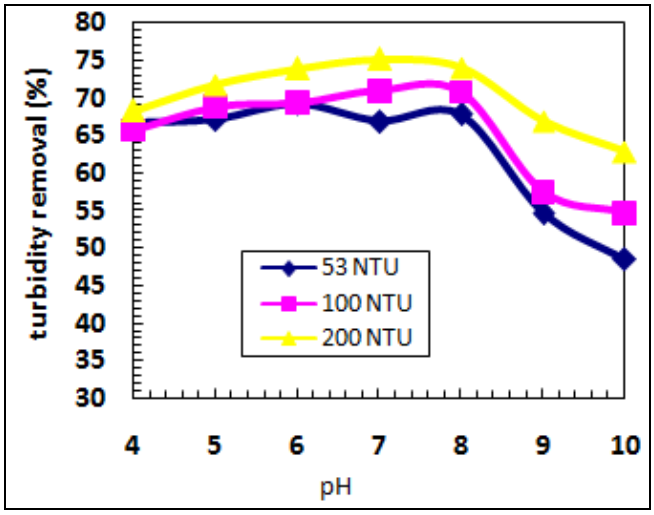

Figure 5: Effect of pH value on turbidity removal for three levels of turbid water

Fig (6) presented three Temperatures 25, 35 and 45 C° which were used in study, there was little variation on water turbidity removal but it is non-significant (P≥0.05). Other study indicated to use Conocarpus's leaves extract as a natural coagulant in raw water purification at a temperature 26 C° had achieved water turbidity removal 48%, while at temperature 55 C° obtained more significant difference of water turbidity reduction (Hamidawi and Al-Obeidi, 2014).

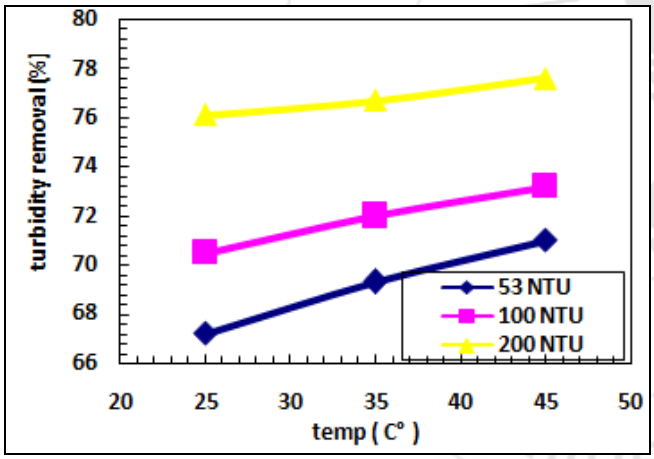

Figure 6: Effect of three temperatures on turbidity removal for three levels of turbid water

Fig (7) adopted several time of sedimentation in experiments, most of them showed non-significant differences (P≥0.05) between 5, 12 and 24 hours and best period of sedimentation 2 and 5 hour, those were given significant difference (P<0.05) in reduction of water turbidity comparison to other treatments were 79.3%, 78.7%, 82% and 84.7%, 86.6%, 87.9% for three levels of turbid water respectively. The sedimentation time of water treatment should not be exceeded 4-5 hours for economic purposes (Shaltout and Ghonam, 2008), while Ramamurthy *et al*., (2012) mentioned that the use of fenugreek seeds extract in turbid water purification for 6 hours of settle time has given the best result in water purification.

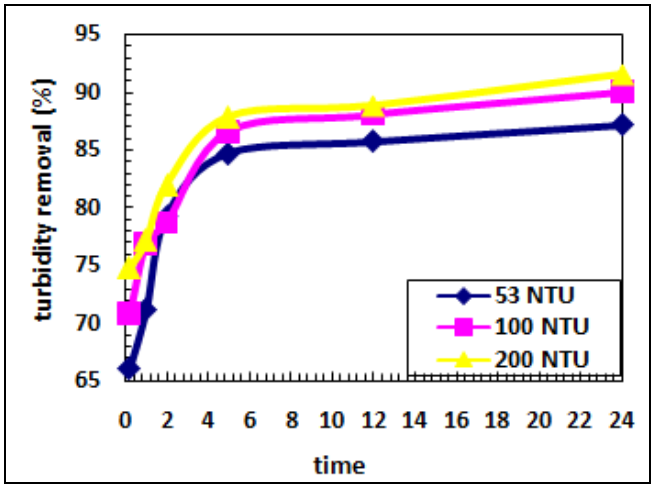

Figure 7: Effect of several periods sedimentation on turbidity removal for three levels of turbid water

Table (2) observed significant decrease of some heavy metals ions after treatment comparison to raw water for three levels of turbid water due to polymer adsorption of these metals.

Table 2: Range of heavy metals concentration in raw water and treated water for three levels of turbid water

sample	*Raw water(ppm)*	*Treated water(ppm)*
Cu	0.06-0.08	0.03-0.05
pb	0.01-0.03	0.01 or less
Zn	0.06-0.1	0.03-0.07
Co	0.01-0.02	-
Cd	0.02-0.03	0.01 or less
Ni	0.01-0.02	0.01 or less

Cactus mucilage as a coagulant aid with alum

Fig (8) comprised using 0.5 optimum dose of cactus coagulant with 0.25 optimum dose of alum, turbidity removal was 65.2%, 68.6% and 70.1%, while using 0.5 optimum dose of each of cactus coagulant aid and alum together in treatment was 74.1%,84.7% and 89.8% for three levels of turbid water respectively, there were significant differences (P<0.05) between two ratio (0.25:0.5) and (0.5:0.5) (alum: coagulant aid) for three levels of turbid water. Alum doses 10, 20 and 35 ppm were used in current study as a optimum dose for three levels of turbid water respectively, alum concentrations are optimum for most studies (Binayke and Jadhav, 2013; Sulaymon *et al*., 2013) . Current study agreed to another study which was indicated using of cactus mucilage as a coagulant aid had achieved turbidity removal approximately 89%, alum dose could be reduced between 15-30% (hayder and Rahim, 2015) and agreed with study of Omer *et al*., (2013) which indicated that using of ratio (1:1) and (2:1) (guar gum : alum) in water purification for initial turbidity more than 1000 NTU contributed to reduce suspended solid value to 5 , 4 ppm and water turbidity to 3.4, 3.3 NTU respectively, natural coagulants also led to reduce alum concentration that is required for treatment .

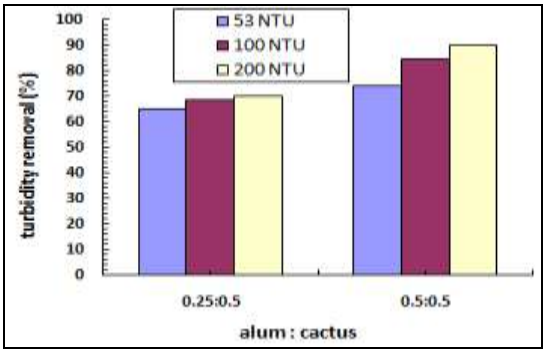

Figure 8: Effect of cactus coagulant combine to alum with different ratio (0.25:0.5) and (0.5:0.5) (alum: coagulant aid) on turbidity removal for three levels of turbid water

Therefore, using of natural coagulants combine to alum was suitable and more efficient at ratio (0.5:0.5) (coagulant aid: alum) comparison with using natural coagulant alone during primary drink water treatment and could be improved it's efficiency by increase coagulant aid concentration or extend period sedimentation. Thereby harmful effects for human's health could be reduced by decrease alum required dose for water purification between 30-40%.

4. Conclusion

Use cactus mucilage as a mainly eco-friendly coagulant or coagulant aid combine to alum could be reduced high concentration of alum that is required for water treatment to decrease human's diseases such as Alzheimer, as well as high reduction in water turbidity is achieved, does not changed pH, little volume with biodegradable sludge is produced, as well as it is used for cold water treatment, natural coagulants also could be derived from a renewable resource, plant waste and applied widely in rural regions.

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