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Research Article

Evaluation of factors affecting coagulation of water with Natural Polymers

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Abstract

Availability of potable water has become one of the most problematic concerns in the present world. As the scarcity of water is increasing with the changing the climatic conditions, requirement of the potable water has become one of the key issues in the developing countries. Surface water, which has inevitable turbidity, has to be treated before consumption. Coagulation and flocculation is the process conventionally used for removing turbidity of water. Complications associated with chemical coagulants like specific pH conditions, voluminous sludge and coagulant dose have made it necessary to look for alternatives which are natural in origin. In the present study the efficiency of natural coagulants at optimized parameters that govern coagulation process: pH, coagulant dose and mixing speed have been studied. Efficiency of coagulants in the removal of turbidity (93 to 100%) have been in the order of chitin>alum=sago. One of the promising results was that the natural coagulants were stable at varied pH conditions of 6, 7 and 8. The concentration of suspended solids in the settled sludge was higher with alum, whereas the total solids residue was higher with both the natural coagulants resulting in sludges which dewater readily producing sludge with higher solids content that have improved characteristics with regards to handling.

Keywords: potable water, Coagulation, flocculation, sludges.

Introduction

By 2030 it is estimated that the annual global demand for water will increase from 4,500 billion m^3 to 6,900 billion m^3 - approximately 40% more than the amount of freshwater available [1]. We are not only facing an increasing scarcity of water, but we also are misusing the available water. There are essentially two strategies to ensure supply of freshwater: we either use less water, or we make more of the water that we do use. The first is a typical accounting approach and is limited in scope, whereas the second calls for better science and engineering approaches [2].

One of the most pervasive problems afflicting people throughout the world is inadequate access to clean water and sanitation. Problems with water are expected to grow worse in the coming decades, with water scarcity occurring globally, even in regions currently considered water-rich. Addressing these problems calls out for a tremendous amount of research to be conducted to identify robust new methods of purifying water at lower cost and with less energy, while at the same time minimizing the use of chemicals and impact on the environment [3].

Turbidity in general is a measure of water cloudiness induced by such colloidal and suspended matters and is also one of the major criteria in raw water monitoring to meet the stipulated water quality guidelines. Turbidity reduction is often accomplished using chemical coagulants such as alum. The use of alum is widely associated with potential development of health issues and generation of voluminous sludge. Natural coagulants that are available in abundance can certainly be considered in addressing the drawbacks associated with the use of chemical coagulants [4].

Plant materials for many centuries have been used as coagulants in developing countries to clarify turbid water [5, 6]. In India, crushed seeds of the Nirmali tree have been used for centuries to clarify muddy water [7]. Jahn and Diar[8] have reported that in Sudan seed powder from the indigenous plant Moringa is added to drinking water to remove turbidity [9].

Natural polymers do not harm the environment. Biomass products have been used in water treatment and wastewater due to their biodegradability. With regard to the adsorption, various types of biomass such as chitosan, charcoal, sugarcane bagasse, dead fungal biomass, green algae and cyanobacteria were used for chromium removal [10, 11, 12, 13 & 14].

Traditionally, coagulation/flocculation is aimed at the removal of suspended colloidal particles when the stabilized colloids are aided to overcome their repulsive forces leading to the aggregation of the particles into flocs [15, 16, 17 & 18]. The factors that affect the process are raw effluent quality, temperature, pH, chemical and bacteriological parameters etc[19, 20].

The optimal design for the turbidity removal is a very important aspect in the development of jar test in water treatment process. The objective of this research work is optimization of operating conditions for the use of natural coagulants in coagulation of turbid water for potable use. The dependent variable is the residual turbidity (NTU), and the independent variables chosen were: i) pH; ii) varied turbidity and iii) dosage of coagulants (mg/L). The purpose of the study is to give sustainable, low cost, locally available, simple, reliable, acceptable, eco-friendly, household level point of use water treatment technology most suitable for rural population of developing countries.

Methodology

Preparation of Synthetic Turbid water samples

The natural turbidity of raw water varies from 10 to 500 NTU for maximum period. So the experiments were carried out for water samples of 70 and 150NTU turbidity values. Turbid water samples were prepared by using Bentonite clay. 5 gm of Bentonite clay was mixed to 500ml distilled water. Mixed clay sample was allowed for soaking for 24 hrs. Suspension was then stirred so as to achieve uniform and homogeneous sample. Supernatant was withdrawn. Turbidity was determined and portions of suspension were diluted to desired turbidity values. Resulting suspension was found to be colloidal and used as stock solution for preparation of turbid water samples. Everyday stock sample of Bentonite clay was diluted by using distilled water to get desired turbidity [21].

Coagulants used in the study

The natural coagulants used in the study are chitin and sago.

Chitin is a natural polymer. Chitin is the second most abundant polysaccharide in nature (after cellulose). At least 10 giga tons of chitin is synthesised and degraded each year in the biosphere. Chitin is present in nature usually complexed with other polysaccharides and with proteins. It is a renewable resource and is isolated from crab and shrimp waste. It is used for waste water clearing among many other applications. Employed as a chelating agent, chitin and its derivatives are used for treating drinking water by separating organic compounds and heavy metals, and for treating sewage by precipitating certain anionic wastes and capturing pollutants such as DDT and PCBs (polychlorobenzene). The Environmental Protection Agency (EPA) has already approved the use of chitosan in water at concentrations of up to 10 mg per litre[22].

Indian sago starch extracted from Tapioca roots finds its application not only as a food but also numerous commercial applications. The sago starch is a cheap, easily available, biodegradable and a versatile polymer. Indian sago starch is extracted from *Manihot esculenta* belonging to family Euphorbiaceace. Sago is native to Brazil, Amazon, Colombia, Venezuela, West Indies, Cuba, and Puerto Rico. In India it was introduced in later part of 19th century. Kerala, Andhra Pradesh and Tamil Nadu are the major producers of sago starch. Tapioca root is the basic raw material for sago and starch. These roots contain about 5-13% starch, 60-70% moisture, 7-12% protein and fat present in trace amount. Indian Tapioca roots are known to have 30-35% starch with appreciable amount of calcium and vitamin-C [23, 24].

Experimental procedure: A conventional jar test apparatus was employed for the process of coagulation and flocculation. All tests were carried out with

500ml samples in 1L beakers. Beakers were filled with 500 ml of the synthetic water, and placed on each slot in a jar tester. Coagulant was added into each beaker at various doses and agitated at mixing speed and time: 80 rpm for 1 min and then reduced to 20 rpm for 30 min. The coagulant dose was added at four concentrations i.e 0.05, 0.1, 0.15 and 0.2 mg/l. The coagulation was performed at three different pH conditions i.e 6,7 and 8 by adding 0.1 M H_2SO_4 and 0.1 M NaOH in all coagulation tests. After sedimentation for 20 min, an aliquot of 10 ml was sampled from the mid depth of the beaker and residual turbidity was determined. Turbidity measurements were conducted using nephelometricturbidimeter (ELICO, CL52D). The pH values of samples were measured using pH meter (ELICO, L1 126).

Pre and post analysis

The second parameter that was analysed is the concentration of suspended solids in the settled sludge and the third parameter is the Total solids residue, carried out with the standard procedures given in Module 9 from iastate.edu.

The concentration of suspended solids in the settled sludge is determined by straining a measured sample through a glass - fibre filter. Nonfilterable residue, expressed in milligrams per litre, is the solids content. Since the filterable portion of sludge is very small, sludge solids are often determined by total residue on evaporation (ie. the total deposit remaining in a dish after evaporation of water from the sample and subsequent drying in an oven at 103^{o}C). [25]

Results

Coagulant dose is one of the prime factors that govern the removal of turbidity / colloidal particles from water. Hence, studies concerned with testing efficiency of coagulants instigate with optimizing the coagulant dosage. In the present study the efficiency and optimization of the coagulants was considered based on the sludge formed.

Synthetic water (70 and 150 NTU) was flocculated with different concentrations of the natural coagulants whose efficiency was compared with that of alum. The observed optimum dosage, which is the minimum dosage corresponding to the lowest turbidity, varied by coagulants is presented in Table 1.

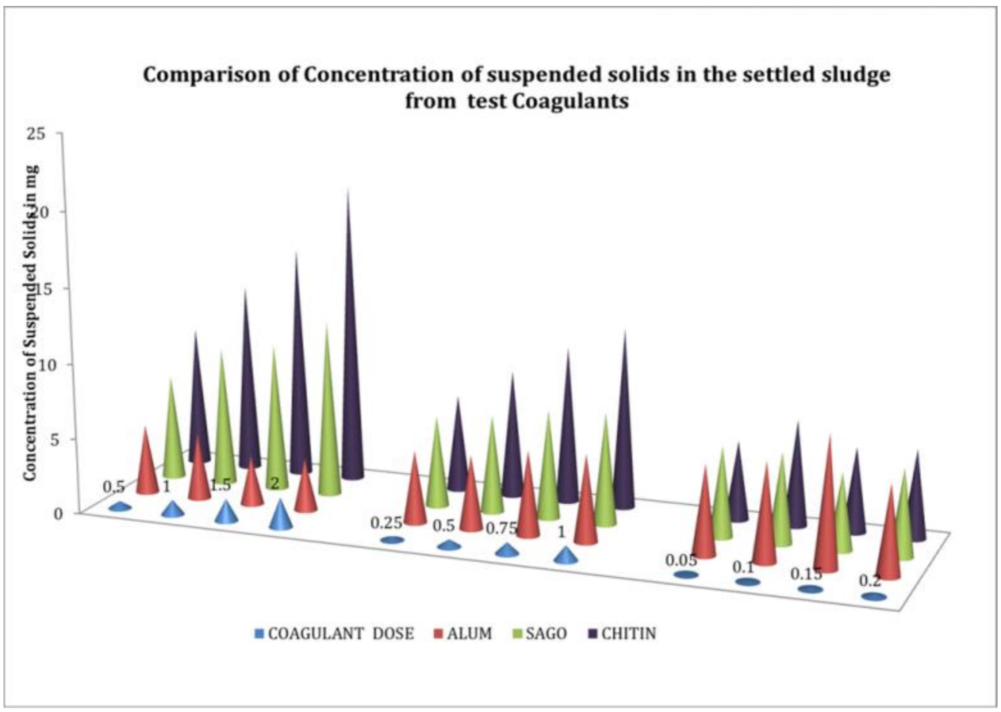
Table – 1: Optimization of Coagulant Dosage – Concentration of suspended solids in settled sludge (SS) and total solids residue (TSR)

DOSE	ALUM			SAGO			CHITIN		
	SS	TSR	% Red	SS	TSR	% Red	SS	TSR	% Red
0.5	4.61	0.82	87.32	7.01	2.77	99.04	9.37	1.82	87.00
1.0	4.42	0.83	89.82	9.27	4.61	98.90	12.68	2.22	88.91
1.5	3.27	0.89	93.04	9.82	5.07	99.62	15.55	2.71	90.82
2.0	3.5	0.88	95.09	11.75	7.24	99.45	20.07	3.58	91.95
0.25	4.81	0.98	95.53	6.08	2.25	95.34	6.48	1.56	86.40
0.5	4.92	1.14	94.03	6.51	2.2	94.23	8.51	1.8	84.93
0.75	5.62	1.06	96.06	7.24	3.07	94.03	10.46	2.06	85.92
1.0	5.8	1.02	97.10	7.47	3.17	92.78	12.04	2.29	83.95
0.05	5.93	1.43	96.82	6.01	1.54	98.50	5.28	1.37	93.40
0.1	6.52	1.42	96.95	6.02	1.62	98.25	7.05	1.42	92.93
0.15	8.68	1.43	97.94	5.11	1.54	99.25	5.67	1.46	91.92
0.2	5.95	1.44	97.96	5.79	1.62	99.42	5.9	1.51	90.95

The initialization of the experiments was carried out with doses of 0.5, 1.0, 1.5 and 2.0 (with a difference of 0.5 between each concentration), of which 0.5 resulted in good turbidity removal with formation of less concentration of suspended solids in the settled sludge (4.61, 7.01 and 9.37mg/500ml by alum, sago and chitin respectively) and higher turbidity removal. Taking this into consideration we progressed to test the efficiency of the coagulants with further concentrations ranging around 0.5. Hence in the next level of experiments the coagulant dose was taken as 0.25, 0.5, 0.75 and 1.0 (with a difference of 0.25 between each concentration). A specific tendency of increased concentration of suspended solids in the settled sludge was observed with increasing concentration of the coagulant by all the three coagulants whereas the reduction in turbidity was contrary, i.e it increased with decreasing dosage (4.81, 6.08 and 6.48mg/500ml with alum, sago and chitin respectively) Table - 1.

Since the prime objective of the study was to determine the lowest concentration of coagulants that can result in efficient reduction of turbidity, in the next stage we tested the doses of coagulants with 0.05, 0.1, 0.15 and 0.2 (with only 0.05 difference between concentrations). These concentrations have resulted in interesting results with increased suspended solids in the settled sludge as the concentration increased from 0.05 to 0.2 by alum and chitin, whereas sago has shown a converse trend of decreasing suspended solids in the settled sludge with increasing concentration (5.93, 6.01 and 5.28mg/500ml by alum, sago and chitin respectively) Fig - 1.

Fig – 1: Comparision of Concentration of suspended solids in the settled sludge from Test Coagulants



Similar results were observed with the Total solids residue. Remarkable result observed in the study is that least sludge was obtained by alum at higher dosages of coagulant that is 0.5, 1.0, 1.5 and 2.0 (4.61, 4.42, 3.27 and 3.5mg/500ml respectively)with least sludge at 1.5 dosage (3.27mg/500ml). Whereas the natural coagulants have shown decreasingconcentration of suspended solids in the settled sludge with decreasing dosage of coagulant, Fig - 2.

Turbidity reduction by the coagulants was in the order of chitin>alum>sago. Chitin showed reduction in turbidity both at higher and lower doses of the coagulant. Infact the highest reduction in turbidity was seen at dose of 1.5mg. All the coagulants were efficient at the doses of 1.5 and 2.0mg doses of coagulant. On a general note the reduction in turbidity was enhanced with reduction in coagulant dose. Even though chitin and other coagulants were efficient at higher doses the noteworthy point is that they were equally efficient at lower doses and with lower sludge volume.

These verdicts have stimulated us to take up the lower doses to be optimized doses for futher studies.

The next stair of study included testing the optimized doses at different turbidities that are generally present in surface waters, in this study the lower and higher turbidities are taken as 70 and 150 NTU with pH conditions ranging from 6, 7 and 8, which is the characteristic of surface water and also is the governing factor for efficiency of coagulants. The mixing speed and time was kept constant at 80 rpm for 1min and 30rpm for 30min (Table – 2 & 3).

pH – 6:

At pH 6 the weight of concentration of suspended solids in the settled sludge was found to be high for alum (9.96mg) with a dose of 0.05g, 150NTU initial turbidity. The least concentration of suspended solids in the settled sludge weight was obtained with sago (4.94) at 0.05g coagulant dose, 70NTU initial turbidity Fig – 3 & 4.

Alum: The higher and lower concentrations of suspended solids in the settled sludge was found tobe 9.96mg and 6.06mg at 150 and 70NTU initial turbidity with 0.05g of coagulant dose. Their respective Total solids residue values are 1.44 and 1.4 with turbidity reduction of 100 and 98.78% respectively.

Sago: Utmost(9.55mg) and least (5.51mg) concentration of suspended solids in the settled sludge are obtained with 0.15g and 0.05g coagulant dose at 150 and 70 NTU initial turbidities respectively. The corresponding Total solids residue are 1.35 and 1.43 with turbidity reduction of 100 and 95.8% respectively.

Chitin: 8.68mg and 6.17mg were the maximum and minimum concentration of suspended solids in the settled sludge at 0.2 and 0.05g of coagulant dose with 150 and 70NTU initial turbidity. The associated Total solids residue values are 1.61mg and 1.45mg with turbidity reductions of 93.38 and 97.58%.

pH – 7:

Prominent (10.76mg) and flat (5.29mg) concentrations of suspended solids in the settled sludge was reported by alum and sago at 0.1g coagulant dose, 150NTU and 70 NTU initial turbidity. Their congruence Total solids residue weights are 1.68mg and 1.45mg with turbidity reduction of 97.11 and 87.19% respectively Fig – 3 & 4.

Alum: The higher and lower weights of concentration of suspended solids in the settled sludge was found tobe 10.76mg and 6.16mg at 150 and 70NTU initial turbidity with 0.1g of coagulant dose. Their individual Total solids residue weights are 1.68 and 1.45 with turbidity reduction of 97.11 and 97.82% respectively.

Sago: Utmost(8.73mg) and least (5.29mg) concentration of suspended solids in the settled sludgewere obtained with 0.2g and 0.1g coagulant dose at 150 and 70 NTU initial turbidities respectively. Their independent Total solids residue are 1.6 and 1.45 with turbidity reduction of 94.23 and 87.19%.

Chitin: 8.58mg and 6.33mg were the maximum and minimum concentration of suspended solids in the settled sludge at 0.2g and 0.05g of coagulant dose with 150 and 70NTU initial turbidity. The associated Total solids residue values are 1.73mg and 1.46mg with turbidity reductions of 92.21 and 94.84%.

pH – 8:

Projecting (10.08mg) and sunken (5.1mg) concentrations of suspended solids in the settled sludge was reported by alum and sago at 0.2g and 0.05g coagulant dose, 150NTU and 70 NTU initial turbidity. Their congruence Total solids residue are 1.5mg and 1.44mg with turbidity reduction of 100% Fig 3 & 5.

Alum: The higher and lower weights of concentration of suspended solids in the settled sludge was found tobe 10.08mg and 5.29mg at 150 and 70NTU initial turbidity with 0.1g and 0.2g of coagulant dose. Their individual Total solids residue are 1.5 and 1.36 with turbidity reduction of 100%.

Sago: Utmost(6.89mg) and least (5.1mg) concentration of suspended solids in the settled sludge were obtained with 0.05g coagulant dose at 150 and

Table – 2: Correlating Concentration of suspended solids in the settled sludge with turbidity reduction (%)

pH	Dose	ALUM				SAGO				CHITIN			
		70 NTU		150 NTU		70 NTU		150 NTU		70 NTU		150 NTU	
		Sludge	Turbidity	Sludge	Turbidity	Sludge	Turbidity	Sludge	Turbidity	Sludge	Turbidity	Sludge	Turbidity
6	0.05	6.06	100.00	9.96	98.78	4.94	95.81	8.53	100.00	6.17	97.58	8.41	93.87
	0.1	6.73	100.00	9.72	98.49	4.95	95.90	7.9	100.00	6.65	94.15	8.32	94.59
	0.15	6.76	100.00	9.92	98.24	5.51	94.84	9.55	100.00	6.72	96.77	8.25	93.73
	0.2	7.85	100.00	9.01	97.67	5.21	94.92	8.88	100.00	7.34	96.62	8.68	93.38
7	0.05	6.49	94.14	9.04	97.20	5.46	85.08	6.89	94.93	6.33	94.84	8.07	93.47
	0.1	6.16	91.82	10.76	97.11	5.29	87.19	7.47	95.70	6.75	97.33	7.54	91.17
	0.15	6.78	84.42	9.92	93.53	5.76	88.46	7.83	94.50	6.99	94.52	8.75	92.93
	0.2	6.89	71.27	9.86	92.28	5.63	85.63	8.73	94.23	7.04	93.33	8.58	92.21
8	0.05	6.0	100.00	9.1	100.00	5.1	100.00	6.89	96.41	6.31	100.00	8.25	96.13
	0.1	5.56	100.00	10.08	100.00	5.85	100.00	6.51	95.90	6.6	100.00	7.78	95.34
	0.15	5.68	100.00	9.23	100.00	5.33	100.00	6.63	96.34	6.79	100.00	7.48	96.87
	0.2	5.29	100.00	8.53	100.00	5.48	100.00	6.62	96.11	7.38	100.00	7.25	95.68

Table – 3: Correlating Total solids residue with turbidity reduction

pH	Dose	ALUM				SAGO				CHITIN			
		70 NTU		150 NTU		70 NTU		150 NTU		70 NTU		150 NTU	
		Sludge	Turbidity	Sludge	Turbidity	Sludge	Turbidity	Sludge	Turbidity	Sludge	Turbidity	Sludge	Turbidity
6	0.05	1.4	100.00	1.44	98.78	1.43	95.81	1.28	100.00	1.45	97.58	1.73	93.87
	0.1	1.44	100.00	1.45	98.49	1.46	95.90	1.29	100.00	1.52	94.15	1.56	94.59
	0.15	1.56	100.00	1.46	98.24	1.52	94.84	1.35	100.00	1.58	96.77	1.63	93.73
	0.2	1.64	100.00	1.46	97.67	1.58	94.92	1.39	100.00	1.63	96.62	1.61	93.38
7	0.05	1.42	94.14	1.53	97.20	1.46	85.08	1.46	94.93	1.46	94.84	1.55	93.47
	0.1	1.45	91.82	1.68	97.11	1.45	87.19	1.5	95.70	1.54	97.33	1.57	91.17
	0.15	1.5	84.42	1.69	93.53	1.53	88.46	1.54	94.50	1.58	94.52	1.71	92.93
	0.2	1.42	71.27	1.55	92.28	1.54	85.63	1.6	94.23	1.62	93.33	1.73	92.21
8	0.05	1.38	100.00	1.55	100.00	1.44	100.00	1.46	96.41	1.58	100.00	1.53	96.13
	0.1	1.36	100.00	1.54	100.00	1.48	100.00	1.5	95.90	2.11	100.00	1.55	95.34
	0.15	1.43	100.00	1.45	100.00	1.51	100.00	1.36	96.34	2.21	100.00	1.58	96.87
	0.2	1.46	100.00	1.5	100.00	1.56	100.00	1.4	96.11	2.57	100.00	1.6	95.68

Fig – 2: Comparision of Total solids residue from Test Coagulants

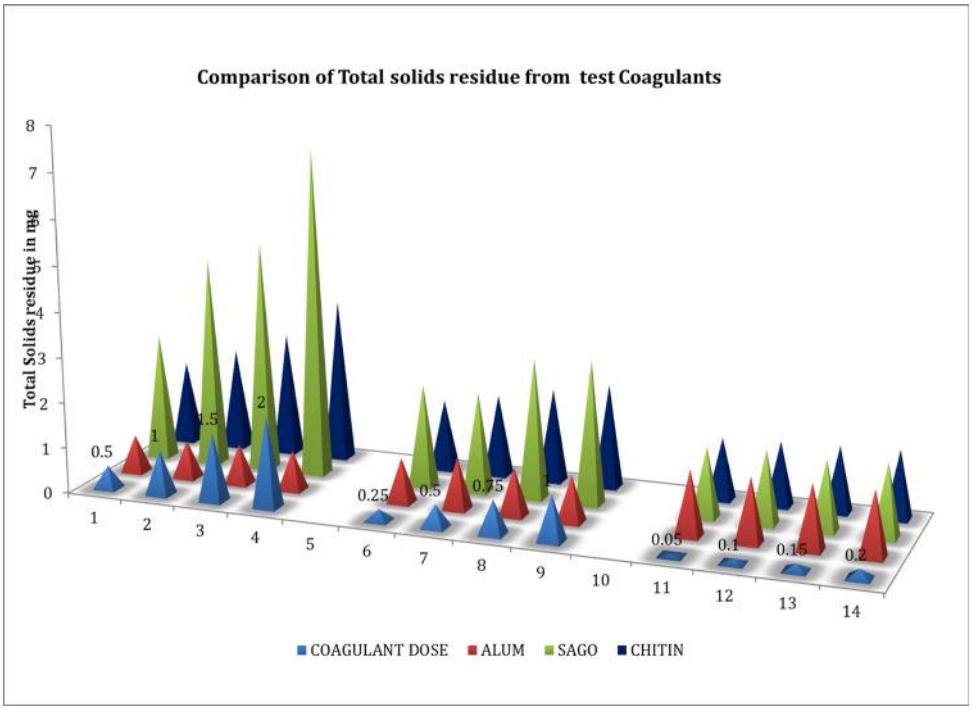


Fig – 3: Comparision of Concentration of suspended solids in the settled sludge with 70 and 150 initial turbidities

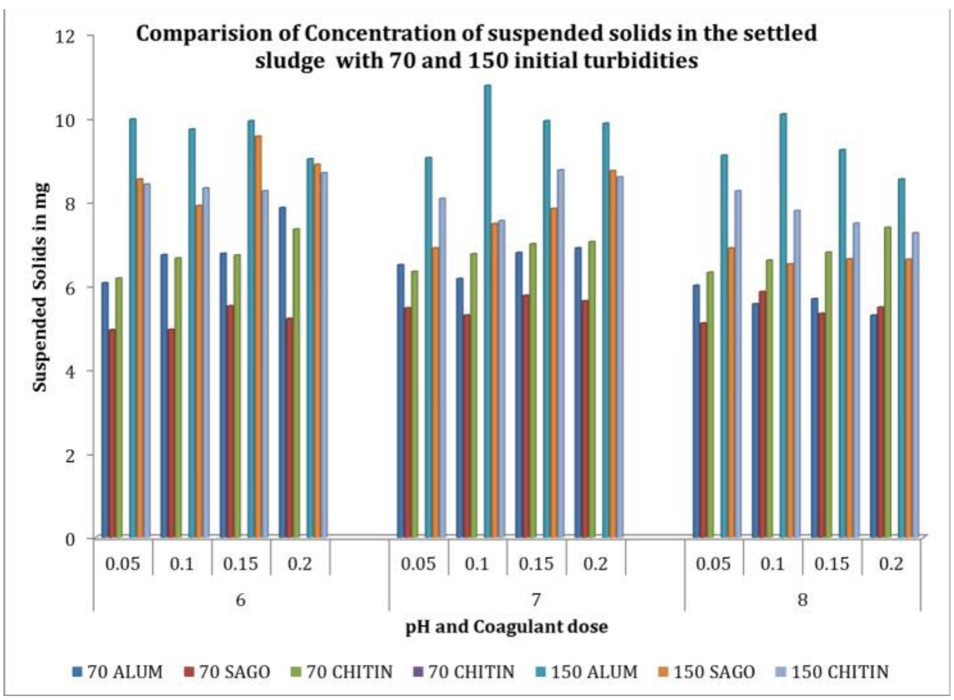


Fig – 4: Comparision of Total solids residue with 70 and 150 initial turbidities

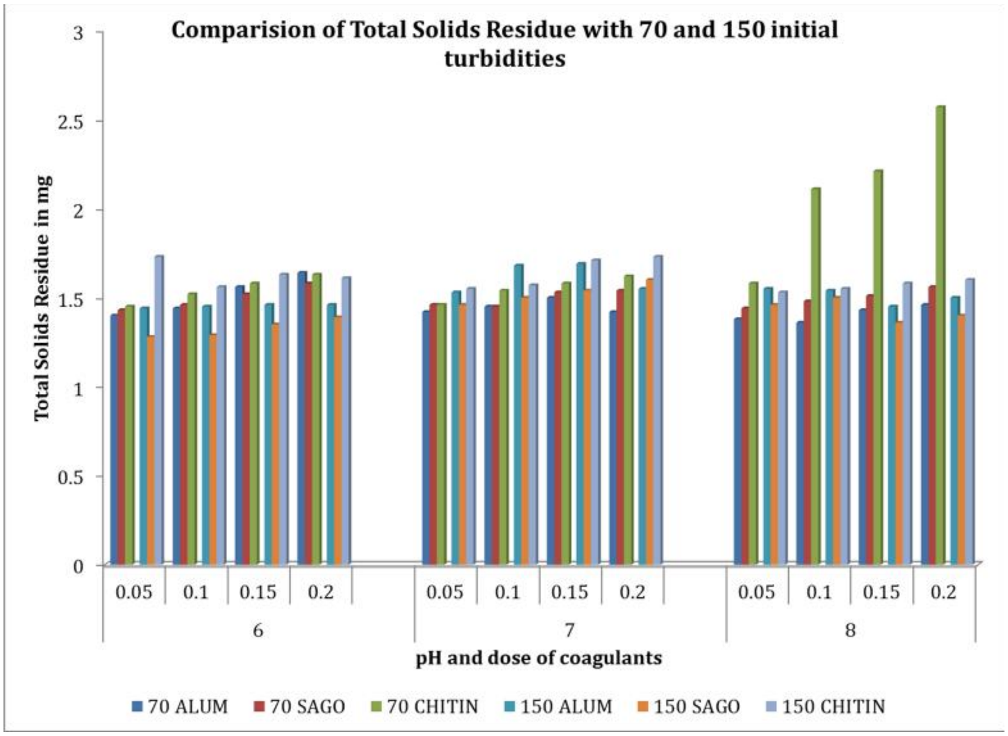


Fig – 5: Reduction in turbidity with 70 initial turbidity

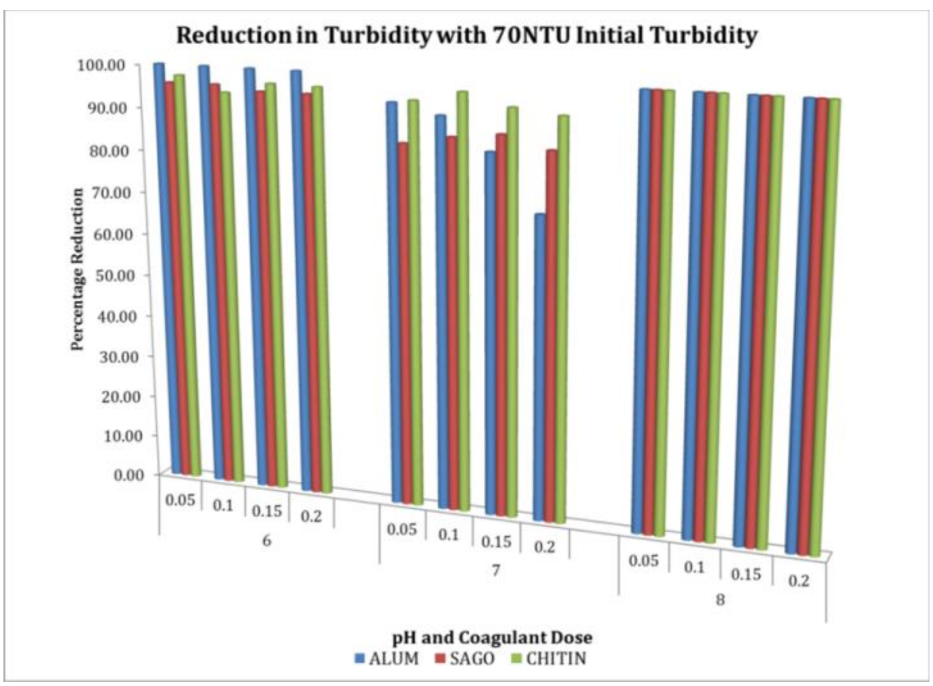
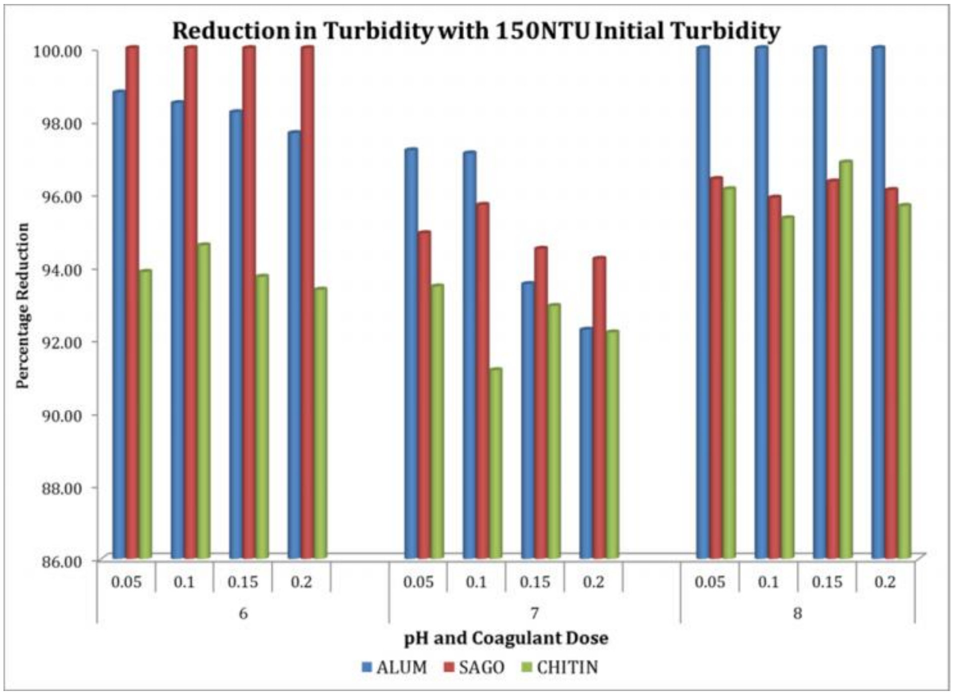


Fig – 6: Reduction in turbidity with 150 initial turbidity



70 NTU initial turbidities respectively. Their independent Total solids residue are 1.46 and 1.44 with turbidity reduction of 100%.

Chitin: 8.25mg and 6.31mg were the maximum and minimum concentration of suspended solids in the settled sludge at 0.05g of coagulant dose with 150 and 70NTU initial turbidity. The associated Total solids residue values are 1.53mg and 1.58mg with turbidity reductions of 96.13 and 100%.

The turbidity reduction was observed to be maximum at pH 8 followed by pH 6. The reduction in turbidity decreased with increasing initial turbidity, i.e turbidity removal was peak 70NTU. On the other hand sago and chitin were equally efficient even at 150NTU reporting turbidity reductions in a range of 95.34 to 96.41%.

Discussion

Rapid industrial developments coupled with surging population growth have complicated issues dealing with water scarcity as the quest for clean and sanitized water intensifies globally. Existing fresh water supplies could be contaminated with organic,

Sago

inorganic and biological matters that have potential harm to the society [4].Suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms are responsible for turbid water. Natural macromolecular coagulants show bright future and are concerned by many researchers because of their abundant source, low price, innocuity, multifunction and biodegradation.

Extended usage of chemical coagulants have disadvantages such as large dosage, low effect, high costs and toxicity [26, 27 & 28]. Due to these reasons, search for a more economical, environmentally safe and natural polymer that may be feasible in treating water has always been focused. Many researchers have previously worked on various natural coagulants which were of both plant and animal origin. In the present study we have concentrated on one plant and one animal based coagulant that is sago, which is very widely available plant source and chitin, which is extracted from exoskeleton of crustaceans. Since the study area is a coastal zone, we found chitin to be both indigenous in origin and adequate in availability.

In the entire study sago has competed intensely with alum in proving its efficiency for removal of turbidity besides generating lesser sludge. Sago has been used in the form of starch. Starches are generally available in almost every continent in the world. Starch is a natural polymer that is categorized as a polyelectrolyte and can be used as a coagulant [29]. While sago has efficiently reduced the turbidity in the present test water, literature has shown that starch is also efficient in treating wastewater to reduce COD and total suspended solids [30].

Study done by Mohd Omar Fatehah [30] on the sludge analysis of coagulation with tapioca starch has shown that the surface structure of tapioca flour is spherical and truncated in shape contrast spots were identified, which proved the presence of elements in the tapioca starch coagulant [30].

Omar et.al., 2008 in their study reported that the natural coagulant sago flour employed in their study have similar characteristics with the commercial coagulants like PAC and alum on removing silica content from the semiconductor wastewater. The mechanism of removing silica content from the wastewater is the polymer characteristic contained in the starch that traps the silica particles in the wastewater, causing them to be unstable and form large aggregates. From the SEM images, they found that the nanosize silica was adsorbed to the starch particles [30].

Starch resources are rich, and the modified starch has better adsorption performance, so it has wide application prospects in water treatment field [31].

Chitin

Chitin is a very good adsorbent since it hold many desired properties for sorbent materials such as biodegradable and cost effective [32, 33].At present, the application of chitin and chitosan in water treatment focuses mainly in coagulation-flocculation processes to remove organic residues, suspended solids, amino acids and dyes [34].

The high nitrogen and hydroxy content of chitin make up a large number of active sites that are subjected to different chemical interactions in water solutions. The free amino group ($-NH_2$) in chitosan exists in equilibrium with the protonated amino group in acidic aqueous solution. Chitosan with positive charge shows greater tendency to adsorb anions. Gao et al. reported that chitosan adsorbed anionic species quantitatively as oxoanions or chloro complex anions of metals in sample solution by an ion-exchange mechanism [33].

Effect of pH on the efficiency of Coagulants

Highest removal efficiency is observed at pH 6 and 8. At low pH chitin undergoes degradation to smaller chains and become soluble in aqueous solution. At pH >8, poor removal efficiencies are observed. At higher pH, the net surface charge on the adsorbent becomes less positive. At pH >pHzpc, the net surface charge becomes negative, resulting in repulsive forces between adsorbent and anionic adsorbate [33].

Yin [35] summarized studies on natural coagulants for treatment of water with low-to-medium range turbidity. Such studies imply application of these coagulants as a simplistic Point of Use (POU) technology meant for treatment of turbid surface waters with approximate values ranging from 50 to 500 NTU. All the natural coagulants exhibit highly effectual turbidity removal capabilities, with some of them removing up to 99% of initial turbidity. Such efficiencies are certainly comparable to the established chemical coagulants (e.g. alum). Optimum dosages are generally within the range from 10 to 60 mg/L. Natural coagulants are most effective at basic waters as evident by the optimum pH values from 7 to 10.

With aluminiumsulphate pH adjustment is often needed at two points in the treatment process. pH correction may be necessary at the heads of works for optimum floc formation and subsequent pH adjustment after filtration is required for reduction of corrosion potential in the water. This is not the case with polymeric coagulants which are generally not sensitive to pH within a fairly wide range of application. The fact that coagulants do not significantly affect the pH of the water is also beneficial as variation in dosage of the polymeric coagulants has virtually no effect on the pH of the treated water [36].

Sludge

From the study it has been seen that the concentration of suspended solids in the settled sludge from natural coagulants is lesser than alum whereas the Total solids residue values were high. The reason for this can be attributed to the fact that inorganic coagulants because of their larger dosages tend to produce larger quantities of sludge than polymeric coagulants which tend to be used at dosages of as little as one tenth of that of the inorganic coagulant. The amount of sludge produced through addition of coagulant is therefore significantly less when using a polymeric coagulant and this reflects in lower sludge production [36].

The results from the study depicted increase in the concentration of suspended solids total solids residue with increase in pH and coagulant dose. The effects of coagulation mechanism (as influenced by coagulant dosage, influent turbidity and coagulation pH) on the thickening and dewatering characteristics of aluminum and ferric hydroxide sludgesas studied byWilliam et.al., 1987 have shown that sludge thickening and dewatering improved with a reduction in coagulation pH or coagulant dosage or with an increase in influent turbidity. Enmeshment coagulation produced a large floc with high water content, resulting in poor water removal during dewatering. Adsorption-charge neutralization coagulation yielded a smaller but much denser floc, which corresponded to greater water removal from the sludge [37] (William et.al., 1987).

Experimental results show that raw water natural organic matter (NOM), coagulant dose and coagulation pH affected both the rate and potential extent of dewatering. Similar effects were observed for both aluminium sulfate and ferric chloride. These results suggest that increasing dose or pH leads to an increase in the proportion of rapidly precipitated material in the sludge or flocs, which form looser aggregates and hence exhibit inferior dewatering properties [38].

Pramod Kumar et.al [39] revealed less sludge production in the case of natural coagulants (agro based material) as a coagulant aid compared to alum alone. Their observation was in agreement with the reported literature, that when synthetic polyelectrolytes are used as coagulant aid or alum sludge conditioning agents, they produced quite less sludge [40, 41].

The natural coagulants resulted lower turbidity after coagulation competing with alum and even better than alum. A lower turbidity of finished water indicates better removal of organic and inorganic contaminants. Many contaminants, such as viruses, heavy metals or some pesticides, may be associated with particulate, and thus efficient removal of particulates can improve the overall water quality [42]. Earlier studies have emphasized that at such low finished water turbidity (0–0.1 NTU) the bacterial removal efficiency would also be high [39].Metal hydroxide sludges from aluminiumsulphate or ferric salts tend to be hydrated and difficult to dewater. This is not the case with sludges from polymeric coagulants which dewater readily producing sludge with higher solids content. The sludges also display improved characteristics with regards to handling [36].

Research indicates that Plant coagulants even showed a better coagulation effect than synthetic coagulant counterpart e.g Alum [43, 44].Natural coagulants produce less sludge volume compared with Alum [45, 46] and they require no pH adjustment [45]. They are of great interest for low cost water treatment and help to provide pure water for world population especially for developing countries who hardly get pure water [47].

Conclusion

Rapid industrial developments coupled with surging population growth have complicated issues dealing with water scarcity as the quest for clean and sanitized water intensifies globally. Existing fresh water supplies could be contaminated with organic, inorganic and biological matters that have potential harm to the society [4].Suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms are responsible for turbid water. Natural macromolecular coagulants show bright future and are concerned by many researchers because of their abundant source, low price, innocuity, multifunction and biodegradation.

Extended usage of chemical coagulants have disadvantages such as large dosage, low effect, high costs and toxicity [26, 27 & 28]. Due to these reasons, search for a more economical, environmentally safe and natural polymer that may be feasible in treating water has always been focused. Many researchers have previously worked on various natural coagulants which were of both plant and animal origin. In the present study we have concentrated on one plant and one animal based coagulant that is sago, which is very widely available plant source and chitin, which is extracted from exoskeleton of crustaceans. Since the study area is a coastal zone, we found chitin to be both indigenous in origin and adequate in availability.

Sago

In the entire study sago has competed intensely with alum in proving its efficiency for removal of turbidity besides generating lesser sludge. Sago has been used in the form of starch. Starches are generally available in almost every continent in the world. Starch is a natural polymer that is categorized as a polyelectrolyte and can be used as a coagulant [29]. While sago has efficiently reduced the turbidity in the present test water, literature has shown that starch is also efficient in treating wastewater to reduce COD and total suspended solids [30].

Study done by Mohd Omar Fatehah [30] on the sludge analysis of coagulation with tapioca starch has shown that the surface structure of tapioca flour is spherical and truncated in shape contrast spots were identified, which proved the presence of elements in the tapioca starch coagulant [30].

Omar et.al., 2008 in their study reported that the natural coagulant sago flour employed in their study have similar characteristics with the commercial coagulants like PAC and alum on removing silica content from the semiconductor wastewater. The mechanism of removing silica content from the wastewater is the polymer characteristic contained in the starch that traps the silica particles in the wastewater, causing them to be unstable and form large aggregates. From the SEM images, they found that the nanosize silica was adsorbed to the starch particles [30].

Starch resources are rich, and the modified starch has better adsorption performance, so it has wide application prospects in water treatment field [31].

Chitin

Chitin is a very good adsorbent since it hold many desired properties for sorbent materials such as biodegradable and cost effective [32, 33].At present, the application of chitin and chitosan in water treatment focuses mainly in coagulation-flocculation processes to remove organic residues, suspended solids, amino acids and dyes [34].

The high nitrogen and hydroxy content of chitin make up a large number of active sites that are subjected to different chemical interactions in water solutions. The free amino group ($-NH_2$) in chitosan exists in equilibrium with the protonated amino group in acidic aqueous solution. Chitosan with positive charge shows greater tendency to adsorb anions. Gao et al. reported that chitosan adsorbed anionic species quantitatively as oxoanions or chloro complex anions of metals in sample solution by an ion-exchange mechanism [33].

Effect of pH on the efficiency of Coagulants

Highest removal efficiency is observed at pH 6 and 8. At low pH chitin undergoes degradation to smaller chains and become soluble in aqueous solution. At pH >8, poor removal efficiencies are observed. At higher pH, the net surface charge on the adsorbent becomes less positive. At pH >pHzpc, the net surface charge becomes negative, resulting in repulsive forces between adsorbent and anionic adsorbate [33].

Yin [35] summarized studies on natural coagulants for treatment of water with low-to-medium range turbidity. Such studies imply application of these coagulants as a simplistic Point of Use (POU) technology meant for treatment of turbid surface waters with approximate values ranging from 50 to 500 NTU. All the natural coagulants exhibit highly effectual turbidity removal capabilities, with some of them removing up to 99% of initial turbidity. Such efficiencies are certainly comparable to the established chemical coagulants (e.g. alum). Optimum dosages are generally within the range from 10 to 60 mg/L. Natural coagulants are most effective at basic waters as evident by the optimum pH values from 7 to 10.

With aluminiumsulphate pH adjustment is often needed at two points in the treatment process. pH correction may be necessary at the heads of works for optimum floc formation and subsequent pH adjustment after filtration is required for reduction of corrosion potential in the water. This is not the case with polymeric coagulants which are generally not sensitive to pH within a fairly wide range of application. The fact that coagulants do not significantly affect the pH of the water is also beneficial as variation in dosage of the polymeric coagulants has virtually no effect on the pH of the treated water [36].

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