Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2014.945487

56 (2015) 1489–1497
November

Cactus opuntia (*ficus-indica*): an eco-friendly alternative coagulant in the treatment of paint effluent

S. Vishali[a,*], R. Karthikeyan[b]

[a]*Department of Chemical Engineering, SRM University, Chennai 603 203, India, Tel. +91 94438 83562; email: meet.vishali@gmail.com*
[b]*AAMEC, Kovilvenni, Thanjavur 614 403, India, Tel. +91 9940561915; email: drrkarthi@yahoo.com*

Received 19 December 2013; Accepted 11 July 2014

ABSTRACT

In this study, the potentiality of *Cactus opuntia* (*ficus-indica*), as a coagulant for the treatment of simulated industrial water-based paint wastewater in terms of colour, chemical oxygen demand (COD) and turbidity was investigated. The coagulation ability was assessed for 1 L of effluent using the standard jar test apparatus by varying the operational variables like eluent type (water, NaCl and $BaCl_2$), eluent concentration (1–5 N), coagulant dosage (1–6 g), coagulant volume (20–100 mL), initial pH (5–11) and initial effluent concentration (3100, 4224, 5650, 6258 and 7693 mg/L named as sample number 1–5, respectively). The results were maximum when 100 mL of 3 g of *C. opuntia*, eluted using 3 N NaCl was used as a coagulant to treat a litre of effluent. The favourable pH to run the treatment was confirmed as the actual pH of the sample (7.2–7.8). It was found that the removal efficiency increased as the pollution load swelled. The FTIR study revealed the presence of various functional groups, which are responsible for the coagulation process. The obtained results were compared with conventional coagulant ferric chloride. The results acknowledged that *Cactus opuntia* (*ficus-indica*) a natural, eco-friendly coagulant, could be a strong alternative to the conventional coagulant in the treatment of water-based paint wastewater.

Keywords: *Cactus opuntia* (*ficus-indica*) coagulation; Eluate; $FeCl_3$; Paint effluent

1. Introduction

Paint is normally a mixture of pigment, binder, solvent and additives. From the environment and treatment point of view, primary solvent is a convenient way to classify paint. According to this method, paints can be classified as water-based, organic solvent-based or powder (dry) and without solvent. The wastewater generated from the paint industry is mainly through cleaning operations of mixers, reactors, blenders, filling lines, packing machines and floor [1,2]. The discharge of such polluted effluents into the environment damages the quality of the receiving stream, aquatic life and enhances the toxicity. In order to respect the environment and the law, the generated wastewater has to be treated prior to disposal.

Researchers have reported the treatment of paint industry wastewater by various methods such as physical–chemical treatment [3], bio-oxidation [4], biological treatment [5], active sludge treatment [6], microfiltration [7], coagulation–flocculation processes [8], Fenton oxidation [9], adsorption [10], electrochemical oxidation [11] and electro-coagulation [12]. Among these, coagulation–flocculation has historically attracted

*Corresponding author.

considerable attention for its high removal efficiency. Its application includes removal of dissolved chemical compounds and turbidity from wastewater via the addition of conventional chemical coagulants, namely alum, ferric chloride and polyaluminium chloride (PAC). An appropriate technology for the treatment of industrial wastewater from paint industry is coagulation [2].

Chemical coagulants are used for the treatment of wastewater from various industries like tannery [13], textile [14], meat processing, [15] and so on. But the disadvantages associated with usage of these chemical coagulants, such as high operation costs, ineffectiveness in low temperature water and large sludge volume, significantly affect the pH of the treated water and considerable effects on human health like Alzheimer's disease [16]. To overcome these difficulties, the desirable alternate for this chemical coagulant is natural, plant-based coagulants. The main advantages of using this are the following: material is eco-rich, cost effective, highly biodegradable and toxic-free treated water and low sludge volume [17].

Environmental scientists identified several plant types, like *Moringa oleifera*, *Stryconus potatorum*, *Cactus* species, *Phaseolus vulgaris*, surjana seed, maize seed, tannin, gum arabic, *Prosopis juliflora* and *Ipomoea dasysperma* seed gum, as coagulants [18]. Among these, *C. opuntia* is a cheap and abundantly available plant. The main constituent of the cactus cladode is a hetero polysaccharide with a molecular weight of 2.3–300 × 10^4 g/mol. Cactus has been used as a food thickener, food emulsifier, as a water purifier and for purposes of cosmetic application [19]. It has long been associated with its medicinal properties and dietary food sources. Besides, it has also been successfully used as a natural coagulant. It has a high possibility of galacturonic acid, and exists predominantly in polymeric form that provides a bridge for particle to adsorb on [17].

Nopal cladode has been used as a coagulant in the turbidity removal of the synthetic water [20,21]. Using Opuntia mucilage as a coagulant–flocculant aid, the conductivity, turbidity, COD, sludge load and oil and greases were reduced from cosmetic industry wastewater [22]. *Cactaceae Nopalea cochenillifera* cell cultures and intact plants (cladodes) transform various toxic textile dyes, including Red HE7B into less phytotoxic, non-hazardous metabolites [23]. The poultry slaughter house wastewater was cleaned using natural polyelectrolytes extracted from the *Cactus opuntia (ficus-indica)* as a coagulant [24]. Cactus species are used as an adsorbent in the removal of dyes [25,26], nitrogen pollution [27] and heavy metals [28,29]. There is no information in literature of using cactus as a coagulant for the treatment of paint effluent.

This study is focused on the comparison between *Cactus opuntia* (*ficus-indica*) and $FeCl_3$ as a coagulant and to evaluate their treatability in terms of colour, COD and turbidity removal under the influence of eluent type (water, NaCl and $BaCl_2$), eluent concentration (1–5 N), coagulant dosage (1–6 g), coagulant volume (20–100 mL), initial pH (5–11) and initial effluent concentration (3,100, 4,224, 5,650, 6,258 and 7,693 mg/L named as sample number 1–5, respectively).

2. Materials and methods

2.1. Simulated effluent

All the chemicals used in the experiments were of analytical grade. Simulated water-based paint effluent was prepared by adding different proportions of white primer and acrylic-based blue colourant and made up to 1,000 mL, using double distilled water (5% (v/v)) [11]. Five different samples were prepared and named as sample numbers 1–5 (Table 1). The physical–chemical properties of the simulated sample (sample 5), which resembled as the real effluent from paint industry, are listed in Table 2.

Table 1
Initial concentration and composition of simulated effluent (made up to 1,000 mL)

Sample number	White primer (mL)	Blue colourant (mL)	Initial COD (mg/L)
1	48	2	3,100
2	46	4	4,224
3	44	6	5,650
4	42	8	6,258
5	40	10	7,693

Table 2
Physico-chemical characteristics of the simulated industrial wastewater (sample 5)

Parameters	Value
pH at 25°C	7.6
Total dissolved solids (mg/L)	304
Total suspended solids (mg/L)	6,880
Oil and grease (mg/L)	19
Chloride as Cl (mg/L)	68
Chemical oxygen demand (COD) (mg/L)	7,693
Sulphate as SO_4 (mg/L)	24
Biochemical oxygen demand (mg/L) (3 d incubated at 27°C)	2,648
Iron as Fe (mg/L)	0.05

2.2. Coagulant

Cactus opuntia (*ficus-indica*) pods were collected from rural areas of Pudukottai district, Tamil Nadu, India. They were washed, sliced and dried at 100˚C for 2 h. The resultant materials were powdered and sieved through a 0.2-mm sieve. Ferric chloride ($FeCl_3$) was used as conventional chemical coagulant.

To extract the active components from *C. opuntia,* the known amount of this powder was suspended in 100 mL of solvent named as eluent. The suspension was stirred for 15 min to extract the active compounds, which are responsible for coagulation. The solution was then allowed to settle for 15 min. The supernatant liquid, known as eluate, was used as a coagulant for further studies.

2.3. Experimental design

To conduct the treatment process, known volume *of C. opuntia* eluate was added in a litre of simulated water-based paint industrial effluent. The jar test apparatus or multiple spindle stirrer (Deep Vision, India) with six stirrer arrangement, and base floc illuminator was used for the coagulation study, and agitated at a rapid mixing of 200 rpm for 2 min and slow mixing at 80 rpm for 2 min, followed by 60 min of settling period. After 60 min of settling period, 50 mL of clarified sample was collected to measure the colour, COD and turbidity.

The experimental procedure was repeated to study the effect of eluent type (water, NaCl and $BaCl_2$), eluent concentration (1–5 N), coagulant dosage (1–6 g), coagulant volume (20–100 mL), initial pH (5–11) and initial effluent concentration (3,100, 4,224, 5,650, 6,258 and 7,693 mg/L named as sample number 1–5, respectively).

To evaluate the efficacy of $FeCl_3$ as a coagulant, the coagulation procedure was rerun to study the influence of amorphous coagulant dose (g), coagulant volume (mL), initial pH (5–11) and initial effluent concentration (sample number 1–5, mg/L) and the settling time was kept to 10 min.

2.4. Parameters evaluation

The coagulation activity of *C. opuntia* was assessed in terms of colour, chemical oxygen demand (COD) and turbidity. All the parameters mentioned in Table 2 were measured using standard methods [30]. Colour was measured using SL 218 double UV visible spectrophotometer (Elico—India) at λ_{max} 612 nm. COD was calculated using the dichromate method [30]. Turbidity was measured using digital nephelo-turbidity meter 132 (Elico—India) and it was expressed in nephelometric turbidity units (NTU). pH is adjusted using digital pH meter MK. V.I (Elico—India).

3. Results and discussion

3.1. Characterization of Cactus opuntia (ficus-indica)

The characterization of cactus was used to differentiate the material. The FTIR spectrum of *C. opuntia* is

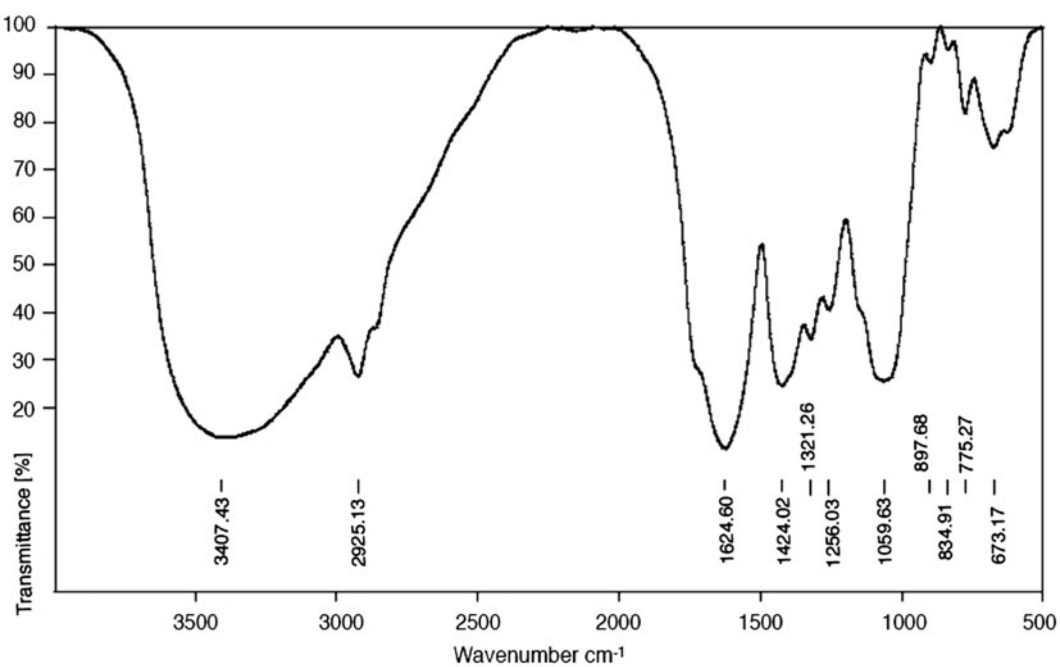

Fig. 1. FT-IR spectrum of *Cactus opuntia (ficus-indica).*

shown in Fig. 1. The strong stretch at 3,405.43 cm^{-1} was due to polymeric OH stretching vibration of water and stretching vibration of amine. Peaks at 3000 cm^{-1}, was due to the presence of C=C–H group, which indicates aromatic ring. Sharp peak at 1,500 cm^{-1} confirmed the presence of benzene group. The peak at 1,424.02 cm^{-1} confirms the presence of carboxylic acid salt. Presence of aromatic primary amine stretch, CN stretch, was confirmed by the peak at 1,321.26 cm^{-1}. Peak at 1,624.60 cm^{-1} shows the C=C stretch. Several peaks were formed from 897 to 673 cm^{-1}, which further confirms the presence of aromatic group. Hence, the FTIR spectra reveal that the seed mainly carries aromatic groups.

3.2. Effect of eluent type and concentration

The active coagulating agents can be extracted from natural organic seeds using water, salt solution and organic solvent [31]. Two grams of *C. opuntia* powder were suspended in 100 mL of water and 1–5 N of NaCl and $BaCl_2$ solution each. After 15 min of stirring, 100 mL of the supernatant liquid was used as a coagulant for the treatment of 1 L of paint effluent (sample 1).

The colour, COD and turbidity removal efficiencies were 6.42, 18.71 and 27.68%, respectively, when water was used as an eluent. The optimum results among the different concentration of $BaCl_2$ solution was attained for 3 N concentration and the results are 82.11% colour removal, 71.25% COD reduction and 78.43% of turbidity removal (Fig. 2(a)–(c)).

Eluates obtained from 1 to 5 N concentration of NaCl solution showed better results compared to the $BaCl_2$ eluent. Cellulose and carbohydrates, eluated from the *C. opuntia,* which are responsible for the coagulation showed different treatment efficiency by gradually increasing the concentration of salt solution, when applied at the same dose. While increasing the concentration of NaCl from 1 to 5 N, the removal was increased gradually until it reached 3 N solution. Beyond this, a decreasing trend was observed. The experiments conducted using the eluates prepared from 3 N NaCl were found to be the highest and optimum results like 82.11%, 79.05%, 78.43% of colour, COD and turbidity removal, respectively (Fig. 3). From the results, it was confirmed that NaCl acts as a better eluent and has the optimum concentration of NaCl to extract the maximum amount of active coagulant components from 2 g of *C. opuntia* in 3 N NaCl. Considering this, the active components extracted from *C. opuntia* using 3 N NaCl were used in further experiments. Similar work was performed in the removal of water turbidity by natural coagulants from chestnut and acorn by varying the concentration of salt solution [32].

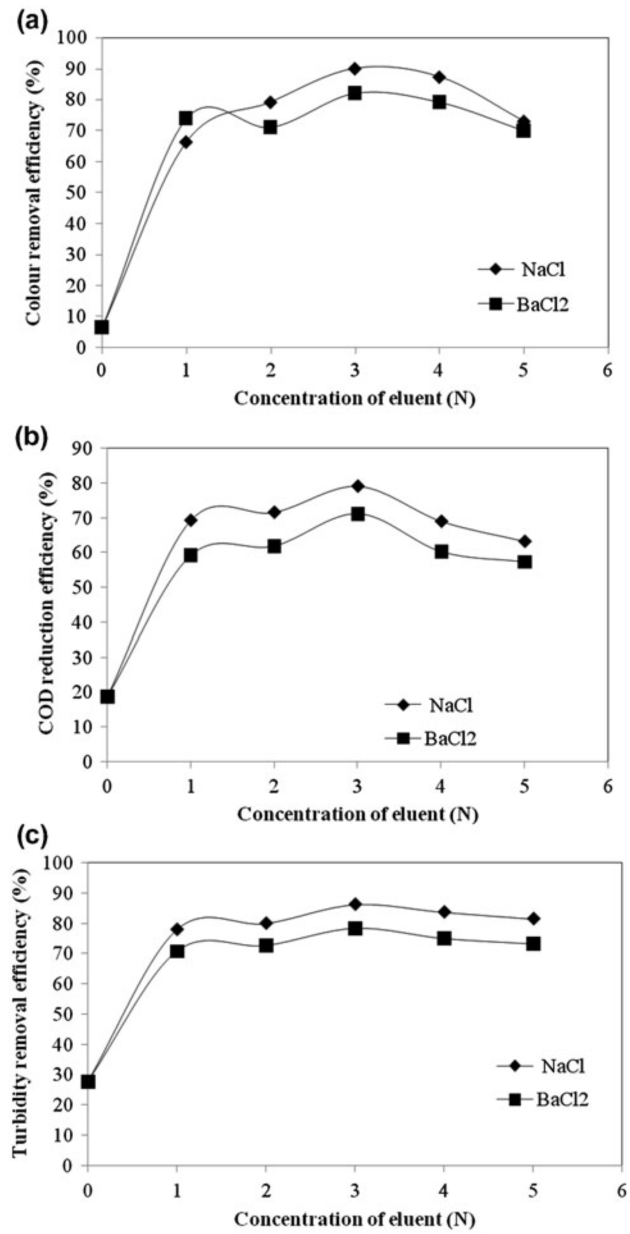

Fig. 2. (a) Effect of eluent on colour removal efficiency, (b) effect of eluent on COD reduction efficiency, and (c) effect of eluent on turbidity removal efficiency. pH = actual effluent pH (7.2–7.8); Coagulant: Extragens = 2 g of *C. opuntia*: 100 mL of water, NaCl and $BaCl_2$ (1–5 N); Coagulant volume = 100 mL; Sample 1.

3.3. Effect of coagulant dose

Coagulant dosage is one of the most important parameters to optimize. Insufficient dosage or overdosing

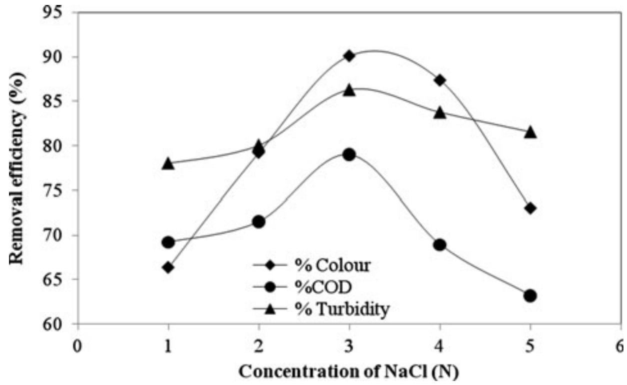

Fig. 3. Effect of NaCl concentration on removal efficiency. pH = actual effluent pH (7.2–7.8); Coagulant: Extragens = 2 g of *C. opuntia*: 100 mL of 1–5 N NaCl; Coagulant volume = 100 mL; Sample 1.

would result in poorer performance in treatment. Optimum dosage will minimize the dosing cost and sludge formation. To find out the optimum dosage, 1–6 g of *C. opuntia* was suspended in 100 mL of 3 N NaCl solutions. This was used to treat a litre of effluent. The efficiency of the treatment was boosted with an increase in the coagulant dose till 3 g. After this, there was a decrease in the removal efficiency. Based on the observed results, 3 g of *C. opuntia* showed the optimum, maximum colour removal efficiency of 89.26% and turbidity of 80.44% (Fig. 4). An equilibrium COD reduction was 78.56% at this dose.

The reason may be that though there was an increase in coagulant dose, the volume of 3 N NaCl used for the elution was maintained constantly at 100 mL. At the higher dose level, the available NaCl volume may be insufficient to extract all the active coagulant content from the *C. opuntia*. The lower concentration in the eluate results in a decrease in the coagulation activity. A similar trend was observed in the removal of congo red dye using natural coagulants [33].

3.4. Effect of coagulant volume

To study the influence of coagulant volume in the treatment, the volume of eluate prepared from 3 g of *C. opuntia* was varied from 20 to 100 mL to treat 1 L of simulated paint industrial wastewater (sample 1). The removal efficiencies were increased when the volume increased from 20 to 100 mL and the maximum removal was 95.16, 89 and 94% for colour, COD and turbidity, respectively, at 100 mL (Fig. 5). The reason for the highest removal of pollutant for 100 mL of *C. opuntia* solution could be the amount of active component, which is responsible for coagulation, is immense. The concentration of *C. opuntia* was in ascending nature when the volume was increased gradually (Table 3). Further increase in volume ends with plateau behaviour. The study conducted on the extraction and partial purification of coagulation active components from common bean seed confirmed the above-discussed results [34].

3.5. Effect of initial pH

The actual pH of simulated sample was between 7.2 and 7.8. pH of the effluent is an important factor in any type of the wastewater treatment. By adding HNO_3/NaOH, the initial pH of the effluent was maintained in acidic–basic region. The treatment was conducted between pH 5 and 11 (experiment could not be

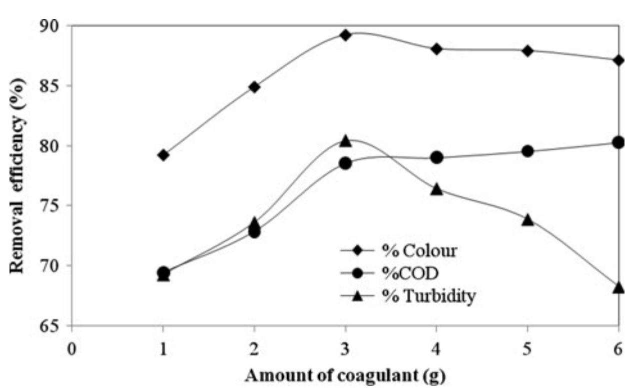

Fig. 4. Effect of coagulant amount on removal efficiency. pH = actual effluent pH (7.2–7.8); Coagulant: Extragens = 1–6 g of *C. opuntia*: 100 mL of 3 N NaCl; Coagulant volume = 100 mL; Sample 1.

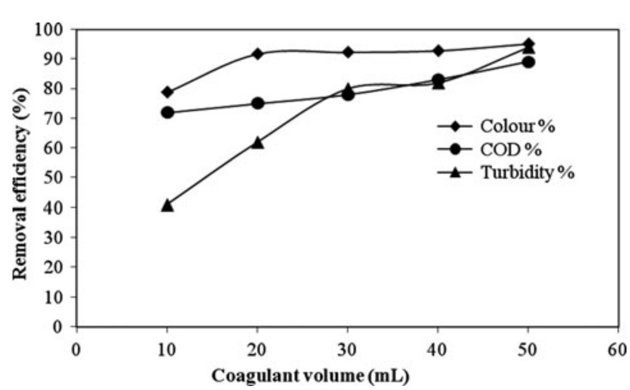

Fig. 5. Effect of coagulant volume on removal efficiency. pH = actual effluent pH (7.2–7.8); Coagulant: extragens = 3 g *C. opuntia*: 100 mL of 3 N NaCl; Coagulant volume = 20–100 mL; Sample 1.

Table 3
Concentration of *C. opuntia* and $FeCl_3$ in jars

Jar number	Volume of coagulant (mL) [prepared using 3 g of *C. opuntia*, eluted in 100 mL of 3 N NaCl]	Concentration of *C. opuntia* (g/L)	Volume of 0.7 g/L of $FeCl_3$ solution as coagulant (mL)	Concentration of $FeCl_3$ (g/L)
1	20	0.58	20	0.014
2	40	1.15	40	0.027
3	60	1.69	60	0.040
4	80	2.22	80	0.052
5	100	2.72	100	0.064

carried out below pH 5 due to precipitation). From the graph, it was observed that the pollutant removal was high at acidic conditions, particularly at pH 5. The highest removal efficiency was found to be 98.62, 88.7 and 99.67% for colour, COD and turbidity, respectively, at pH 5. Almost equal values were attained when the treatment was conducted at pH 7. The results were 98.03, 87.9 and 99.86% of colour, COD and turbidity, respectively (Fig. 6). In basic conditions, the removal efficiency was decreased.

The reason was the functional groups present in *C. opuntia*, such as $-COOH^-$, $-OH^-$ ion, which enhance the coagulation ability. These surface groups perform well in the presence of more positively charged ions, i.e. at acidic region. Charge neutralization was the believed mechanism behind this. It was continued till neutral pH. The posture was reversed at basic region. From the results, the suggested pH for the treatment was found to be 7. The actual pH of the simulated sample was in the range of 7.2–7.8. It is very economical and convenient aspect to conduct the treatment process at actual pH itself. Similar trend was observed in a preliminary study on cactus as coagulant in water treatment [35].

3.6. Effect of initial concentration

Five different initial concentrations of simulated samples, such as 3,100, 4,224, 5,650, 6,258 and 7,693 mg/L, were prepared and named as sample numbers 1–5, respectively. The maximum efficiencies were achieved for the sample of initial concentration 7,693 mg/L and the values were 88.37% for colour, 78.20% for COD and 88.30% for turbidity (Fig. 7). The pollutant removal is augmented with the increase in the initial concentration of effluent from 3,100 to 7,693 mg/L. This is because a more efficient utilization of the coagulant is expected due to a greater driving force by a higher concentration gradient. Similar studies were carried out, while decolourizing the brilliant green from aqueous solution using cactus fruit peel [21].

3.7. Effect of $FeCl_3$ coagulant dose, volume, initial pH and initial concentration of paint effluent on colour, COD and turbidity removal

To study the influence of amorphous iron chloride dosage on the colour, COD and turbidity removal, experiments have been undertaken by varying the

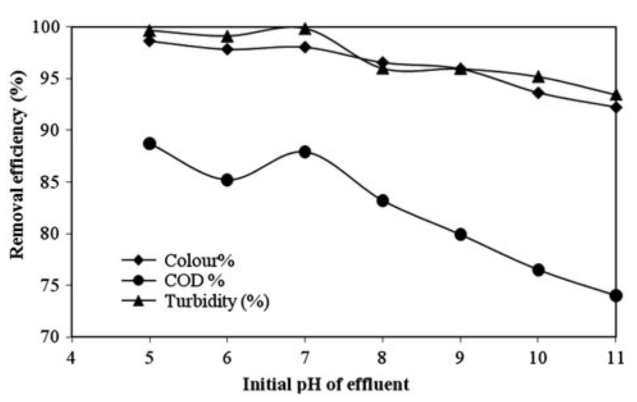

Fig. 6. Effect of initial pH on removal efficiency. pH = 5–11; Coagulant: Extragens = 3 g *C. opuntia*: 100 mL of 3 N NaCl; coagulant volume = 100 mL; Sample 1.

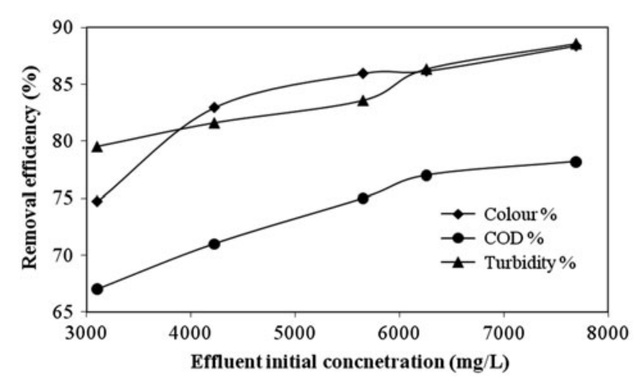

Fig. 7. Effect of initial concentration on removal efficiency. pH = actual effluent pH (7.2–7.8); Coagulant: extragens = 3 g *C. opuntia*: 100 mL of 3 N NaCl; coagulant volume = 100 mL; Sample 1–5.

$FeCl_3$ dose in the wastewater, by keeping the pH of the effluent as it is. $FeCl_3$ was varied from 0.2 to 1 g/L of effluent. It was observed that maximum of 93.78% of turbidity and 94.52% of COD is removed for 0.6 and 0.8 g of iron chloride (Fig. 8(a)). The optimum dose was selected as 0.7 g. The further increase in dose does not produce better removal rate. The coagulant dosage is directly proportional to the quality of colloids present. A further increase in iron chloride amount ends in a decrease in removal efficiency, due to destabilization of the particles as the charge reversal of the colloids occurs [8].

To enhance the quick dispersion of ferric chloride into all parts of effluent in the beaker [36], 0.7 g/L of $FeCl_3$ feed stock solution is prepared. Various volumes of the $FeCl_3$ solution, such as 20–100 mL, were taken and the concentration of coagulant in each jar is listed in Table 3. The removal increases with boost-in volume of coagulant. A maximum of 80.14% of colouring matter, 60.35% of COD and 92.83% of turbidity is removed from effluent when 100 mL of 0.7 g/L of $FeCl_3$ is used (Fig. 8(b)). The corresponding concentration of coagulant is 0.064 g/L, which is the maximum one.

To optimize the initial pH of the treatment process, pH varies from 5 to 10 by adding suitable acid and base. It was seen that the removal was effective at a pH range of 8–9. The values were 83.58% for colour, 73.69% for COD and 90.93% for turbidity (Fig. 8(c)), and it was also confirmed with the previous results [8].

To evaluate the influence of initial effluent concentration, five different concentrations of samples, namely sample numbers 1–5 were used to conduct the experiment. The higher removal was found in highly polluted effluent, i.e. for 7,693 mg/L initial concentration effluent. The values were 86.43, 83.40 and 93.03% for colour, COD and turbidity, respectively. This could be due to higher difference in concentration (Fig. 8(d)).

The characteristics of the raw effluent and effluent treated using *C. opuntia* and ferric chloride as coagulant were compared in Table 4. It was observed from the table that the removal was found to be more for ferric chloride, and the removal efficiencies obtained were found as 89.35% for colour, 83.40% for COD and 88.53% for turbidity and were almost similar to that of *C. opuntia*.

The usage of ferric chloride should be avoided, in view of higher operational cost and problems associated with the disposal of the sludge, which may lead to contamination of the ground water if sufficient care is not taken. On the other hand, *Cactus opuntia (ficus-indica)*, a natural plant-based coagulant, is abundant with low processing. Being biodegradable, the problem of sludge disposal is not cumbersome. There are

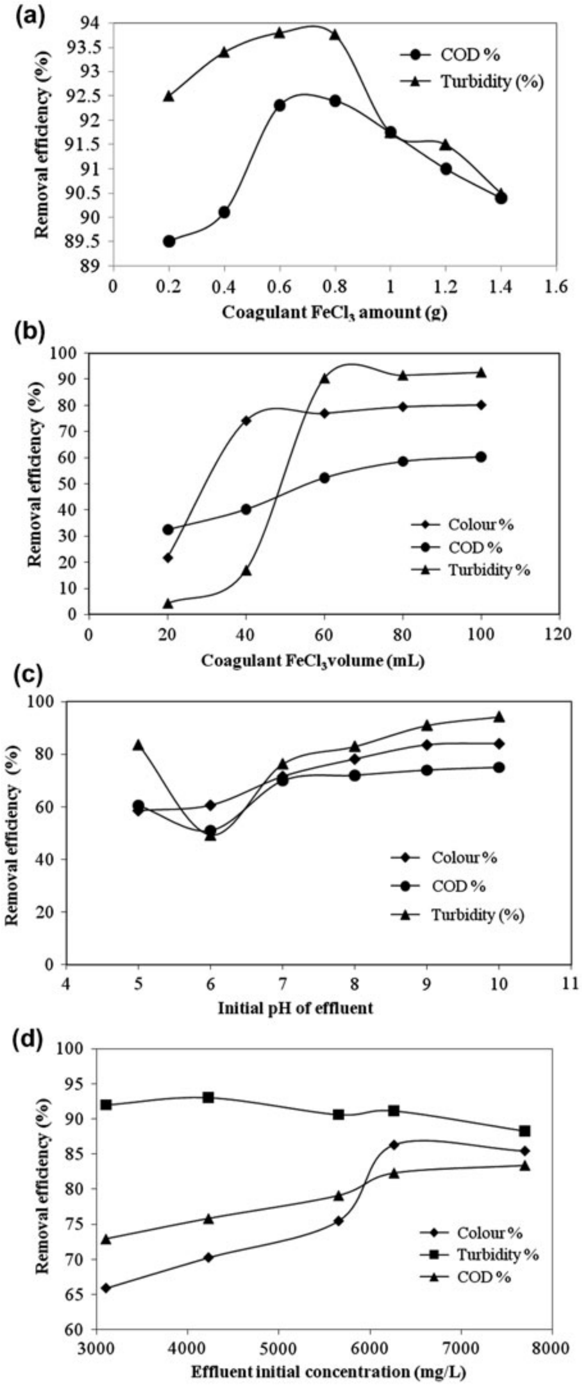

Fig. 8. (a) Effect of $FeCl_3$ coagulant amount on removal efficiency. pH = actual effluent pH (7.2–7.8); Coagulant amount = 0.2–1.4 g of $FeCl_3$; Sample 1, (b) effect of $FeCl_3$ coagulant volume on removal efficiency. pH = actual effluent pH (7.2–7.8); Coagulant amount = 0.7 g of $FeCl_3$; Coagulant volume = 20–100 mL; Sample 1. (c) effect of initial pH on removal efficiency. pH = 5–10; Coagulant volume: 100 mL of 0.7 g/L of $FeCl_3$ solution; Sample 1, and (d) effect of initial concentration on removal efficiency. pH = actual effluent pH (7.2–7.8); Coagulant volume: 100 mL of 0.7 g/L of $FeCl_3$ solution; Sample 1–5.

Table 4
Comparison of the characteristics between raw effluent and treated effluents under optimum conditions

Parameters	Raw effluent (sample 5)	Treated effluent using *C. opuntia* as a coagulant	Percentage of removal	Treated effluent using ferric chloride as a coagulant	Percentage of removal
pH at 25°C	7.6	7.16	–	7.52	–
Colour (nm)	0.4583	0.0533	88.37	0.0488	89.35
COD (mg/L)	7,693	1,677	78.20	1,277	83.40
Turbidity (NTU)	7,760	1,350	82.60	890	88.53

potential possibilities for modifying the matrix for improving its performance.

In view of the above considerations, it is felt that *C. opuntia* can be a better coagulant compared to synthetic ones such as ferric chloride. However, still some improvements to the matrix are required before taking it to industrial applications.

4. Conclusions

An eco-friendly and natural coagulant, *C. opuntia (ficus-indica)*, was identified as an alternative to conventional chemical coagulants in the treatment of paint industry effluent. The purpose of this study was to investigate the ability of *C. opuntia* as a coagulant and to compare the results with $FeCl_3$. The experiment confirmed the positive coagulation properties of *C. opuntia*. The specific conclusions derived from the studies are as follows: the FTIR study confirmed the presence of various functional groups which are responsible for the coagulation process. Extraction of active components from *C. opuntia*, which is responsible for the coagulation, was good when NaCl was used as an eluent rather than $BaCl_2$, especially for 3 N NaCl. Three grams of *C. opuntia* showed the optimum removal results to treat 1L of effluent (sample 1) under neutral pH. High pollutant load sample achieved better removal due to the magnificent difference in the concentration. Hundred millilitres of 0.7 g/L $FeCl_3$ solution was identified as an optimum dosage to treat a litre of effluent at pH 8–9 range. Being biodegradable, eco-friendly, abundant, inexpensive and safe to human health, *C. opuntia* is a promising alternative to the conventional coagulants used in the treatment of paint industry wastewater.

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