Proceedings of the Pakistan Academy of Sciences 52 (2): 117–124 (2015)

ISSN: 0377 - 2969 (print), 2306 - 1448 (online)

Pakistan Academy of Sciences

Research Article

A Preliminary Study of *Opuntia stricta* as a Coagulant for Turbidity Removal in Surface Waters

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Abstract: Natural polymers, extracted from plants, can be used as coagulants for water treatment in addition to metal salts and synthetic polymers. Natural materials may offer benefits such as local production, lesser health hazards and affordability for developing world. *Opuntia stricta* plant, a cactus specie native to Mexico, has been explored in this study for its efficacy as coagulant. Efficiency of *Opuntia stricta* was assessed on the basis of turbidity removal from lab prepared and surface water samples. The effect of water pH on its performance was also analyzed. The study results revealed that removal efficiency of *Opuntia stricta* for turbidity removal remains consistent within a wide pH range (pH 5 to 10), in contrast to other coagulants which are pH dependent. Furthermore, pH of the water remains constant during coagulation and pH adjustment may not be required for subsequent treatment processes, which is often needed in case metal coagulants are used. Residual turbidity below 20 NTU is conveniently achieved by using *Opuntia stricta* even when it is used at very low doses. Formation of exceptionally large flocs and their linear configuration reveals the possibility that mechanism of coagulation by *Opuntia stricta* is adsorption and inter-particle bridging.

Keywords: *Opuntia stricta*, cactus, water, treatment, coagulation

1. INTRODUCTION

About 187 million of world population relies on the unimproved surface water sources [1]. Such water use poses high risk of water borne diseases. Turbidity is one of the major problems of surface waters and shallow open wells, as observed in studies in Pakistan [2], Bangladesh [3], Ghana [4, 5], Malawi [6] and Cameroon [7]. Removal of turbidity is necessary to improve its bacteriological quality by subsequent treatment i.e. disinfection. Conventional coagulants, such as aluminum and iron salts, have been successfully used in treatment of turbid waters. Effectiveness of these chemical coagulants is well recognized [8,9]; however, certain disadvantages such as production of large sludge volumes, ineffectiveness in low-temperatures, high procurement costs, and Alzheimer's disease [10, 11] tend to limit their use, particularly in countries of the developing world. Synthetic polymers, such as poly acryl-amide and poly diallyl-dimethyl ammonium chloride, are alternative coagulants used to remove turbidity in water. They can reduce the turbidity of water without increase in sludge volumes;however, health concerns related to the release of carcinogenic oligomer constrain their use [12-15].

In addition to conventional metallic coagulants and synthetic polymers, natural materials like *Moringa oleifera*, *Opuntiaspp*., *Strychnos potatorum* and *Tannin* can also be used for treating

Received, December 2014; Accepted, April 2015
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turbidity present in the water through coagulation [12]. These coagulants are not only naturally reproducible but may also offer many other advantages like local availability, adaptability, and lesser health hazards than residual mineral coagulants or synthetic polymers. Among these coagulants, *Opuntia Spp.* are the ones which have been recently deliberated for detailed laboratory investigations to explore its coagulation properties and mechanisms [13].

Opuntiagenus is a group of succulent plants which spreads from Mexico to other parts of the world. *Opuntiaficus-indica* is most common specie of this group which has multiple uses in the industry and everyday life [14].*Opuntia ficus-indica* has been extensively studied for the coagulation of colloidal suspensions by some researchers [13, 15-17]. Mostly, internal part (parenchyma) of *Opuntia cladode* has been used to prepare coagulant solutions after drying and grinding to make a powder. However, Butticeet al. [17] have used chemically extracted mucilage of the *Opuntia cladode* in coagulation studies. Mucilage is the gummy material and a biopolymer found in *Opuntia cladode* [12]. While treating colloidal suspensions with *Opuntia ficus-indica,* as coagulant, zeta potential of colloids and micro-photographs of flocs indicate that potential mechanism of coagulation is absorption and inter-particle bridging [13]. It is found that *Opuntia ficus-indica* has the ability to bring down residual turbidity to around 5 NTU for different initial turbidities of synthetic and natural colloidal samples but the best removal occurs around pH 9-10, and the removal efficiency decrease gradually by lowering the pH to 7 [12-13, 16]. However, the required pH range of the drinking water is 6.5-8.5 according to WHO guidelines for drinking water [18]. Adjustment of pH of natural water to pH 9-10 for optimal coagulation using *Opuntia ficus-indica* requires significant amount of chemicals, which might not be affordable for developing countries.

Opuntia stricta, have not been studied for its coagulation characteristics so far. It is a less common *Opuntia spp.* than *Opuntiaficus-indica*, but is widely spread over South America and Australia. It is also found in Cuba, Haiti and West Indies as well. *Opuntia stricta* has light-green oval to elliptical shaped matured cladodes, which are more often spineless; however, there are widely spaced small glochids on the cladodes. It has seasonal lemon-yellow colored flowers and carmine-red colored elongated club-shaped ripped fruits [19]. Fig. 1 shows cladodes, flowers and fruits of *Opuntia stricta*.

Although actual coagulating agents in *Opuntia* are uncertain;mucilage was found with coagulation properties pertaining to *Opuntia* [12]. Chemically, mucilage of *Opuntia stricta* contains protein, fat, crude fiber, and ash content of about 5.18%, 0.38%, 0.07% and 29.93%, respectively. It has low acute toxicity levels and can be used as additives in the pharmaceutical and food products [20]. Mucilage has complex chemical ingredients, but mostly it is considered to contain polysaccharides abundantly [21]. Mucilage contains varying proportions of l-arabinose, d-galactose, l-rhamnose, and d-xylose, as well as galacturonic acid [22]. The results of a study indicated that turbidity removal of synthetic polysaccharides of mucilage was about 50% only, which suggests the presence of some other active coagulant agents than mucilage in the *Opuntia* [13]. However, analysis of the poly-galacturonic acid, a major constituent of many plants, for coagulation rather than simple galacturonic acid, used by Miller S.M. et al, 2008, may yield a better insight into coagulation ingredients of *Opuntia* [12].

Keeping in view the potential advantages of *Opuntia spp.* as coagulant and constraints of pH adjustment for *Opuntia ficus-Indica*, turbidity removal in surface water using *Opuntia stricta* have been explored in this study.

2. MATERIALS AND METHODS

2.1 Water Sampling

Both natural and synthetic colloidal samples have been used in the study. Natural sample was obtained from River Ravi near Ravi Syphon, District Lahore, Punjab-Pakistan. Samples were stored at room temperature and used for study after

Fig. 1. Cladodes, flowers and fruits of *Opuntia stricta*.

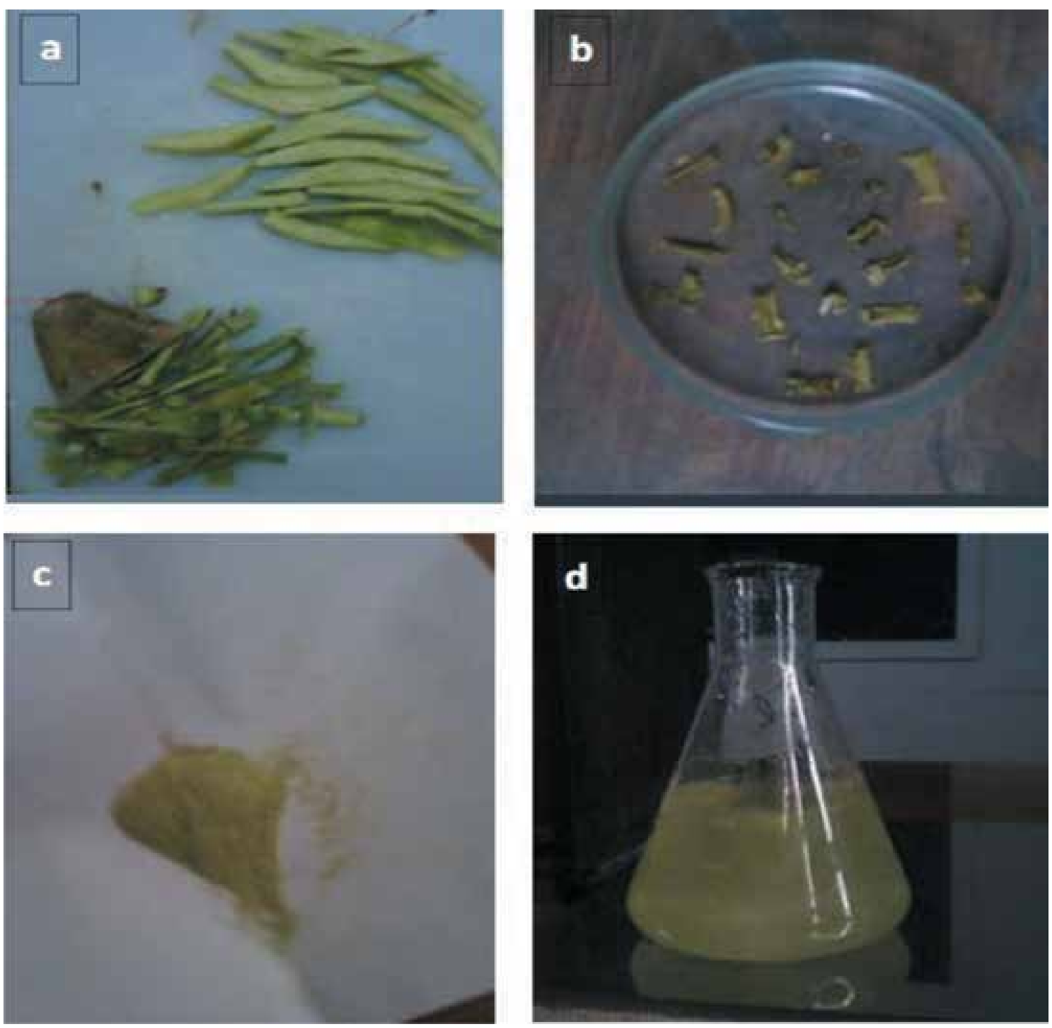

Fig. 2. Extraction and preparation of coagulant solution.

Table 1. Salient physical and chemical characteristics of colloidal samples.

Sr. No.	Parameter	Units	Sample Type	
			River water*	Synthetic water
1	Turbidity	NTU	105	150±10
2	pH	-	7.1	8.0-8.3
3	Electrical Conductivity	µS/cm	238	270±20
4	Alkalinity	mg/L as $CaCO_3$	138	104±10

* Average Values

homogenization through mixing. Synthetic samples were prepared using industrial grade kaolin. Ground kaolin was sieved to get particles less than 75 µm in size and mixed in the blend of distilled and tap water (1:1), settled for 1 hour and supernatant was decanted. The decanted supernatant was used as synthetic colloidal sample for coagulation analysis. Important physical and chemical characteristics of the samples are given in Table 1. Tests were performed according to the "Standard Methods for Examination of Water and Wastewater" [23].

2.2 Preparation of Coagulant Solutions

Opuntia stricta cladodes were obtained from Karachi Golf Club, Karachi, Pakistan. Pads were brought to Lahore and planted in the sandy soil for further natural growth. For preparation of coagulant solution, cladodes were washed with tap water and laterally cut into strips of about 1cm, outer skin was removed manually using knife, and internal parenchyma part was dried in the oven at 65ºC for 24 hours. Dried *Opuntia* was grinded in the Panasonic MJW-176P grinder and sieved to get powder containing particles of sizes ranging from 180 µm to 300 µm. This fine powder was used to make suspension of 1 g/L in distilled water and stirred for 1 hour to liberate active coagulant agents,which was then used as the coagulant solution. The process of coagulant extraction and preparation of coagulant solution is shown in Fig. 2.

2.3 Experimental Procedure

Coagulation experiments were performed using Phipps & Bird BP-900 jar test apparatus. Water samples were poured in 1 liter beakers and varying doses of *Opuntia* were added in different beakers. pH of the Synthetic colloidal suspensions was measured using HACH SensIon3 pH meter and adjusted to desired pH using 1N solutions of NaOH or H_2SO_4. Natural colloidal sample was used without adjustment of its pH. A blank sample was also analyzed in parallel for comparison. Samples were stirred at 100rpm for 2 minutes and slowly mixed at 30 rpm for 20 minutes followed by settling of 30 minutes. Effectiveness of *Opuntia stricta* was evaluated by measuring removal of turbidity at various pH and coagulant doses, both for synthetic and river water. Turbidity of the settled samples was measured using HACH 2100N turbidity meter. All the samples were tested three times and mean values are reported. Flocs formed during coagulation, at optimum dose and pH, were examined with the help of Olympus STM 6 microscope and micro-photographs were taken at appropriate resolution.

3. RESULTS AND DISCUSSION

Coagulation of synthetic water, at *Opuntia* dose of 2 mg/L to 30 mg/L, was carried out at pH 5 to 10. Results of the experiments are presented in Fig. 2. Over the tested pH range, there is insignificant change in residual turbidity for a given coagulant dose. Furthermore, there is a gradual increase in residual turbidity with increasing coagulant dose from 2 mg/L to 30 mg/L. This may be due to destabilization of particles observed at high doses of adsorbed polymers [24].

For initial turbidity of 150 NTU, residual

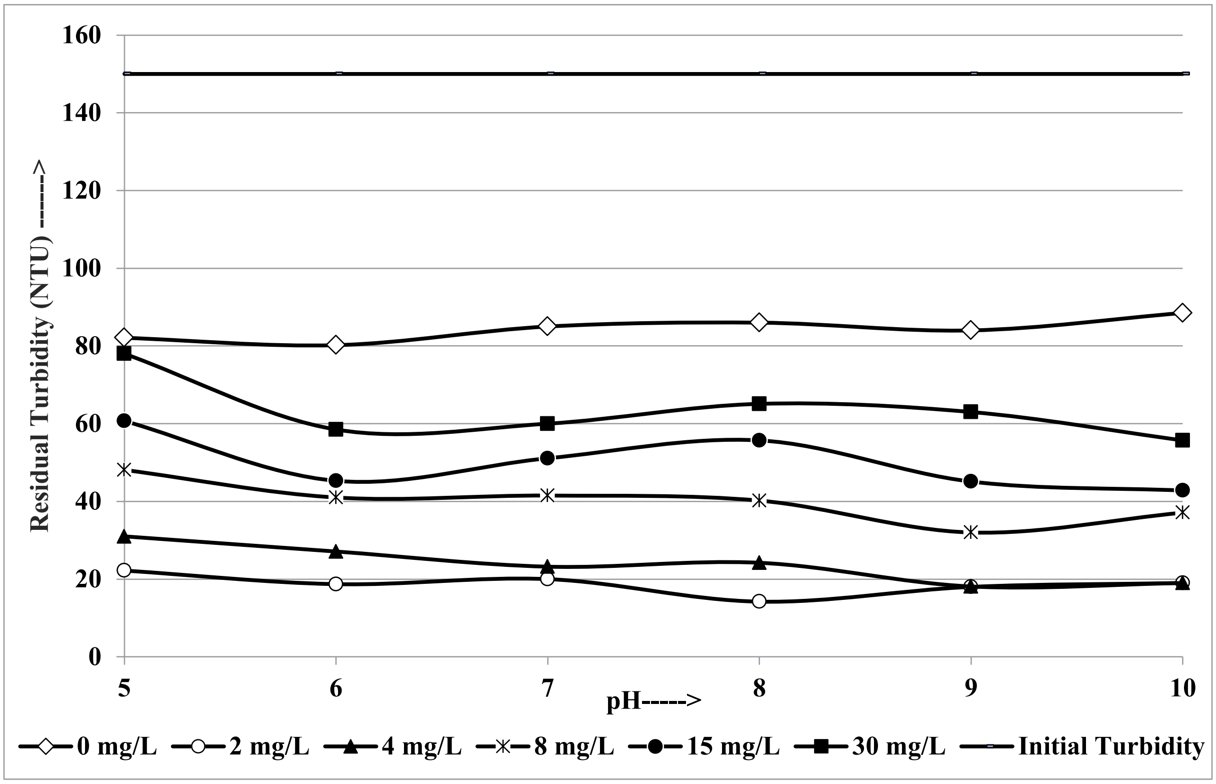

Fig. 3. Initial and residual turbidity in synthetic water sample for different doses of *Opuntia stricta* at varying pH.

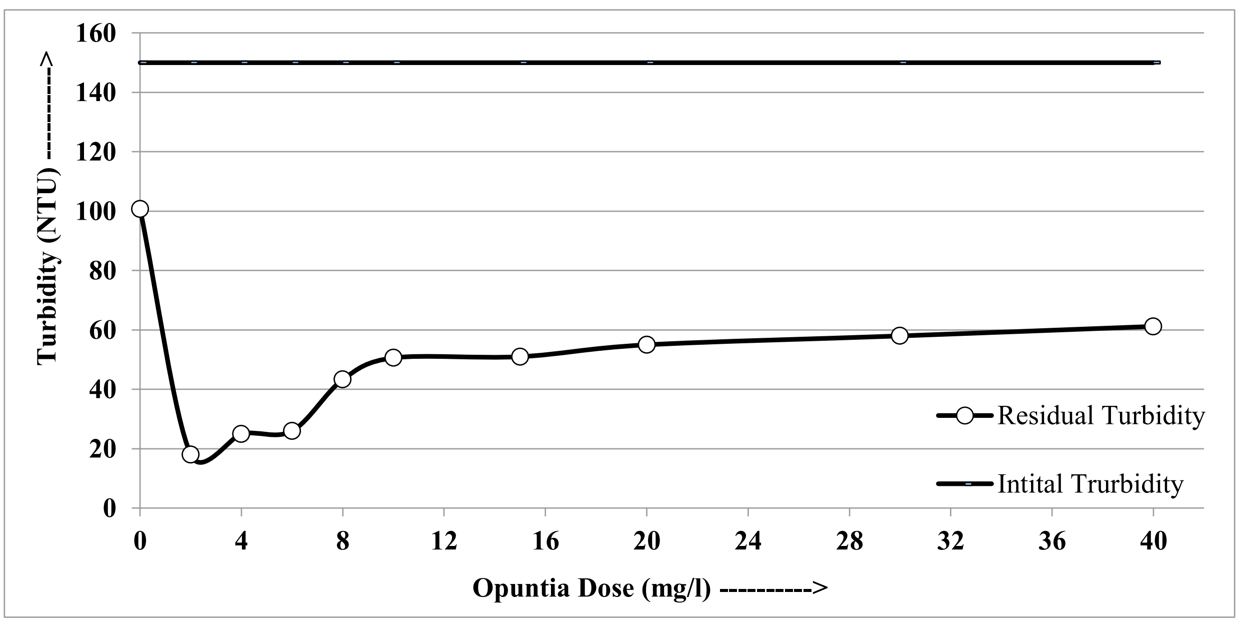

Fig. 4. Initial and residual turbidity of synthetic sample using different doses of *Opuntia stricta* at pH 7.0.

turbidities at pH 9-10 lie between 18 NTU – 63 NTU for different *Opuntia* doses and at pH 5-6, residual turbidities are 18 NTU – 78 NTU. Similarly, residual turbidities in pH range 6-8 lie between 14 NTU – 65 NTU for different *Opuntia* doses. These results indicate that efficiency of the *Opuntia stricta* is not strictly dependent upon the pH of the water; whereas, efficiency of *Opuntia ficus-Indica* and other coagulants is highly pH dependent [13]. It was also observed that there is

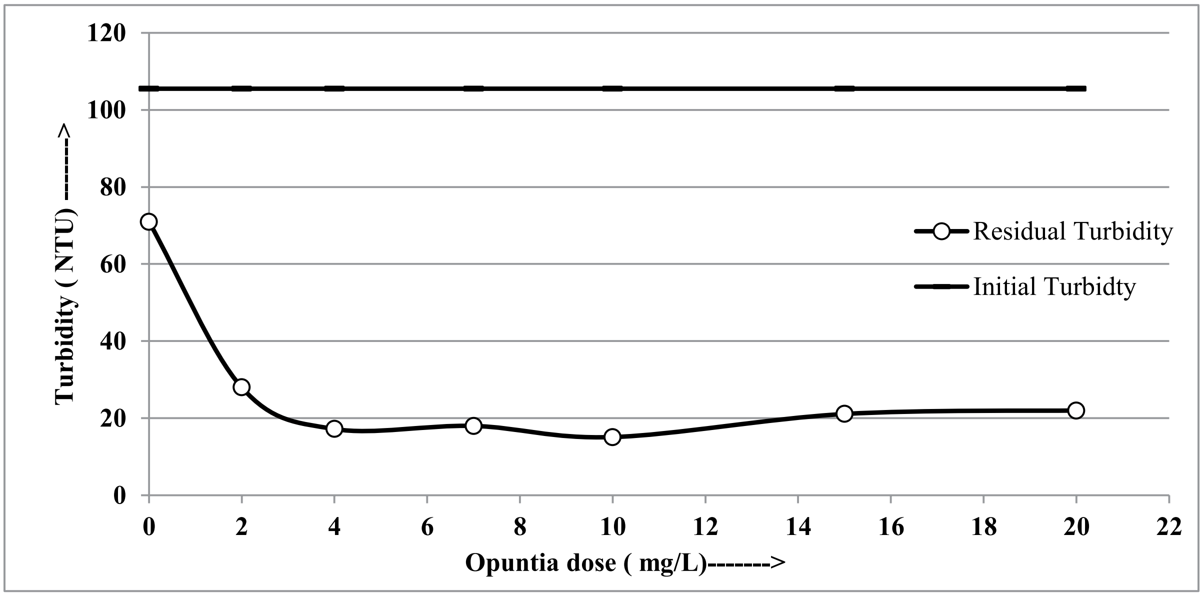

Fig. 5. Initial and residual turbidity of river sample using different doses of *Opuntia stricta* at pH 7.1.

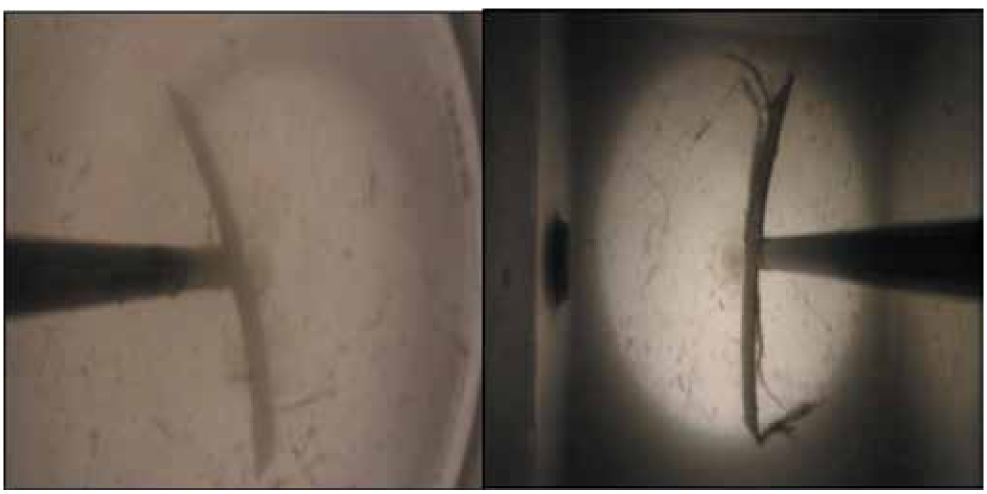

Fig. 6. Flocs formed during coagulation of river water with *Opuntia stricta*.

no significant change in the pH during coagulation process. Insignificant change in the final pH has been reported for *Opuntiaficus-Indica* by Miller et al. and Yang et al. [13, 16].Such performance of *Opuntia stricta* which is independent of water pH along with the least effect on the final pH is unique and favors its practical use.

To explore the effect of *Opuntia stricta* dose on turbidity removal, jar test was performed for both synthetic and natural samples at pH 7.1. Fig. 3 is showing the results of synthetic water, when dose was increased from 2 mg/L to 40 mg/L. It is seen that minimum residual turbidity of 18 NTU was achieved for 2 mg/L dose and the residual turbidity sharply increases by increasing the dose. This implies significant sensitivity of *Opuntia stricta* towards over-dozing. Fig. 4 presents results of coagulation of natural river water sample when *Opuntia* dose is increased from 2 mg/L to 20 mg/L. Turbidity reduced from 105 NTU to minimum of15 NTU for *Opuntia* dose of 10 mg/L. Increased residual turbidity was also observed at high doses for river sample; however, the trend was not as sharp as was in the case of synthetic water.

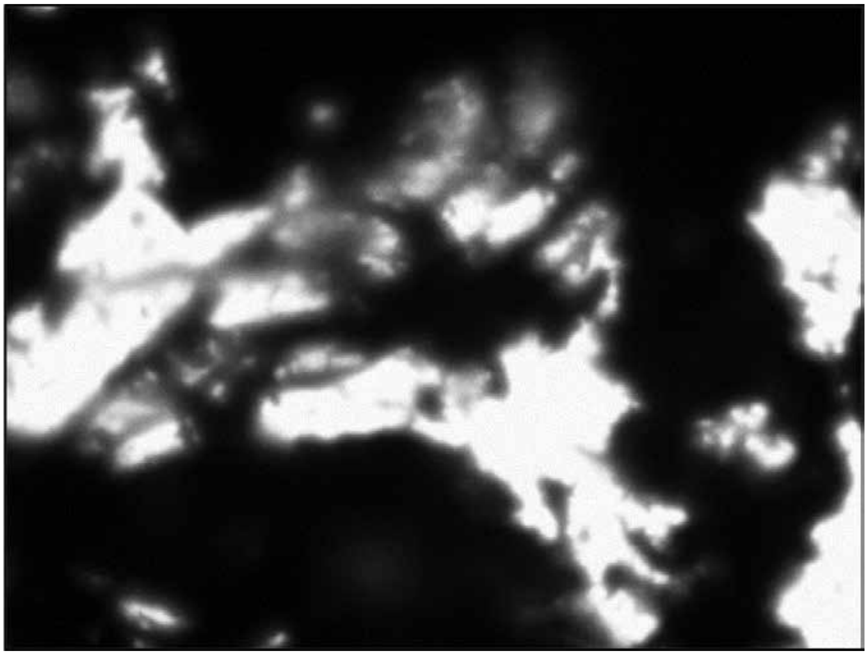

Fig. 7. 50x enlarged view of flocs shown in Fig. 6.

Although, turbidity of the river sample was less than synthetic water, but significant higher requirement of *Opuntia* dose indicates the possible reaction of *Opuntia* with humic substances naturally present in surface waters. Residual turbidities less than 10 NTU were achieved using *Opuntia ficus-Indica* [13, 16]; however *Opuntia stricta* was not able to get such better removal (Fig. 3 to 5). The reason may be the development of a number of smaller flocs which were not able to grow in size or attach with larger flocs,and thereby were unable to settle within 30 minute settling time.

Fig. 6a and Fig. 6b exhibit the floc formation during the coagulation of river water using *Opuntia stricta*. It is observed that large thread like flocs (Fig. 6a) were formed during rapid mix stage, which started diminishing during initial slow mixing but again grew in size (Fig. 6b) as slow mix proceeded. Fig. 7 gives a 50x enlarged view of these flocs under microscope indicating strong binding links within the flocs. Such behavior is only possible with a high molecular-weight polymer with numerous active sites. Linear configuration of the flocs also justifies the inter-particle bridging mechanism of coagulation through *Opuntia* as suggested by Miller et al [13].

4. CONCLUSIONS

Contrary to *Opuntia ficus-Indica*, removal efficiency of *Opuntia stricta* as coagulant for turbidity removal in surface water remains consistent within a wide pH range (pH 5 to 10). Furthermore, pH of the water remains unaffected during coagulation and pH adjustment may not be required for subsequent treatment processes such as filtration or disinfection,which might be needed in case metal coagulants are used. Presence of humic substances in natural surface water may significantly alter *Opuntia*dose for optimal coagulation. *Opuntia stricta* was not able to bring residual turbidity below 10 NTU as achievable through *Opuntia ficus-indica*. However, residual turbidity below 20 NTU is conveniently achieved even at very low doses of *Opuntia stricta*. Therefore, *Opuntia stricta* may prove useful as primary coagulant for subsequent treatment through slow sand filters. However, its efficiency should also be further investigated for water of different qualities in addition to its use as coagulant aid. Analysis of size and nature of flocs achieved through coagulation using *Opuntia stricta*is coherent with the previous suppositions that potential mechanism of coagulation through *Opuntia* is adsorption and inter-particle bridging.

5. ACKNOWLEDGEMENTS

This research publication is based on the post-graduate research conducted at the IEER, UET Lahore. The authors acknowledge the assistance provided by the laboratory staff of IEER.

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