Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2020.26031

196 (2020) 189–197
August

A sustainable approach for the treatment of industrial effluent using a green coagulant *Cassia fistula* vs. chemical coagulant

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Received 15 November 2019; Accepted 17 April 2020

ABSTRACT

The presence of contaminants in the paint industry effluent confirms the necessity of its treatment before disposal. This study aims to assess the potentiality of green coagulant *Cassia fistula* by treating it against the synthetic paint industry wastewater. The process of coagulation was done using standard jar test apparatus. The operational variables like solvent type (NaCl, KCl, and distilled water), solvent concentration (1–5 N), coagulant dosage (1–10 g/L), coagulant-extract volume (40–240 mL/L), initial pH (5–11), and initial concentration (1,200; 1,350; 1,850; 2,200; and 2,700 mg/L) had been varied. The recommended condition to treat a liter of effluent was 160 mL of coagulant extract prepared using 5 g of *C. fistula* and 2 N NaCl, at its initial pH (7.8–8.4). The settling studies were conducted to evaluate the sludge volume index, hindered settling velocity, and sludge weight. The obtained results of *C. fistula* is compared with the chemical coagulant ferrous sulfate. The results acknowledged that *C. fistula*, a natural, eco-friendly, green coagulant, could be a strong alternative to the chemical coagulant in the treatment of paint industry wastewater.

Keywords: Synthetic paint industry wastewater; *Cassia fistula;* Coagulation; Settling; Floc

1. Introduction

Manufacturing of paint is a branch of chemical industry. Generally, paint is the mixture of pigments, binders, solvents, and additives. The binder provides adhesion, integrity, and toughness to the dry paint film by binding the pigment together. Paints are classified into solvent-borne paints, water-borne paints, high-solid paints, power coatings, radiation curable paints. Paint wastewater contains high concentrations of suspended solids, pigments, color, heavy metals, oil, and grease [1].

Solvent-borne paints contain up to 80% of solid constituent (binders, pigments) dispersed in the organic solvent. Solvent-borne paints dry fast and may contain a wide range of binders. The main disadvantages of the solvent-borne paints are their toxicity and combustibility. Water-borne paints contain water as the paint solvent. Water-borne paints are non-toxic and non-combustible but they are characterized by long drying time due to slow evaporation rate of water [2].

The effluents of the paint manufacturing company contain highly toxic compounds. These cause harm to fish and wildlife. Paint wastewater also has an adverse effect on human health. If it is used in closed areas, its chemical components can cause irritation to eyes, skin, and lungs and cause headaches and nausea. It can also contribute to respiratory problems, muscle weakness, and liver and kidney damage [3]. Legal restrictions in organized industrial zone and environment conservation make it mandatory that the effluent is treated before it is discharged into the environment.

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1944-3994/1944-3986

There are different methods used to treat the paint industry wastewater that are as follows micro filtration, coagulation, and flocculation, adsorption, biosorption, bio-degradation, physical adsorption. From these methods coagulation is considered as better method to treat paint industry wastewater [4,5].

The treatment done with chemical coagulant gives best result but, it has many disadvantages that are ineffectiveness in low temperature water, relatively high procurement cost, and adverse effects on human health, and production of large volumes of sludge and their significant effect on pH of treated water. Therefore, it is better to change the chemical coagulants with plant based green coagulants to overcome the effects caused by chemical coagulants. The advantages of using natural coagulants are as follows: material is apparent, it is cost effective, unlikely to alter the pH of treated water, and is highly biodegradable. In the age of climate change and depletion of the earth's natural resources usage of plant based coagulants for wastewater treatment is a global sustainable development initiative [6].

Researchers have identified several plant types like *M. oleifera*, *Strychnos potatorum*, *Cactus opuntia*, *Cassia fistula*, *Phaseolus vulgaris*, *Prosopis juliflora*, and *Ipomoea dasysperma* as coagulants [7].

From these *C. fistula* known as golden rain tree which is the national tree of Thailand and used for production of many cosmetic products due to its herbal properties. The *C. fistula* was highlighted for its traditional, tribal and advanced medicinal, and commercial importance [8]. The gum extracted from the seeds of *C. fistula* Linn. (CF) was used as a replacement for the conventional coagulant polyaluminum chloride (PAC), for the decolorization of reactive dyes Blue 19 (RB19) and Black 5 (RB5) using jar-test experiments [9].

Laboratory trials were undertaken on the most promising plant extracts, namely: *Moringa concanensis* (kernel), *C. fistula* (kernel), and *Azadirachta indica* (leaf). Overall, *M. concanensis* powder produced superior results, followed by *C. fistula* (kernel) and *A. indica* (leaf). There are need to carry out further more detailed tests, which include toxicity to guarantee the safety of using plant extracts as a coagulant in the purification of drinking water for human consumption [10].

The polyelectrolyte present in the internal mass of *C. fistula* pods were used as the coagulant for the water treatment in developing countries. Studies have also been carried out to check the changes in the physico-chemical properties of the textile wastewater using *C. fistula* [11].

The ability of *C. fistula* seed gum (CFG) as a coagulant, aided with PAC in the treatment of textile wastewater containing Methyl blue and RB21 dyes was checked. CFG supplementation has assisted the process effects at nearly 98% color, 85% COD for RB21, and 90% color, 70% COD for MB at the best dose of CFG 0.15 and 0.1 mL, respectively [12].

Low-cost water processes were developed to purify the water from the collection point (a) using two natural coagulants, *M. oleifera* and *C. fistula*; (b) filtration through a bio-sand filter and a carbon activated filter; and (c) disinfection through UV-C Radiation and through solar disinfection. *C. fistula* showed 96% of turbidity removal, 76.9% and 98.8% of coliform reduction after the filtration process and disinfection process, respectively [13].

A single-layer artificial neural network (ANN) model was also developed to predict the removal efficiency (color, OCD) of the reactive dye (Red 195) using natural seed gum extracted from *C. fistula* Linn (CF). The selected influencing parameters viz., pH, reaction time, agitation speeds, dye concentration, and CF gum concentration were used to evaluate a one-factor-at-a-time experiment with jar-test apparatus [14].

From the literature review, it was observed that the research based on the use of *C. fistula*, in the treatment of paint wastewater was not done so far. The identified gap inspired us to do the research work using *C. fistula* as a coagulant in the treatment of the paint industry effluent.

In this study, the ability of *C. fistula*, as a natural coagulant, for the treatment of the synthetic water based paint industry effluent (SPIW) was evaluated and the results were compared with the conventional coagulant ferrous sulfate. The treatability was evaluated in terms of color and turbidity by varying the operational parameters. The flowsheet of the current study is given in Fig. 1.

2. Materials

All chemicals used in the study were of analytical grade (AR). Commercial grade white primer was mixed with acrylic-based blue colorant in different proportions and then diluted using distilled water (Table 1). Samples were prepared freshly before every run. The physicochemical characteristics of the effluent were analyzed and the results are given in Table 2. Standard methods were followed for the determination of characterization [15].

The seeds of *C. fistula* were collected from SRM University Campus, a Sub-urban area in Chennai, South India. The seeds were washed thoroughly, dried in an oven for 4–6 h, powdered and sieved through 0.5 mm sieve (CFP). Ferrous sulfate ($FeSO_4$), a reducing agent, is used as a chemical coagulant.

2.1. Methods

A measured mass of natural coagulant (CFP) was mixed in 100 mL of solvent and kept under the stirrer for 15 min at 200 rpm using a magnetic stirrer to extract the critical component polysaccharide, which is responsible for coagulation. Then the resultant solution was allowed to settle for 10 min. A known volume of the supernatant liquid, known as extract, was used as a coagulant for the treatment of synthetic paint industry wastewater (SPIW) [9].

A six stirrer arrangement of jar test apparatus (Deep vision-India) with base floc illuminator, an inbuilt speed regulator (up to 300 rpm), and timer, was used for the batch mode of the coagulation process. The length and breadth of stirrer paddles are 8 and 22 cm, respectively.

2.2. Experimental procedure

2.2.1. Batch coagulation studies

Six beakers of 2 L capacity each, were used to conduct the batch mode coagulation process. A liter of SPIW and a known volume of coagulant-extract were taken for each run to evaluate the operating variables. The mixture was subjected to rapid mixing for 5 min at 200 rpm and followed by slow mixing for 20 min at 80 rpm [7]. The settling period for natural coagulants will vary from 25 to 60 min and the chemical coagulant will be less than 10 min [7].

Table 1
Concentration of SPIW

Sample number	Initial COD (mg/L)
1	1,200
2	1,350
3	1,850
4	2,200
5	2,700

At the end of the set period, 20 mL of the supernatant sample was withdrawn from 2 cm below the water surface, for analysis (i.e., residual color and residual turbidity) and volume, the weight of sludge formed was also noted.

The above procedure was repeated using green and chemical-based coagulants to study the influence of solvent type, solvent concentration, coagulant dose, coagulant-extract volume, initial pH, and initial concentration of the effluent on color and turbidity removal of SPIW. All the experiments were repeated at least thrice for consistency and the results were averaged. A graph was plotted using the averaged values.

2.2.2. Settling studies

The batch settling test was performed in a column of 65 mm in diameter and 430 mm deep, and by gently stirring

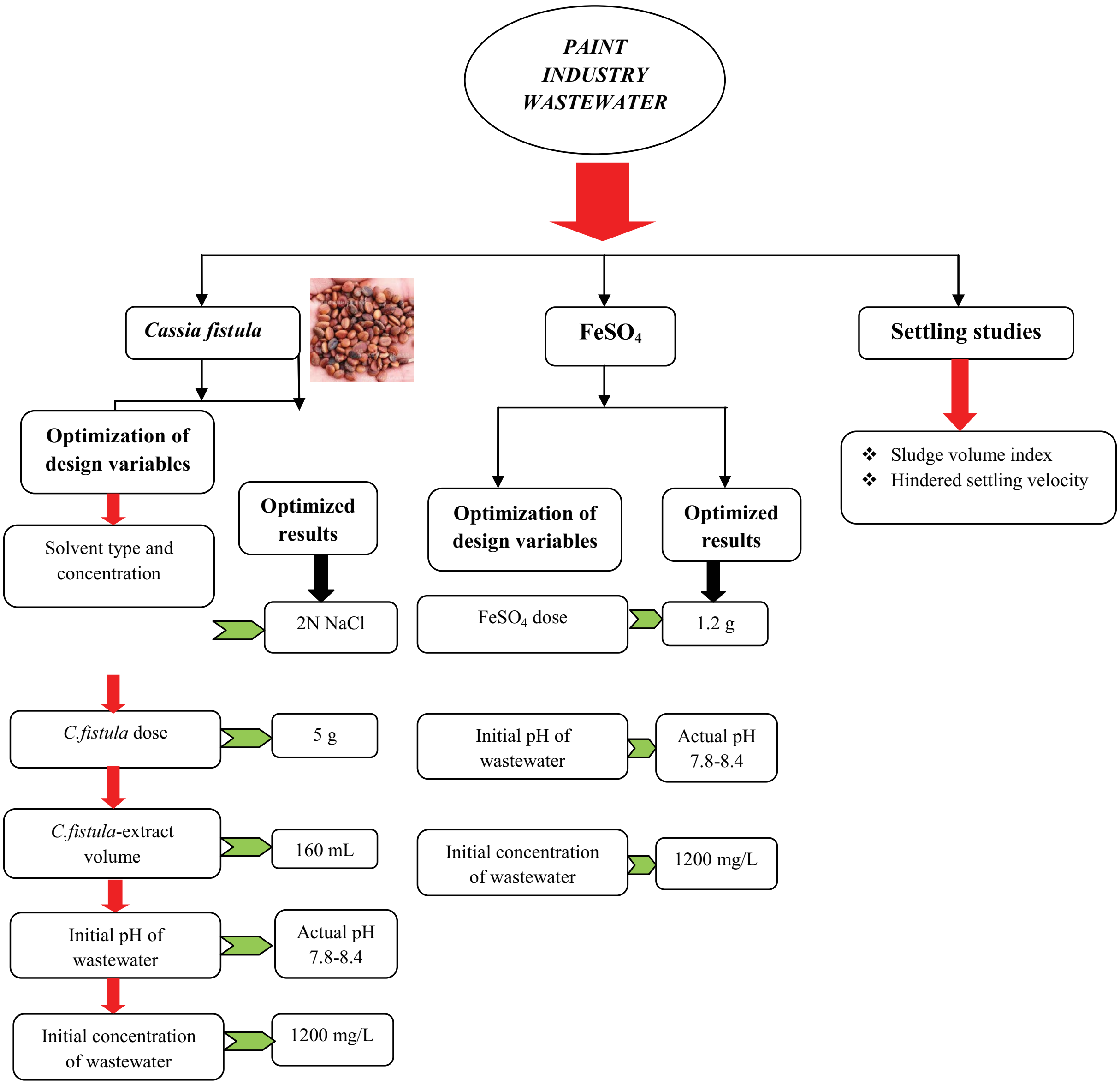

Fig. 1. Flowsheet of the current study.

Table 2
Physico-chemical characteristics SPIW [11]

Concentration (except for pH, color and turbidity, viscosity)	
Parameters	Sample No. 5
pH at 25°C	8.4–8.6
Color	Blue
Total dissolved solids, mg/L	214
Total suspended solids, mg/L	11,286
Oil and grease, mg/L	19
Sulfate as SO_4, mg/L	24
Chemical oxygen demand (COD), mg/L	2,700
Biochemical oxygen demand, mg/L (3 d incubated at 27°C)	1,254
Turbidity, NTU	5,210
Viscosity, kg/ms	0.0144

(1 rpm) the sample during settling. The sludge volume produced after a fixed settling span is the basis for the measurement of the sludge settleability parameters of the coagulant used. Among these, the sludge volume index (SVI) is the most known. The dimensions of the settling cylinder influence on it. These problems can be significantly reduced by conducting the test under certain prescribed conditions.

2.2.3. Analysis

Through color and turbidity removal, the treatability of the green coagulant was assessed. Color was measured using an SL218 double UV visible spectrophotometer (Elico – India) at λmax 612 nm. Turbidity was measured using digital Nephelo-turbidity meter 132 (Elico – India) and expressed in nephelometric turbidity units (NTU). pH was adjusted using a digital pH meter MK. V.I (Elico – India).

3. Results and discussion

3.1. Characterization of C. fistula

The potential of *C. fistula* is mainly attributed by the presence of the chemical functional groups present in it. Fourier-transform infrared spectroscopy (FTIR) analysis was conducted to detect the distinct functional groups present in the natural coagulant. Several peaks were observed at 530.21; 667.55; 744.46; 917.83; 1,005.28; 1,440.29; 1,646.47; 1,725.61; 2,921.79; 3,383.49; 3,683.51; and 3,778.09 cm^{-1}. The maximum peak at 3,778.09 cm^{-1} is due to the OH stretching vibration of water and amine. The peak at 3,383.49 cm^{-1} is due to the presence of amine group in them. Alkene and amide group presence was also confirmed by the bending vibration at 1,646.47 cm^{-1}. The steep peak at 1,003.28 cm^{-1} indicated the –CO stretching vibration of ether groups. Thus, it reveals that CFP carries aliphatic grouping with ether linkages and amine groups (Fig. 2a). The peaks at similar wavelength affirmed the presence of polysaccharides, a key coagulant component, in CFP. The peaks identified in the range of 668–745 cm^{-1} confirms the appearance of strong C=C bending and the presence of the alkene group. The presence of halo compounds are confirmed through the appearance of strong C-I stretching at 530 cm^{-1} [16]. The SEM image of *C. fistula* is given in Fig. 2b.

3.2. Batch coagulation studies

3.2.1. C. fistula vs. synthetic paint factory effluent

3.2.1.1. Effect of solvent type and concentration on the treatment efficiency of SPIW

The coagulant extract prepared using solvent viz., 100 mL of water, 2 N NaCl, 2 N KCl solutions each was added with the effluent. The supernatant liquid formed after the mixing is used as a coagulant-extract. The observed removal efficiency when water is used as solvent was 60.21% color and 50% turbidity and 87.61% color, 97.67% turbidity for KCl, when NaCl is used as solvent the result was 90.14% color and 98.54% turbidity. Based on the higher removal efficiency NaCl was selected as a better solvent (Fig. 3). The presence of polysaccharides in the *C. fistula* powder makes it to act as a coagulant. The NaCl solvent has more tendencies to liberate the polysaccharides than the water and KCl. The believed mechanism behind this is ion exchange property of salt ions [17]. The environmentalists have tried to liberate the proteins from *M. oleifera* and succeeded with NaCl solvent [18].

The concentration of the NaCl solvent was further varied (1–5 N) to know the optimized value. The result obtained from 2 N NaCl was comparatively better than other concentrations (Fig. 4). The removal efficiency obtained at 2 N was 98.73% for color and 99.86% for turbidity. The results completely denoted that 2 N NaCl was an optimum solvent concentration, which liberates maximum amount of polysaccharides from 3 g of CFP. The decrease in coagulation activity upon reaching the optimum level suggested that some polysaccharides may be denatured at NaCl concentrations higher than 2 N. Similar outcomes were observed when the liberation of cellulose was attempted from *C. opuntia* [19].

3.2.1.2. Effect of C. fistula dose on the treatment efficiency of SPIW

The coagulant dosage plays a pivotal role in determining the optimum condition for the performance of

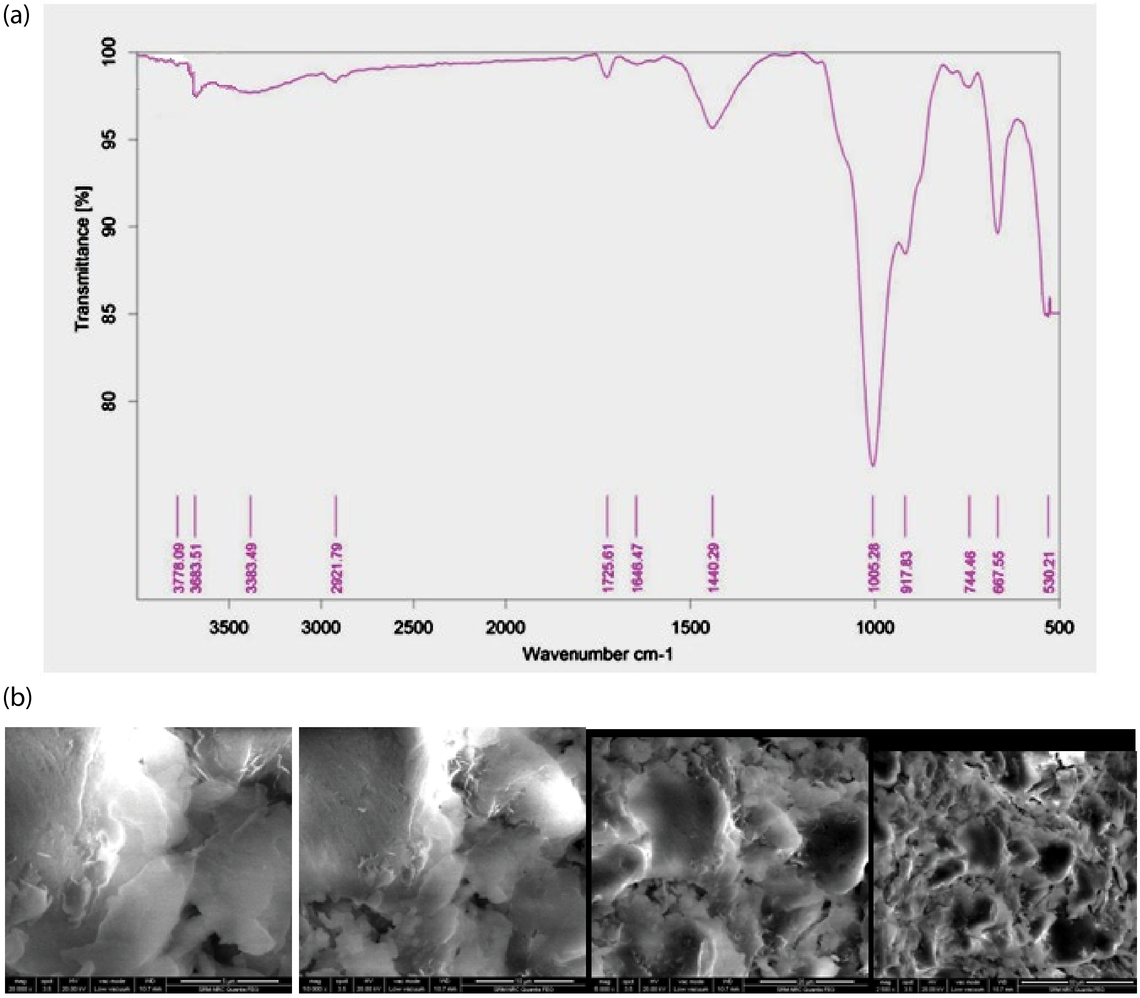

Fig. 2. (a) FTIR spectrum of *C. fistula.* (b) SEM images of *C. fistula.*

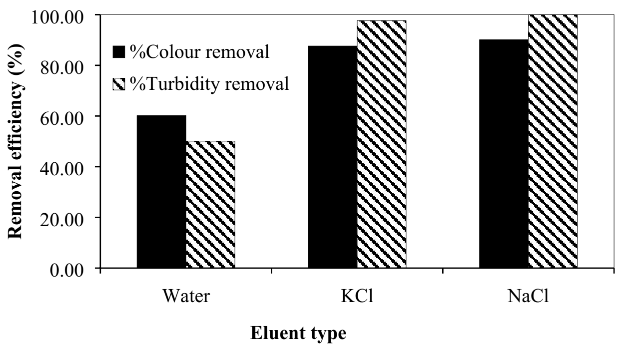

Fig. 3. Effect of solvent type on removal efficiency. SPIW volume: 1 L; initial pH of SPIW (actual): 8.4–8.6; initial concentration of SPIW: 1,200 mg/L; coagulant: solvent = 5 g of CFP: 2 N NaCl, 2 N KCl, distilled water; coagulant-extract volume: 0.1 L.

coagulant in the treatment process. Unsuitable dosing will result in poor coagulation process and ends with maximize the dosing cost and sludge formation. This study was conducted by varying dosage of coagulant from 1 to 10 g in 100 mL of 2 N NaCl solution. These mixtures were added to a liter of effluent (Sample 1). From Fig. 5, it was found that 93.76% color and 98.67% for turbidity were removed when 5 g of CFP was used as a coagulant. The reduction in the removal efficiency was observed when the dosage was further improved. The reason for this is through the coagulant dose was increased, the volume of solvent used for extraction was continued to be constant (100 mL of 2 N NaCl). The reason for the decreasing trend could be that the available salt solution was insufficient to liberate the entire polysaccharides content present in the CFP. Results were matched with the outcomes of the treatment of paint industry effluent using guar gum as a coagulant [20].

3.2.1.3. Effect of coagulant C. fistula-extract volume on the treatment efficiency of SPIW

The stock solution was prepared using 5 g of CFP dissolved in 100 mL of 2 N NaCl solution. Different volume of this coagulant-extract (40–240 mL) was used to examine the pollutant removal in a liter of effluent. The equilibrium values were observed while using 160 mL of extract volume. The results were 91.53%, 92.93% for color and turbidity,

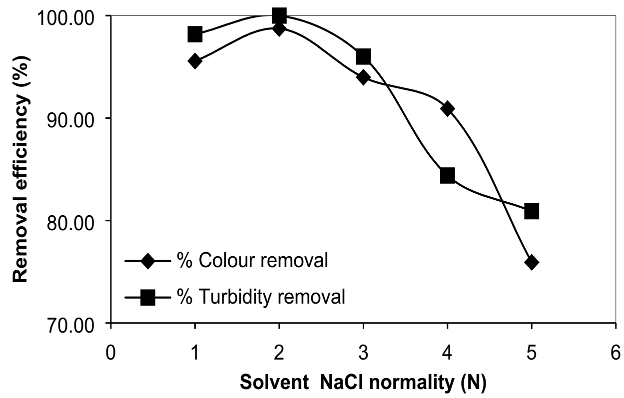

Fig. 4. Effect of solvent concentration on removal efficiency. SPIW volume: 1 L; initial pH of SPIW (actual): 8.4–8.6; initial concentration of SPIW: 1,200 mg/L; coagulant: solvent = 5 g of CFP: NaCl (1–5 N); coagulant-extract volume: 0.1 L.

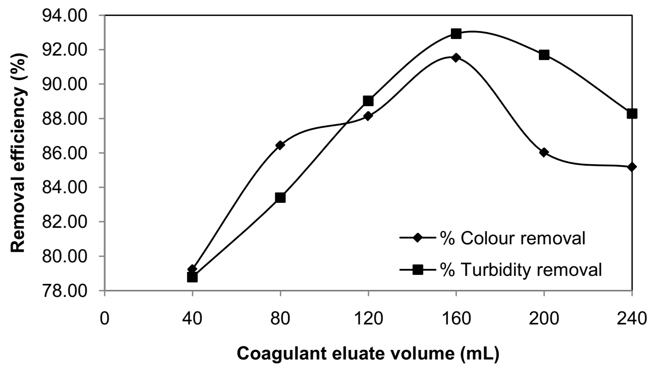

Fig. 6. Effect of coagulant (CFP)-extract volume on removal efficiency. SPIW volume: 1 L; initial pH of SPIW (actual): 8.4–8.6; initial concentration of SPIW: 1,200 mg/L; coagulant: solvent = 5 g of CFP: 2 N NaCl; coagulant-extract volume: 40–240 m/L.

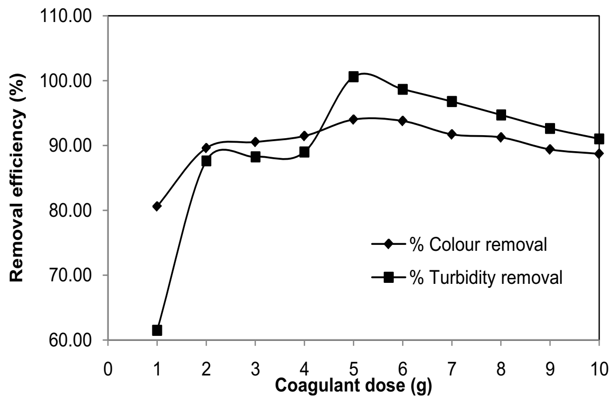

Fig. 5. Effect of coagulant (CFP) dose on removal efficiency. SPIW volume: 1 L; initial pH of SPIW (actual): 8.4–8.6; initial concentration of SPIW: 1,200 mg/L; coagulant: solvent = 1–10 g of CFP: 2 N NaCl; coagulant-extract volume: 0.1 L.

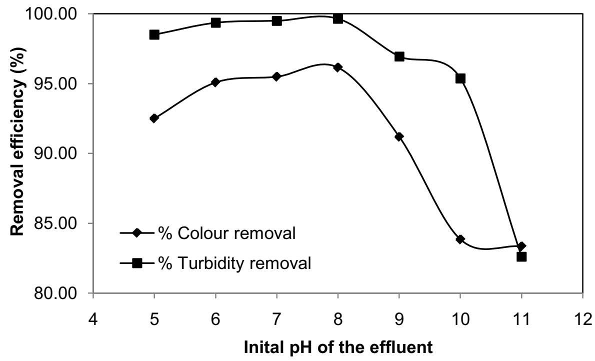

Fig. 7. Effect of initial pH of SPIW on removal efficiency. SPIW volume: 1 L; initial pH of SPIW: 5–11; initial concentration of SPIW: 1,200 mg/L; coagulant: solvent = 5 g of CFP: 2 N NaCl; coagulant-extract volume: 160 mL/L.

respectively (Fig. 6). The believed reason for this was that, higher the coagulant-extract volume ended with higher polysaccharide concentration. The presence of charge reversal mechanism was the responsible source for the reduction in the removal efficiency beyond the optimized value [21].

3.2.1.4. Effect of initial pH of SPIW on the treatment efficiency of SPIW

The actual pH of SPIW lies between 7.8 and 8.4. The initial pH of the synthetic industrial wastewater varied from 5 to 11 by adding HNO_3/NaOH solution accordingly. It was noted that the removal efficiency was higher at pH 8 and it was 96.15% color removal and 99.64% turbidity removal (Fig. 7). The outcome confirmed that the treatment could be proceeding with unaltered initial pH, which minimizes the cost and added pollution. The treatment was good at most basic and neutral pH. Results noted for neutral pH is 95.49% color removal and 99.49% turbidity removal. This is because of charge neutralization mechanism [22].

3.2.1.5. Effect of initial concentration of SPIW

Five different samples with initial concentrations 1,200; 1,350; 1,850; 2,200; and 2,700 mg/L, were prepared and named as sample 1–5, respectively. The sample with lower initial concentration resulted in higher removal efficiency it was read as 97.66% color removal and 92.52% turbidity removal (Fig. 8). The increase in the pollution load (1,200–2,700 mg/L) ended with decreasing trend in the removal efficiency due to scarcity of the active coagulant compound [23].

3.2.2. Ferrous sulfate

The effluent was also treated with chemical coagulant ferrous sulfate. The effect of ferrous sulfate dosage, initial pH of effluent, and initial concentration of effluent were studied.

3.2.2.1. Effect of $FeSO_4$ coagulant dosage, initial pH, and initial concentration of wastewater

The effect of dosage was tested by varying the ferrous sulfate amount from 0.2 to 2 g per liter of effluent. The better

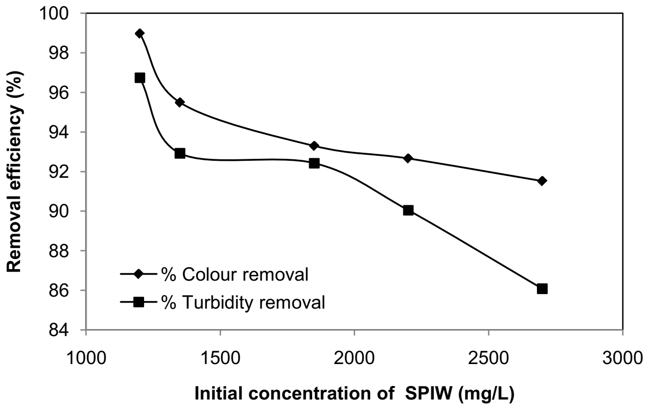

Fig. 8. Effect of initial concentration of SPIW on removal efficiency. SPIW volume: 1 L; initial pH of SPIW (actual): 8.2–8.6; initial concentration of SPIW: 1,200–2,700 mg/L; coagulant: solvent = 5 g of CFP: 2 N NaCl; coagulant-extract volume: 160 mL/L.

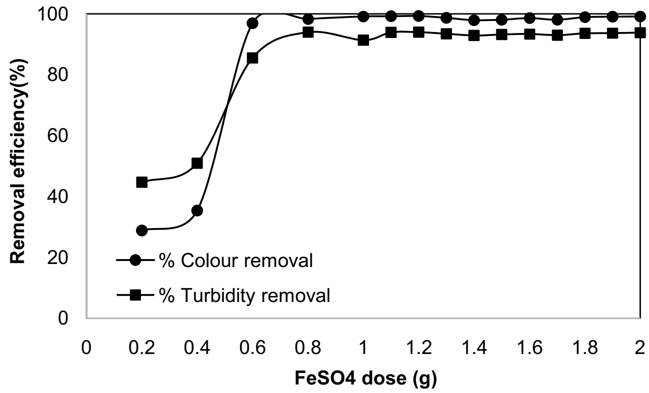

Fig. 9. Effect of coagulant ($FeSO_4$) dose on removal efficiency. SPIW volume: 1 L; $FeSO_4$ dose: 0.2–2 g/L; initial pH of SPIW (actual): 8.4–8.6; initial concentration of SPIW: 1,200 mg/L.

value was obtained at 1.2 g of coagulant and the results noted were 99.38% of color removal and 93.93% of turbidity removal (Fig. 9). To examine the influence of initial pH of the effluent on removal, the initial pH varied from 5 to 11. At initial pH 8, the topmost removal efficiency was noted, that is, 97.85% color and 96.11% turbidity removal (Fig. 10). Among the five different samples with concentrations 1,200; 1,350; 1,850; 2,200; 2,700 mg/L, the highest removal was noted at the lowest concentration 1,200 mg/L. The results obtained were 98.72% color removal and 97.01% turbidity removal (Fig. 11). The characteristics of the raw effluent and the treated effluent using CFP and ferrous sulfate as coagulants are compared in Table 3 [19].

3.3. Sludge settleability parameters

3.3.1. Sludge volume index

SVI is used to describe the settling characteristics of sludge in the aeration tank in an activated sludge process. It is defined as the volume (in mL) occupied by 1 g of activated sludge after settling in the aerated tank for 30 min [24]. The sludge volume of the sample after 30 min (SV_{30}) and final sludge volume (SV_f) was observed for various initial concentrations, it showed the increased trend due to which the SVI results of the CFP were ranged as 71.43–91.23 mL/g (Fig. 12) which indicated that the formed sludge has good settling properties. Typical SVI values can be found between 50 (very good settleability) and 400 mL/g (poor settleability). The dry weight of the sludge was ranged from 17.25 to 38.36 g and its density was between 3,324 and 7,774 kg/m^3, with increase in initial concentration of SPIW [25].

$$\mathrm{SVI} = \frac{\mathrm{SV}_{30}\left(\frac{\mathrm{mL}}{\mathrm{L}}\right)}{X_{\mathrm{TSS}}\left(\frac{\mathrm{g}}{\mathrm{L}}\right)}, \frac{\mathrm{mL}}{\mathrm{g}} \tag{1}$$

where, SV_{30} is sludge volume after 30 min, mL/V, X_{TSS} is total suspended solids, g/L.

3.3.2. Batch settling curve

Generally from the graph (Fig. 13), it is clear that increase in initial concentration is directly proportional to sludge volume. From the batch settling results, the plot was made between the sludge bed heights over time for five different initial concentrations of SPIW (Fig. 14). The particles are settled, due the equilibrium between the gravitational forces. If the column is kept unstirred, then the velocity at which the interface moves downward is called the hindered settling velocity (V_{HS}) at the inlet SPIW concentration [24].

3.3.3. Hindered settling velocity

The hindered settling velocity slows down at higher concentrations because the settling particles will be increasingly hindered by the surrounding particles. Generally, the hindered settling velocity is computed by determining the steepest slope between three consecutive data points from Fig. 15. At higher concentrations, the settling particles will

Table 3
Optimized values of operational parameters to treat a litre of SPIW and their treatment efficiency

Coagulant	Eluent and concentration	Dose and eluate volume	Initial pH (actual)	Initial concentration (mg/L)	Color removal %	Turbidity removal %
C. fistula	2 N NaCl	5 g, 160 mL	7.8–8.4	1,200	96.15	97.85
Ferrous sulfate	–	1.2 g	7.8–8.4	1,200	96.11	98.54

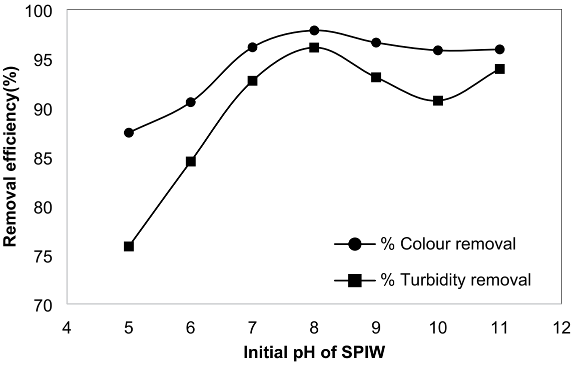

Fig. 10. Effect of initial pH of SPIW on removal efficiency using $FeSO_4$. SPIW volume: 1 L; $FeSO_4$ dose: 1.2 g/L; initial pH of SPIW (actual): 5–11; initial concentration of SPIW: 1,200 mg/L.

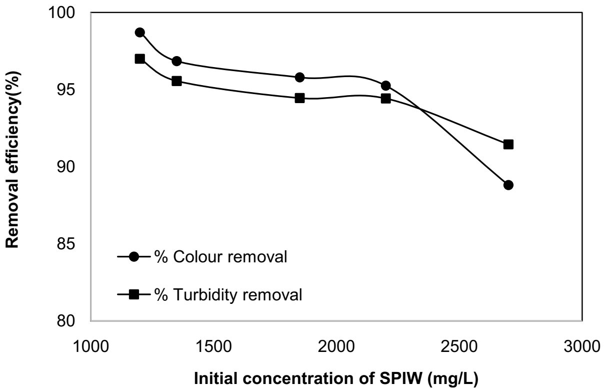

Fig. 11. Effect of initial concentration of SPIW on removal efficiency using $FeSO_4$. SPIW volume: 1 L; $FeSO_4$ dose: 1.2 g/L; initial pH of SPIW (actual): 8.4–8.6; initial concentration of SPIW: 1,200–2,700 mg/L.

be increasingly hindered by surrounding particles, which slows down the V_{HS} [24].

Mathematically, the relation between the sludge concentration and the zone settling velocity can be described by an exponential decaying function, Vesilind equation.

$$V_{HS} = V_0 \cdot e^{(-r_V).(TSS)} \tag{2}$$

where V_{HS} is the hindered settling velocity of the sludge, cm/min; V_0 is the maximum settling velocity, cm/min; TSS is the suspended solids concentration, g/L, and r_V is a model parameter.

The observed hindered settling velocity from the batch settling curves were compared with V_{HS} calculated from the Vesilind model (Fig. 15). The maximum settling velocity (V_0), model parameter (r_V) are found to be 1.16×10^{-5} cm/min and 0.36, respectively [22].

4. Conclusions

The following suggestions are recommended after assessing the potentiality of green coagulant *C. fistula* against the SPIW.

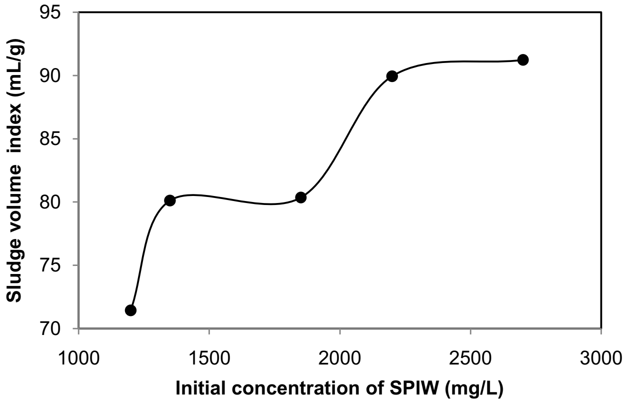

Fig. 12. Sludge volume index as a function of the initial concentration.

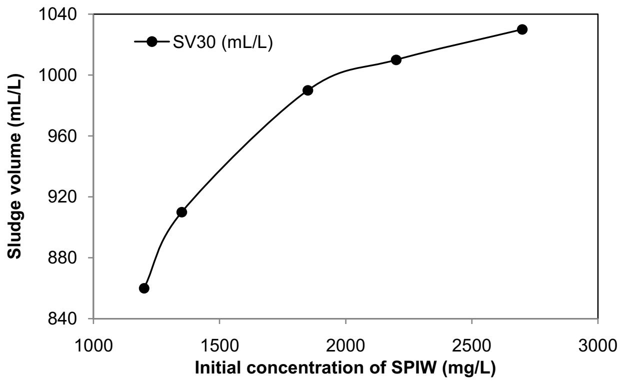

Fig. 13. Sludge volume as a function of the initial concentration.

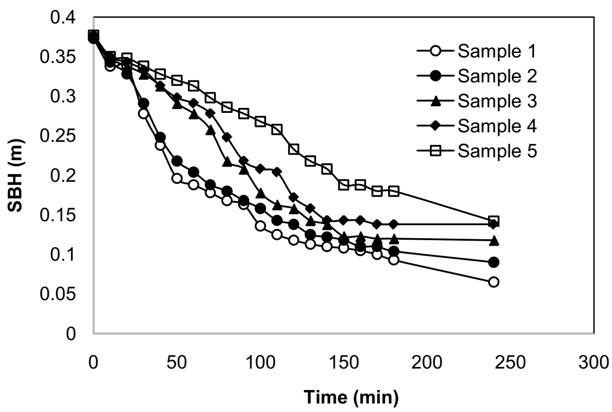

Fig. 14. Batch settling curves at different initial concentrations.

- 2 N NaCl is able to liberate the maximum amount of active polysaccharides from the *C. fistula* powder.
- One hundred and sixty milliliters of coagulant extract prepared using 5 g of *C. fistula* powder exhibited the maximum treatment efficiency of 96.15% (color), 97.85% (turbidity) in SPIW with unaltered initial pH.
- The obtained results of *C. fistula* are comparable with the chemical coagulant ferrous sulfate.

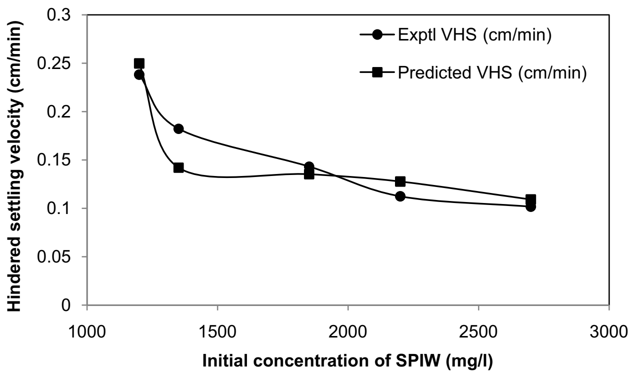

Fig. 15. Settling velocity as a function of the solids concentration.

- The SVI results were ranged as, 71.43–91.23 mL/g, indicated the very good settle ability of the sludge formed.
- The hindered settling velocity of the formed sludge was in the declining trend with the increase in the initial COD of the effluent. The maximum velocity (V_0) was found as 1.16×10^{-5} cm/min.
- The dry weight of the sludge was ranged from 17.25 to 38.36 g and its density was between 3,324 and 7,774 kg/m^3, with an increase in the initial concentration of SPIW.
- The results acknowledged that *C. fistula* a natural, eco-friendly, green coagulant, could be a strong alternative to the chemical coagulant in the treatment of paint industry wastewater.

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