International Journal of Advanced Research in Engineering and Applied Sciences
ISSN: 2278-6252
Impact Factor: 6.655

FEASIBILITY ANALYSIS FOR CHITOSAN AS AN EFFECTIVE COAGULANT IN PUBLIC HEALTH ENGINEERING

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Abstract: Rapid industrialization and urbanization has resulted in several of nature's water resources becoming unfit for most of its originally intended purposes, thereby posing a great threat to public health and aquatic eco-systems; and as well severely increasing the challenges in cleanup. In the current study, the applicability of chitosan as a coagulant on domestic wastewater samples obtained from sewage farm has been probed. Chitosan as cationic polysaccharide is an important natural coagulant biopolymer obtained by de-acetylation of chitin which is the second most abundant material on earth. The methodology primarily decided the optimum dosage of chitosan and of commercially available ferric chloride from Jar-Test experiment as to be 15 and 30 mg/l respectively whilst removing physico-chemical parameters. The studies indicate that when compared with ferric chloride; chitosan is a better coagulant in the removal of turbidity, solids, nitrates, phosphates, sulphates and BOD_5, at lower dosage. Also the application of chitosan neither alters the p^H nor contributes to the organic content of wastewater. It is bio-degradable, thereby minimizing sludge disposal problems. The study economically concludes that chitosan is a more effective-economical coagulant.

Keywords: Chitosan, ferric, coagulant, jar-test, sludge.

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INTRODUCTION

Water is one of the basic elements for the existence of all forms of life on the earth. One of the greatest problems confronting the modern civilization is water pollution; with growing population overburdening the self-purification capacity of recipient water-bodies. Improved awareness on the ecological and health problems has hence necessitated the demand for purification of industrial and domestic wastewater prior to their discharge into water-bodies [1].

Additionally, the discharge criteria are sterner in accordance with existing legislations in-force to avert water pollution and consequential contamination of drinking water sources. The need of hour therefore decrees more effective treatment methodologies within existing unit operations such as coagulation-flocculation. The efficiency of coagulation-flocculation processes is known to strongly influence the overall treatment performance with enhanced destabilization of colloidal suspensions. This treatment technique is generally achieved with the use of appropriate chemicals such as aluminium or iron salts, the so-called coagulant agents [2].

Many coagulants widely used in conventional water treatment processes can be classified into inorganic coagulants (aluminium and ferric salts) and synthetic organic polymers (polyacryl amine derivatives and polyethylene amine). As aluminium and ferrous salts are cheap most are widely employed as synthetic polymers. However, due to the presence of residual monomers, these are undesirable owing to neuro-toxicity and strong carcinogenic properties [3].

Recent studies have also clarified that aluminium and iron chemical coagulant dosages are inefficient in dealing with the nano-sized particles in wastewater. Also their over dosing generates hazardous chemical sludge at higher chemical costs, which further mandates its disposal as scheduled waste. Extended usages of chemical coagulants have hence several shortcomings such as need for larger dosage, lower effectiveness, higher costs and enhanced toxicity levels [4].

The aforementioned situation thereby warrants the need for a more economical and environmentally sustainable and ‘safe’ natural solution. In recent years, there has been considerable interest in the development of usage of biodegradable natural coagulants which can be produced or extracted from microorganisms, animal or plant tissues; and are presumably safe for human health. Natural coagulants have noteworthy benefits as they are economical, existing in profusion, environmental friendly, and produce less voluminous sludge that amounts only 20 to 30% than that of its chemical counterpart in the process of clarification of water and wastewater [5].

LITERATURE REVIEW

Few researches have advocated natural polyelectrolytes of plant seeds, namely *Moringa oleifera seeds, Cactus latifaria, nirmali seed, mesquite bean* as coagulants [5], however these too project certain demerits. 'Moringa' which is the most used natural coagulant is indigenous to Sudan, and is yet not considered as complete replacement to alum in the near future. To overcome this drawback, endeavors have been made to assess the influence of environmentally safe bio-polymer 'chitosan' as a coagulant in Sanitary Engineering.

Chitosan (poly-B-(1,4)-glucosamine) is a natural product derived from de-N-acetalylation of chitin (the second most abundant biopolymer derived from exoskeletons of crustaceans and also from cell walls of fungi and insects) in the presence of a hot alkali. Chitosan production involves four major steps namely de-proteination, de-mineralization, bleaching and de-acetylation [6]. Over the years, Chitosan has been extensively used across wide range of applications such as bio-material in medicines and bio-degradable edible coating in food packaging industries. This is possible due to their properties such as bio-compatibility, bio-degradability, non-toxicity and adsorption [7]. Researches have clarified that chitosan is profoundly more effective than other polymers such as synthetic resins, activated charcoal and even chitin itself [8]. It also has great potential for certain environmental applications. This includes remediation of organic and inorganic contaminants, including toxic metals and dyes in soil, sediment and water, and development of contaminant sensors. Chitosan has hence proved to be versatile for several environmental applications on account of it possessing key functional groups namely OH and NH_2 [6]. There are also quite a few studies on the removal of turbidity by chitosan as a coagulant aid. A study found that using chitosan as 'coagulant-aid' with alum increased turbidity removal efficiency from 74.3 to 98.2% and as well reduced residual Al^{+3} [9]. Yet another study examining the effects of $FeCl_3$ as a coagulant (in conjunction with chitosan as natural coagulant aid) reported removal of 95% turbidity from turbid waters. The optimum dosage of $FeCl_3$ and chitosan was achieved as 10 and 0.5 mg/l respectively. When chitosan was used as a coagulant aid, efficiency in turbidity removal was increased and optimal dosage of $FeCl_3$ turbidity removal was reduced to 50% of initial dosage [10].

EXPERIMENTAL METHODOLOGY

In the present research, the sample was collected from a sewage farm receiving domestic wastewater from a residential township located in the southern part of Mysore. The study initially involved characterization, and then it probed the role of chitosan as a coagulant w.r.t. its optimum dosage as a part of comparative feasibility analysis with commonly used coagulant: Ferric Chloride ($FeCl_3.6H_2O$).

The Central Food Technology Research (CFTRI, Mysore) supplied the sample of chitosan; from which a solution was prepared in 0.1% acetic acid solution. Since literatures have confirmed that chitosan solutions in acid over a period undergo certain change in properties; the solutions were prepared freshly before each set of experiments [11]. To analyze the physico-chemical parameters, the samples were collected once in a week during the peak hours after the wastewater passed through the bar screens. The sample was collected using plastic cans (Plate 1) and preserved until the various analysis were complete. While p^H was found out using a digital p^H meter, alkalinity was estimated by titrimetric method. The logic for analysis of chlorides was as per Argentometric method and that for Nitrates by PDA method and that of BOD_5 estimation as per Azide modification method. While solids determination was done by gravimetric methods, the determination of phosphates and sulphate was adopted from spectrophotometric methods. Procedures of all the aforementioned parametric analysis was referred from Standard Methods [12].

Plate 1: Sampling

Plate 2: Jar Test Apparatus

Finally, the jar-test experiment (Plate 2) was conducted to determine the optimum dosage for best removal efficiency with chitosan in comparison with ferric chloride. Jar test apparatus essentially facilitates a batch test by accommodating a series of six beakers together with six-spindle steel paddles. To find the optimum dosage and time, the concentration of Chitosan and Ferric Chloride was increased in the increments of 5 mg/l; from 5 to 25 mg/l, and 20 to 40 mg/l respectively. The removal efficiency was constantly monitored w.r.t time. After certain dosage, it may be noticed that any additional increments do not cause appreciable removal. Hence, an optimum dosage is the maximum dosage beyond whose addition, appreciable removal is not observed.

RESULTS AND DISCUSSION

In the experiment, major control factors considered were coagulant dosage (5,10,15,20,25,30,35,40 mg), p^H (2,3,4,5,6) and contact time (5,10,15,20,25,30 minutes). The temperature of the sample naturally varied between 26 to 30°C, and the p^H of the wastewater under scrutiny was nearly neutral.

Effect of Coagulant Dosage on Removal efficiency

The maximum removal of turbidity was found as 73.95% and 72.6%, for addition of 15 mg/l and 30 mg/l of chitosan and ferric chloride respectively. As observed, chitosan at lower dosage is found to be more effective in reducing turbidity and Chart 1 depicts the same graphically. The maximum removal of Alkalinity was observed as 95.96% and 95.16% upon addition of 20 mg/l chitosan and 30 mg/l ferric chloride respectively. Chart 2 depicts the same graphically. As both species concentration lies within the tolerance limits (10 NTU and 250 mg/l respectively), hence it can be safely disposed on land for effluent irrigation and sewage farming.

The best removal efficiency w.r.t chloride was observed as 36.60% and 15.88% upon treatment with 15 mg/l of chitosan and 35 mg/l ferric chloride respectively. Chart 3 depicts the same graphically. Upon testing, maximum reduction in nitrates was obtained for 15 mg/l of chitosan and 30 mg/l ferric chloride, with 78.99% and 38.38% respectively. Hence Chitosan was more effective in the case of nitrates de-contamination, and Chart 4 depicts the same graphically. As chlorides and nitrates concentration lies within the tolerance limits (600 mg/l and 250 mg/l respectively), hence it can be safely disposed on land for effluent irrigation and sewage farming.

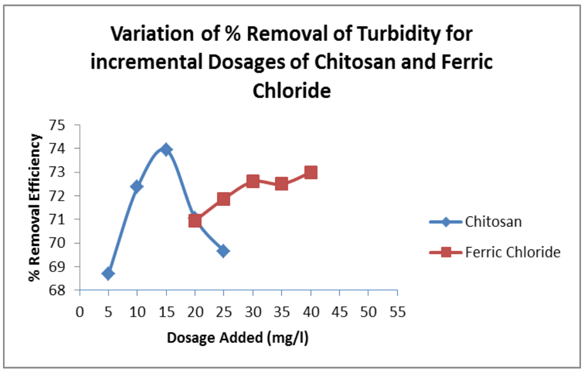

Chart 1: Variation of % Removal of Turbidity.

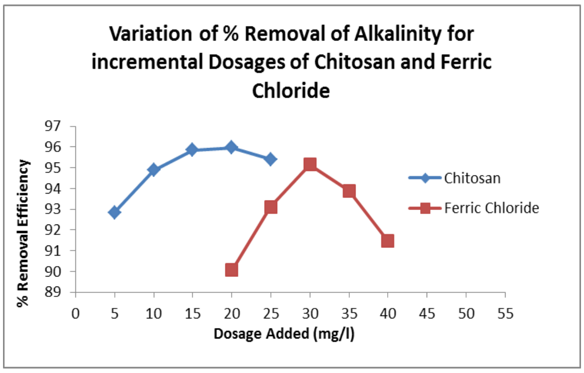

Chart 2: Variation of % Removal of Alkalinity.

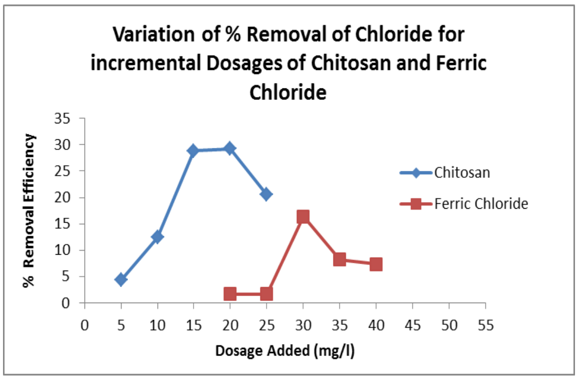

Chart 3: Variation of % Removal of Chlorides.

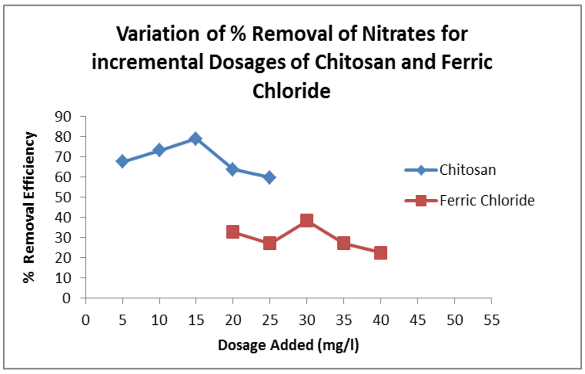

Chart 4: Variation of % Removal of Nitrates.

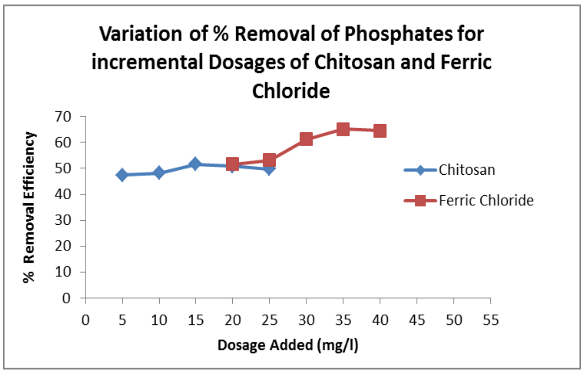

Chart 5: Variation of % Removal of Phosphate.

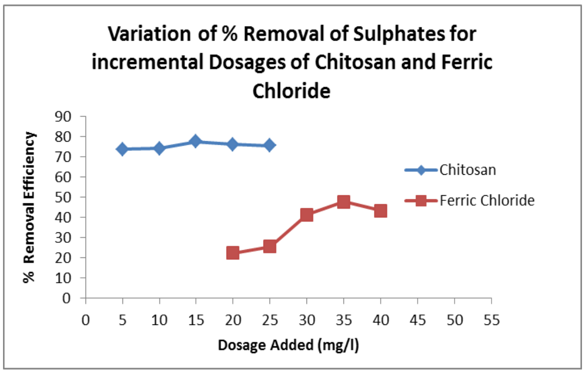

Chart 6: Variation of % Removal of Sulphate.

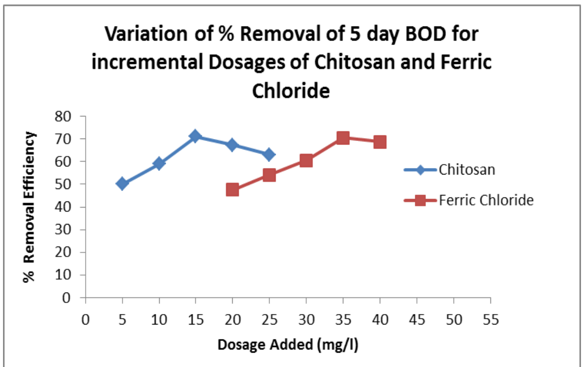

Chart 7: Variation of % Removal of BOD_5.

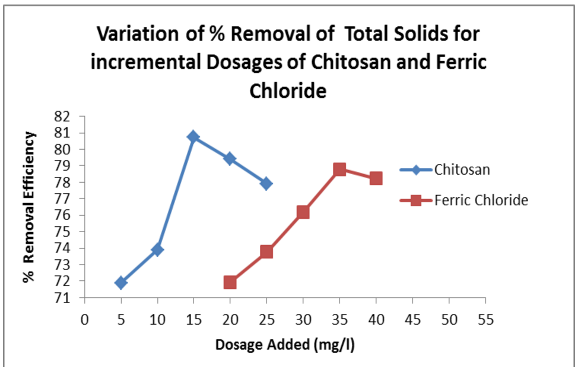

Chart 8: Variation of % Removal of Total Solids.

In the case of phosphate concentration, it was best reduced by 51.15% and 65.16% upon addition of 15 mg/l of chitosan and 35 mg/l ferric chloride respectively. Here it may be highlighted that though $FeCl_3$ is removing more than Chitosan, it occurs at significantly higher dosage. Chart 5 depicts the same graphically. The concentration for sulphate was found to reduce best by 77.48% and 47.77% for addition of 15 mg/l of chitosan and 40 mg/l ferric chloride respectively. Chart 6 depicts the same graphically.

The phosphates and sulphate concentration after treatment are within the tolerance limits (250 mg/l and 250 mg/l respectively); and hence can be safely disposed on land for irrigation. The variation in BOD_5 with different dosages of chitosan and ferric chloride is presented in Chart 7. While the maximum reduction achieved with ferric chloride was 70.6 % upon addition of 35 mg/l, 71.08% removal efficiency was achieved with the addition of just 15 mg/l of chitosan. Also, the BOD_5 of wastewater is within the tolerance limits (300 mg/l) and can be hence disposed onto land for irrigation.

In regards to Total Solids experiment, the best results were found as 90% and 79% upon addition of 15 mg/l of chitosan and 35 mg/l ferric chloride respectively. Chart 8 depicts the same graphically. In regards to Volatile Solids, the best results were found as 85.42% and 84.10% upon addition of 15 mg/l of chitosan and 30 mg/l ferric chloride respectively. Finally, in the case of Dissolved Solids, the best results were found as 90.29% and 85.80% upon addition of 15 mg/l of chitosan and 35 mg/l ferric chloride. The results are illustrated through Charts 9 and 10.

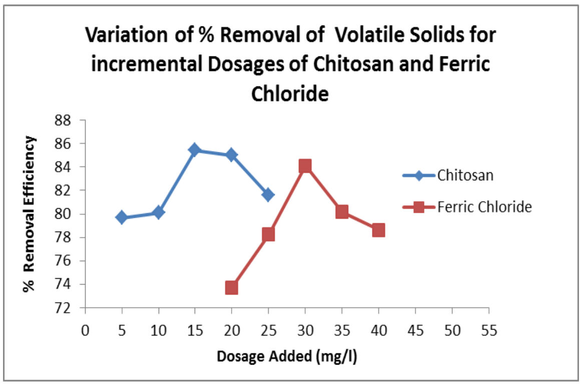

Chart 9: Variation of % Removal of Volatile Solids.

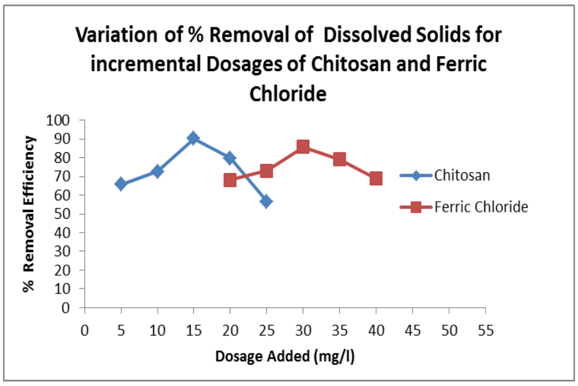

Chart 10: Variation of % Removal of Dissolved Solids.

Hence in all the results, it's most evident that chitosan is more effective than ferric chloride as it consumes lesser dosage, thereby projecting several direct and indirect benefits. The aforementioned results can be substantiated by the hypothesis that chitosan perform by bridging or charge neutralization (de-stabilization by adsorption of particles with consequent formation of particle-polymer-particle bridges), while coagulation process using ferric chloride is a consequence of charge neutralization or bulk precipitation. Hence, chitosan produces better quality flocs of larger size and faster settling velocity. Also at higher dosages, the reduced efficacy is owing to re-stabilization of colloidal particles [13].

Effect of p^H on Removal efficiency

Now since it is confirmed that chitosan gave higher removal percentages for a dosage of 15 mg/l at normal p^H, it was necessary to understand at what p^H the removal efficiency could be enhanced. As the p^H of the aqueous solution has a key role in the coagulation-flocculation processes, it was found that while ferric chloride is usually preferred in the alkaline range, chitosan is more effective in the acidic range and best at p^H of 4.

Table 1 presents the removal efficiency obtained over the range from p^H 2 to 6. The reactivity of chitosan for coagulation and flocculation of suspended particles results from electrostatic attraction, bio-sorption and bridging. The contribution of each of these mechanisms depends mainly on the p^H of the suspension, as attributed to the increase in number of protonated amine groups on chitosan at lower p^H. Below the p^H of 4, the performance of chitosan was found to weaken due to its increased solubility and instability. In future scope of research, this limitation can be addressed by modifying chitosan's structure via cross-linking to enhance the structural stability and to improves its physicochemical characteristics (porosity, hydraulic conductivity, permeability, surface area and sorption capacity) [13].

Table 1: Variation of % Removal w.r.t p^H

p^H	Turbidity	Alkalinity	Nitrate	Chloride	Phosphate	Sulphate	Total Solids	Volatile Solids	Dissolved Solids	BOD_5
2	67.00	94.65	75.32	34.46	52.16	72.46	79.50	87.10	73.25	52.57
3	70.45	96.41	76.36	35.44	52.70	75.39	82.94	90.90	72.67	59.05
4	73.70	96.50	77.40	34.62	53.24	76.29	84.26	91.46	73.19	71.42
5	71.59	95.47	73.50	34.29	51.62	73.58	83.60	90.79	71.63	66.39
6	72.50	95.33	73.36	33.55	51.08	73.13	81.62	88.44	71.98	63.82

Effect of Contact Time on Removal efficiency

Now since it is confirmed that chitosan gave higher removal percentages for a dosage of 15 mg/l at a p^H of 4; it was necessary to understand at what shortest time the optimum results could be drawn. As can also be observed from Table 2; it was found that the percentage removal efficiency was found to rapidly increase and later fallback. The variation in removal of aforementioned parameters happened best at the 15th minute.

Table 2: Variation of % Removal w.r.t Time

Time (min)	Turbidity	Alkalinity	Nitrate	Chloride	Phosphate	Sulphate	Total Solids	Volatile Solids	Dissolved Solids	BOD_5
5	62.69	92.85	61.50	03.93	47.08	71.00	70.60	77.83	65.95	45.00
10	64.72	94.89	65.07	11.76	50.48	73.20	72.10	78.98	66.82	55.70
15	67.68	97.21	71.17	27.44	53.88	75.60	78.03	88.59	71.54	70.47
20	66.56	95.91	69.30	29.42	54.56	74.20	72.38	83.59	67.70	68.33
25	65.93	95.73	70.85	28.93	53.59	73.48	71.32	79.90	69.51	64.28
30	64.52	95.53	63.59	27.53	48.49	71.10	70.70	78.63	69.39	59.51

Based on the market rate and the optimal quantity needed to attain best removal efficiency (15 kg and 30 kg of chitosan and ferric chloride respectably) to treat 1 MLD of wastewater; eventually the cost analysis projects a savings 2268000 per year.

CONCLUSION

The studies indicates chitosan as a potential coagulant for the removal of turbidity, solids, nitrates, phosphates, sulfates and BOD_5; at a remarkably lower dosage (15 mg/l) as compared to that of ferric chloride (30 mg/l). The removal process of physico-chemical parameters with respect to chitosan is also economical and much better than that by Ferric chloride. The results of 'chitosan treated wastewater' facilitates safer disposal for sewage farming and effluent irrigation; as the treatment ensued final characteristics within effluent disposal limits on land. Also as chitosan is a natural coagulant and bio-degradable; the subsequent sludge disposal problems are also compromised.

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