Competence of blended coagulants for surface water treatment

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Abstract

Owing to the advantages of the natural coagulants under study, the present objective is to study the efficiency of blended coagulants: alum and chitin; alum and sago; and alum + chitin + sago. In this attempt, we have reduced the quantity of alum dose and added increasing quantities of the natural coagulants. The surface water samples collected from nearby sources were analyzed for the following parameters pre- and post-treatment with the coagulants. Coagulation and flocculation experiments were carried out using conventional jar test apparatus. Turbidity removal was observed to be nearly 99.29% at all pH ranges and doses. Removal of conductivity, solids and hardness was 58.83%, 32.03% and 33.33%, respectively. From the results obtained, it can be observed that the efficiency of blended coagulants in removal of various physicochemical parameters from the waters was better when compared to individual coagulants. The floc size in blend coagulants was larger than that of single coagulants. The data obtained in this study indicated the coagulation efficiency could be enhanced by using the blend coagulant.

Keywords Dissolved organic carbon (DOC) · Turbidity · Blended coagulant · Dose

Introduction

It has been understood that the efficiency of coagulation is influenced by certain factors, such as pH, temperature, alkalinity, coagulant type and mixing intensity (Camp and Root 1940; Kawamura 1976; Morris and Knocke 1984; Mhaisalkar et al. 1991; Muyibi and Evison 1995; Rossini et al. 1999). Many researchers have recommended a pH adjustment method to enhance the coagulation efficiency (Semmens and Field 1980; Gregor et al. 1997; Myung et al. 2001). Temperature is also a critical factor in the removal of turbidity (Myung et al. 2001; Vara 2012). Dharmappa et al. 1993 focused on rapid mix parameters as a critical parameter for optimizing the coagulation process. Specific values were suggested for the optimal detention time and intensity of rapid mix by Mhaisalkar et al. 1991. Sludge dewater ability is known as one economic factor in water treatment that affects the condition of pH, temperature, viscosity and so on.

Preceding two objectives have studied some of the said governing factors and optimized them. From the second objective, it is observed that the natural coagulants, though efficient in removing various physicochemical parameters, are leaving dissolved organic content in water, which was analyzed using total organic carbon. The advantages of natural coagulants over alum can be described as being renewable, contributing to a sustainable and economical water treatment. These coagulants decrease the volume of sludge and do not alter the pH of the water under treatment, comparatively to conventional products based on metallic salts, and also application on a large pH range (6 to 8), without much alteration of the effluents pH.

Coagulation for removal of DOC and turbidity has been reported to be improved when the coagulant is made with a one-to-one blend, for example, alum and ferric chloride compared to a single coagulant. Morris and Knocke reported that ferric chloride was less influenced at a low temperature compared with alum, and they suggest the combination of alum and ferric chloride as a potential method (Morris and Knocke 1984). Recent studies have tested blending alum with natural coagulants in order to reduce the sludge originating from alum and at the same time to reduce the dissolved organic matter caused due to natural coagulants

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(Halkude and Pise 2013; Saritha et al. 2019; Dwarapureddi et al. 2018).

Owing to the advantages of the natural coagulants under study, observed from the above two objectives and previous studies, the present objective is to study the efficiency of blended coagulants: alum and chitin; alum and sago; and alum + chitin + sago. In this attempt, we have reduced the quantity of alum dose and added increasing quantities of the natural coagulants.

Methodology

Preparation of blended coagulants

Natural coagulants were blended with alum to obtain four ratios, keeping alum concentration standard and increasing the concentrations of the natural coagulants:

Alum + chitin—1:1; 1:2; 1:3 and 1:4

Alum + sago—1:1; 1:2; 1:3 and 1:4

Alum + chitin + sago—1:1; 1:2; 1:3 and 1:4

Each ratio is again tested in four concentrations, i.e., 0.2, 0.4, 0.6 and 0.8 mg/l, which are coded with reference to the pH range as follows:

Preparation of synthetic turbid water samples

The turbidity of raw surface water usually varies from 10 to 500 NTU for maximum duration of the year. Hence in the present study, two different turbidities 70 and 150 NTU were selected which come under moderate turbidity values. Synthetic turbid water samples were prepared by mixing 5gm of bentonite clay into 500 ml distilled water (Fig. 1). This mixed sample was allowed to soak for 24 h after which the suspension was stirred to achieve uniform and homogeneous

sample. Turbidity of the supernatant was determined, and portions of suspension were diluted to desired turbidity values (Gidde et al. 2008).

Collection of surface water samples

In the second stage of the experiment, coagulants were evaluated for their efficiency on turbidity removal from the surface water. The water samples were collected from a lake near Pothinamallayyapalem, located at a distance of 5 km from the Environmental Monitoring Laboratory, GITAM University, where the experiments were carried out. This particular water body serves as a source of domestic water for the residents nearby. Care was taken while collecting the samples so that a representative sample is obtained. All samples were collected in sterile plastic containers.

The samples were transported to the laboratory, and all the experiments were conducted within duration of 24 h. The physical parameters like temperature and color were noted at the point of sample collection. The water samples were analyzed for the following parameters pre- and post-treatment with the coagulants (Table 1). The coagulants were tested at various concentrations like 0.1, 0.2, 0.3 and 0.4 mg/l at three pH ranges of 6, 7 and 8.

Experimental procedure

Coagulation and flocculation experiments were carried out using conventional jar test apparatus. Two-liter beakers were used with one liter water samples (synthetic and surface) along with coagulant doses of 0.1, 0.2, 0.3 and 0.4 mg/l. Mixing speed and time which is a governing factor for the process has been optimized in the previous studies to 100 rpm for 1 min and then reduced to 20 rpm for 30 min. Experiments were carried out at three pH ranges generally existing in the surface water, i.e., 6, 7 and 8. pH was adjusted using 0.1 M H_2SO_4 and 0.1 M NaOH for synthetic waters. Twenty min was given for sedimentation, after which an aliquot of 10 ml was taken from the mid-depth of the beaker and residual turbidity was determined. Turbidity measurements were conducted

Fig. 1 Flowchart of the methodology adopted for blended coagulants

Table 1 Codes and their respective denotes

Code	Definition	Code	Definition	Code	Definition
6a	6 pH—0.1 dose	7a	7 pH—0.1 dose	8a	8 pH—0.1 dose
6b	6 pH—0.2 dose	7b	7 pH—0.2 dose	8b	8 pH—0.2 dose
6c	6 pH—0.3 dose	7c	7 pH—0.3 dose	8c	8 pH—0.3 dose
6d	6 pH—0.4 dose	7d	7 pH—0.4 dose	8d	8 pH—0.4 dose

using nephelometric turbidimeter (ELICO, CL52D). The pH values of samples were measured using pH meter (ELICO, L1 126).

Results

Alum + Chitin (1:1 ratio)

Table 2 presents the results obtained from treatment of water with blended coagulant (alum + chitin) with ratio 1:1. Turbidity removal was observed to be highest with 99.29% at 6 pH and 0.15 mg/l dose. Conductivity removal was stable with 58.83% at most of the pH and doses. Total solids reduction was observed to be 32.03% at 6 pH and 0.15 mg/l dose. Removal of magnesium hardness was stable with 33.33%, in similar lines with alkalinity 42.86%. Chloride concentration has enhanced with – 52.64%.

Table 2 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + chitin—1:1 ratio)

Code	Conductivity	Turbidity	TDS	TH	MH	Alkalinity	Chlorides
6a	58.83	88.65	11.63	– 20.83	33.33	42.86	– 52.64
6b	58.83	90.07	13.05	– 20.83	33.33	42.86	– 52.64
6c	58.83	99.29	32.03	– 20.83	33.33	42.86	– 52.64
6d	58.83	98.94	25.34	– 20.83	33.33	42.86	– 52.64
7a	56.00	95.04	8.26	– 20.83	33.33	42.86	– 52.64
7b	56.94	91.84	7.87	– 20.83	33.33	42.86	– 52.64
7c	57.89	91.49	7.68	– 20.83	33.33	42.86	– 52.64
7d	56.00	98.23	8.26	– 20.83	33.33	42.86	– 52.64
8a	58.83	90.07	– 1.41	– 20.83	33.33	42.86	– 52.64
8b	58.83	88.65	0.23	– 20.83	33.33	42.86	– 52.64
8c	58.83	96.45	2.04	– 20.83	33.33	42.86	– 52.64
8d	58.83	88.65	3.13	– 20.83	33.33	42.86	– 52.64

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

Table 3 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + chitin—1:2 ratio)

Code	Conductivity	Turbidity	TDS	Hardness	MH	Alkalinity	Chlorides
6a	34.30	91.13	– 12.45	– 20.83	33.33	42.86	– 10.53
6b	31.47	100.00	– 10.24	– 20.83	33.33	42.86	– 10.53
6c	35.25	99.29	– 11.30	– 20.83	33.33	42.86	– 10.53
6d	35.25	100.00	– 12.07	– 20.83	33.33	42.86	– 10.53
7a	33.36	100.00	– 10.38	– 20.83	33.33	42.86	– 10.53
7b	42.79	100.00	– 23.19	– 20.83	33.33	42.86	– 10.53
7c	41.85	98.58	– 21.75	– 20.83	33.33	42.86	– 10.53
7d	39.02	90.07	– 18.86	– 20.83	33.33	42.86	– 10.53
8a	55.06	100.00	– 33.72	– 20.83	33.33	42.86	– 10.53
8b	53.17	97.16	– 33.87	– 20.83	33.33	42.86	– 10.53
8c	53.17	90.07	– 34.84	– 20.83	33.33	42.86	– 10.53
8d	54.11	94.33	– 33.78	– 20.83	33.33	42.86	– 10.53

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

Alum + Chitin (1:2 ratio)

Table 3 presents the results obtained from treatment of water with blended coagulant (alum + chitin) with ratio 1:2. Turbidity removal was observed to be highest with 100% at most of the pH ranges and doses of coagulants. Conductivity removal was observed to be highest with 54.11% at 8 pH. Total dissolved solids concentration has increased. Removal of magnesium hardness was stable with 33.33%, in similar lines with alkalinity 42.86%. Chloride concentration has enhanced with – 10.53%.

Alum + Chitin (1:3 ratio)

Table 4 presents the results obtained from treatment of water with blended coagulant (alum + chitin) with ratio 1:3. Turbidity removal was observed to be highest with 98.94% at 6 pH and 0.15 and 0.20 mg/l doses of coagulants. Conductivity removal was observed to be highest with 53.17% at 8 pH

Table 4 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + chitin—1:3 ratio)

Code	Conductivity	Turbidity	TDS	TH	MH	Alkalinity	Chlorides
6a	51.28	95.04	4.49	−20.83	0.00	42.86	−10.53
6b	45.62	93.62	4.22	−20.83	0.00	42.86	−10.53
6c	45.62	98.94	3.45	−20.83	0.00	42.86	−10.53
6d	45.62	98.58	3.79	−20.83	0.00	42.86	−10.53
7a	48.45	94.68	4.66	−20.83	0.00	42.86	−10.53
7b	51.28	94.68	3.83	−20.83	0.00	42.86	−10.53
7c	48.45	96.45	4.26	−20.83	0.00	42.86	−10.53
7d	50.34	94.68	4.66	−20.83	0.00	42.86	−10.53
8a	53.17	94.68	0.00	−20.83	0.00	42.86	−10.53
8b	52.23	95.04	1.84	−20.83	0.00	42.86	−10.53
8c	49.40	94.68	2.26	−20.83	0.00	42.86	−10.53
8d	47.51	95.04	2.24	−20.83	0.00	42.86	−10.53

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

and 0.05 mg/l dose. Total dissolved solids reduction was very less ranging from 0 to 4.49%. Total hardness concentration has increased and so is the concentration of chlorides. Alkalinity reduction was 42.86%.

Alum + Chitin (1:4 ratio)

Table 5 presents the results obtained from treatment of water with blended coagulant (alum + chitin) with ratio 1:4. Turbidity removal was observed to be highest with 99.24% at 8 pH and 0.1 mg/l dose of coagulant. Conductivity removal was observed to be within the range of 47.51–51.28%. Total dissolved solids reduction was very less ranging from 0 to 4.49%. Total hardness concentration has increased and so is the concentration of chlorides and alkalinity.

Figure 2 demonstrates the sludge obtained from the treatment, and it is observed that the sludge concentration was directly proportional to the dose of the coagulant and increase in pH.

Table 5 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + chitin—1:4 ratio)

Code	Conductivity	Turbidity	TDS	TH	MH	Alkalinity	Chlorides
6a	51.28	95.39	4.49	−20.83	0.00	−28.57	−10.53
6b	51.28	93.62	4.22	−20.83	0.00	−28.57	−10.53
6c	50.34	95.39	3.45	−20.83	0.00	−28.57	−10.53
6d	51.28	95.39	3.79	−20.83	0.00	−28.57	−10.53
7a	51.28	95.39	4.66	−20.83	0.00	−28.57	−10.53
7b	50.34	93.62	3.83	−20.83	0.00	−28.57	−10.53
7c	50.34	93.62	4.26	−20.83	0.00	−28.57	−10.53
7d	51.28	95.39	4.66	−20.83	0.00	−28.57	−10.53
8a	49.40	93.97	0.00	−20.83	0.00	−28.57	−10.53
8b	52.23	99.29	1.84	−20.83	0.00	−28.57	−10.53
8c	51.28	97.16	2.26	−20.83	0.00	−28.57	−10.53
8d	47.51	98.94	2.24	−20.83	0.00	−28.57	−10.53

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

Alum + Sago (1:1 ratio)

Table 6 presents the results obtained from treatment of water with blended coagulant (alum + sago) with ratio 1:1. Turbidity removal was observed to be in the range of 98.58 to 99.24%. Conductivity removal was observed to be highest of 50.34% at pH 8 and 0.15 mg/l dose. Total dissolved solids reduction was highest with 43.40% at 6 pH and 0.20 mg/l dose. Total hardness concentration has increased and so is the concentration of calcium hardness and chlorides. Alkalinity reduction was stable with 42.86%.

Alum + Sago (1:2 ratio)

Table 7 presents the results obtained from treatment of water with blended coagulant (alum + sago) with ratio 1:2. Turbidity removal was observed in the range of 94.68 to 97.87%. Conductivity removal was observed in the range of 45.62 to 49.40%. Total dissolved solids reduction was very less with

Fig. 2 Sludge weight (mg/l) obtained from water treated with blended coagulant (alum + chitin)

Table 6 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + sago—1:1 ratio)

Code	Conductivity	Turbidity	Total solids	TDS	TH	CH	MH	Alkalinity	Chlorides
6a	28.64	98.58	60.00	31.60	−20.83	−55.56	0.00	42.86	−52.64
6b	14.49	98.58	50.00	42.27	−20.83	−55.56	0.00	42.86	−52.64
6c	26.75	98.58	50.00	31.49	−20.83	−55.56	0.00	42.86	−52.64
6d	13.55	98.58	50.00	43.40	−20.83	−55.56	0.00	42.86	−52.64
7a	45.62	98.58	30.00	6.88	−20.83	−55.56	0.00	42.86	−52.64
7b	44.68	98.58	10.00	9.60	−20.83	−55.56	0.00	42.86	−52.64
7c	41.85	98.58	20.00	11.45	−20.83	−55.56	0.00	42.86	−52.64
7d	49.40	98.58	−10.00	14.76	−20.83	−55.56	0.00	42.86	−52.64
8a	49.40	99.29	50.00	−1.17	−20.83	−55.56	0.00	42.86	−52.64
8b	50.34	99.29	40.00	0.00	−20.83	−55.56	0.00	42.86	−52.64
8c	39.96	99.29	40.00	1.14	−20.83	−55.56	0.00	42.86	−52.64
8d	47.51	99.29	70.00	2.26	−20.83	−55.56	0.00	42.86	−52.64

TDS total dissolved solids, TH total hardness, MH magnesium hardness

highest reduction of 4.34% at 8 pH and 0.15 mg/l dose. Total hardness concentration has increased and so is the concentration of calcium hardness and chlorides. Alkalinity reduction was stable with 42.86%.

Alum + Sago (1:3 ratio)

Table 8 presents the results obtained from treatment of water with blended coagulant (alum + sago) with ratio 1:3. Turbidity removal was observed in the range of 89.01 to 100%. Conductivity removal was observed to be less at pH 6 in the range of 13.55 to 17.32% which increased with increased dose of the coagulant. Highest conductivity reduction was

observed with 0.15 mg/l at pH 8. Total solids reduction was observed to be 90% at pH 7 and 0.20 mg/l dose. Total dissolved solids reduction was highest with 41.46% at 6 pH 0.15 mg/l. Total hardness concentration has increased and so is the concentration of calcium hardness and chlorides. Alkalinity reduction was stable with 42.86%.

Alum + Sago (1:4 ratio)

Table 9 presents the results obtained from treatment of water with blended coagulant (alum + sago) with ratio 1:4. Turbidity removal was observed in the range of 90.07 to 96.45%. Conductivity removal was stable with 46.57%.

Table 7 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + sago—1:2 ratio)

Code	Conductivity	Turbidity	Total solids	TDS	TH	CH	MH	Alkalinity	Chlorides
6a	48.45	95.74	80.00	3.63	−20.83	−55.56	0.00	42.86	−26.33
6b	47.51	96.45	40.00	3.33	−20.83	−55.56	0.00	42.86	−26.33
6c	48.45	96.45	40.00	4.27	−20.83	−55.56	0.00	42.86	−26.33
6d	47.51	95.74	40.00	4.18	−20.83	−55.56	0.00	42.86	−26.33
7a	48.45	94.68	100.00	1.94	−20.83	−55.56	0.00	42.86	−26.33
7b	49.40	94.33	70.00	2.71	−20.83	−55.56	0.00	42.86	−26.33
7c	48.45	95.04	50.00	3.68	−20.83	−55.56	0.00	42.86	−26.33
7d	49.40	94.68	40.00	2.36	−20.83	−55.56	0.00	42.86	−26.33
8a	45.62	97.16	70.00	3.27	−20.83	−55.56	0.00	42.86	−26.33
8b	47.51	97.52	50.00	2.77	−20.83	−55.56	0.00	42.86	−26.33
8c	47.51	97.87	40.00	4.34	−20.83	−55.56	0.00	42.86	−26.33
8d	48.45	97.16	60.00	4.06	−20.83	−55.56	0.00	42.86	−26.33

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

Table 8 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + sago—1:3 ratio)

Code	Conductivity	Turbidity	Total solids	TDS	TH	CH	MH	Alkalinity	Chlorides
6a	13.55	89.01	40.00	39.65	−20.83	−55.56	0.00	42.86	−26.33
6b	13.55	99.65	40.00	32.40	−20.83	−55.56	0.00	42.86	−26.33
6c	14.49	97.52	40.00	41.46	−20.83	−55.56	0.00	42.86	−26.33
6d	17.32	97.87	20.00	31.37	−20.83	−55.56	0.00	42.86	−26.33
7a	46.57	95.39	60.00	11.61	−20.83	−55.56	0.00	42.86	−26.33
7b	43.74	98.94	−10.00	11.06	−20.83	−55.56	0.00	42.86	−26.33
7c	43.74	98.94	30.00	9.00	−20.83	−55.56	0.00	42.86	−26.33
7d	42.79	100.00	90.00	11.42	−20.83	−55.56	0.00	42.86	−26.33
8a	47.51	96.10	60.00	1.40	−20.83	−55.56	0.00	42.86	−26.33
8b	47.51	98.23	50.00	0.92	−20.83	−55.56	0.00	42.86	−26.33
8c	50.34	99.65	60.00	2.51	−20.83	−55.56	0.00	42.86	−26.33
8d	48.45	98.94	40.00	2.71	−20.83	−55.56	0.00	42.86	−26.33

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

Table 9 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + sago—1:4 ratio)

Code	Conductivity	Turbidity	Total solids	TDS	TH	CH	MH	Alkalinity	Chlorides
6a	46.57	92.55	70.00	31.60	−20.83	−55.56	0.00	42.86	−26.33
6b	46.57	94.68	70.00	42.27	−20.83	−55.56	0.00	42.86	−26.33
6c	46.57	92.91	70.00	31.49	−20.83	−55.56	0.00	42.86	−26.33
6d	46.57	90.07	80.00	43.40	−20.83	−55.56	0.00	42.86	−26.33
7a	46.57	94.33	80.00	6.88	−20.83	−55.56	0.00	42.86	−26.33
7b	46.57	94.33	80.00	9.60	−20.83	−55.56	0.00	42.86	−26.33
7c	46.57	96.45	40.00	11.45	−20.83	−55.56	0.00	42.86	−26.33
7d	46.57	91.84	40.00	14.76	−20.83	−55.56	0.00	42.86	−26.33
8a	46.57	91.13	70.00	−1.17	−20.83	−55.56	0.00	42.86	−26.33
8b	46.57	93.62	50.00	0.00	−20.83	−55.56	0.00	42.86	−26.33
8c	46.57	93.62	60.00	1.14	−20.83	−55.56	0.00	42.86	−26.33
8d	46.57	94.33	60.00	2.26	−20.83	−55.56	0.00	42.86	−26.33

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

Total solids reduction was observed to be minimum of 40% and maximum of 80%. Total dissolved solids reduction was highest with 42.27% at 6 pH and 0.1 mg/l dose. Total hardness concentration has increased and so is the concentration of calcium hardness and chlorides. Alkalinity reduction was stable with 42.86%.

Figure 3 demonstrates the sludge obtained from the treatment, and it is observed that the sludge concentration was inversely proportional to the dose of the coagulant and increase in pH.

Alum + Chitin + Sago (1:1 ratio)

Table 10 presents the results obtained from treatment of water with blended coagulant (alum + chitin + sago) with ratio 1:1. Turbidity removal was observed in the range of 91.49 to 99.29%. Conductivity removal was stable with 48.45%. Total solids reduction was observed to be minimum of 10% and maximum of 80%. Total dissolved solids reduction was highest with 23.09% at 8 pH and 0.2 mg/l dose. Total hardness concentration has increased and so is the concentration of calcium hardness and chlorides. Alkalinity reduction was stable with 42.86%.

Fig. 3 Sludge weight (mg/l) obtained from water treated with blended coagulant (alum + sago)

Table 10 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + chitin + sago—1:1 ratio)

Code	Conductivity	Turbidity	Total solids	TDS	TH	CH	MH	Alkalinity	Chlorides
6a	48.45	95.74	20.00	− 11.89	− 20.83	− 55.56	0.00	42.86	− 26.33
6b	48.45	95.74	30.00	0.23	− 20.83	− 55.56	0.00	42.86	− 26.33
6c	48.45	96.45	10.00	0.69	− 20.83	− 55.56	0.00	42.86	− 26.33
6d	47.51	95.74	70.00	20.55	− 20.83	− 55.56	0.00	42.86	− 26.33
7a	48.45	91.84	70.00	20.26	− 20.83	− 55.56	0.00	42.86	− 26.33
7b	47.51	91.49	60.00	15.43	− 20.83	− 55.56	0.00	42.86	− 26.33
7c	48.45	94.68	− 10.00	21.70	− 20.83	− 55.56	0.00	42.86	− 26.33
7d	47.51	98.94	30.00	22.12	− 20.83	− 55.56	0.00	42.86	− 26.33
8a	44.68	94.33	70.00	1.59	− 20.83	− 55.56	0.00	42.86	− 26.33
8b	43.74	95.74	60.00	23.36	− 20.83	− 55.56	0.00	42.86	− 26.33
8c	44.68	99.29	40.00	22.68	− 20.83	− 55.56	0.00	42.86	− 26.33
8d	43.74	98.58	80.00	23.09	− 20.83	− 55.56	0.00	42.86	− 26.33

TDS total dissolved solids, TH total hardness, MH magnesium hardness

Table 11 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + chitin + sago—1:2 ratio)

Code	Conductivity	Turbidity	Total solids	TDS	TH	CH	MH	Alkalinity	Chlorides
6a	48.45	95.04	20.00	− 11.89	− 20.83	− 55.56	0.00	42.86	− 26.33
6b	48.45	95.74	30.00	0.23	− 20.83	− 55.56	0.00	42.86	− 26.33
6c	47.51	95.74	10.00	0.69	− 20.83	− 55.56	0.00	42.86	− 26.33
6d	47.51	96.45	70.00	20.55	− 20.83	− 55.56	0.00	42.86	− 26.33
7a	48.45	84.75	70.00	20.26	− 20.83	− 55.56	0.00	42.86	− 26.33
7b	47.51	91.13	50.00	15.43	− 20.83	− 55.56	0.00	42.86	− 26.33
7c	48.45	84.04	60.00	21.70	− 20.83	− 55.56	0.00	42.86	− 26.33
7d	47.51	93.62	60.00	22.12	− 20.83	− 55.56	0.00	42.86	− 26.33
8a	39.96	95.04	50.00	1.59	− 20.83	− 55.56	0.00	42.86	− 26.33
8b	40.91	96.10	60.00	23.36	− 20.83	− 55.56	0.00	42.86	− 26.33
8c	44.68	95.04	80.00	22.68	− 20.83	− 55.56	0.00	42.86	− 26.33
8d	43.74	91.13	70.00	23.09	− 20.83	− 55.56	0.00	42.86	− 26.33

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

Alum + Chitin + Sago (1:2 ratio)

Table 11 presents the results obtained from treatment of water with blended coagulant (alum + chitin + sago) with ratio 1:2. Turbidity removal was observed in the range of 84.04 to 96.45%. Conductivity removal was in the range of 39.96 to 48.45%. Total solids reduction was observed to be minimum of 10% and maximum of 80%. Total dissolved solids reduction was highest with 23.86% at 8 pH 0.1 mg/l. Total hardness concentration has increased and so is the concentration of calcium hardness and chlorides. Alkalinity reduction was stable with 42.86%.

Alum + Chitin + Sago (1:3 ratio)

Table 12 presents the results obtained from treatment of water with blended coagulant (alum + chitin + sago) with ratio 1:3. Turbidity removal was observed in the range of 91.49 to 98.58%. Conductivity removal was mostly stable

with 48.45%. Total solids reduction was also mostly stable ranging from 30 to 60% reduction. Total dissolved solids reduction was highest with 23.36% at 8 pH and 0.1 mg/l dose. Total hardness concentration has increased and so is the concentration of calcium hardness and chlorides. Alkalinity reduction was stable with 42.86%.

Alum + Chitin + Sago (1:4 ratio)

Table 13 presents the results obtained from treatment of water with blended coagulant (alum + chitin + sago) with ratio 1:4. Turbidity removal was observed in the range of 89.01 to 96.45%. Conductivity removal was stable with range of 43.74 to 48.45%. Total solids reduction was observed to be minimum of 10% and maximum of 80%. Total dissolved solids reduction was highest with 23.09% at 8 pH 0.2 mg/l. Total hardness concentration has increased and so is the concentration of calcium hardness and chlorides. Alkalinity reduction was stable with 42.86%.

Table 12 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + chitin + sago—1:3 ratio)

Code	Conductivity	Turbidity	Total solids	TDS	TH	CH	MH	Alkalinity	Chlorides
6a	48.45	95.74	50.00	− 11.89	− 20.83	47.78	0.00	42.86	− 26.33
6b	48.45	95.74	60.00	0.23	− 20.83	47.78	0.00	42.86	− 26.33
6c	47.51	96.45	30.00	0.69	− 20.83	47.78	0.00	42.86	− 26.33
6d	47.51	95.74	40.00	20.55	− 20.83	47.78	0.00	42.86	− 26.33
7a	48.45	91.84	50.00	20.26	− 20.83	47.78	0.00	42.86	− 26.33
7b	47.51	91.49	40.00	15.43	− 20.83	47.78	0.00	42.86	− 26.33
7c	48.45	94.68	50.00	21.70	− 20.83	47.78	0.00	42.86	− 26.33
7d	47.51	98.94	30.00	22.12	− 20.83	47.78	0.00	42.86	− 26.33
8a	44.68	94.33	50.00	1.59	− 20.83	47.78	0.00	42.86	− 26.33
8b	43.74	95.74	50.00	23.36	− 20.83	47.78	0.00	42.86	− 26.33
8c	44.68	99.29	50.00	22.68	− 20.83	47.78	0.00	42.86	− 26.33
8d	43.74	98.58	50.00	23.09	− 20.83	47.78	0.00	42.86	− 26.33

TDS total dissolved solids, *TH* total hardness, *MH* magnesium hardness

Table 13 Percentage reduction in various physicochemical parameters of surface water after treatment with blended coagulant (alum + chitin + sago—1:4 ratio)

Code	Conductivity	Turbidity	Total solids	TDS	TH	CH	MH	Alkalinity	Chlorides
6a	48.45	95.74	20.00	−11.89	−20.83	−55.56	0.00	42.86	−26.33
6b	48.45	95.74	30.00	0.23	−20.83	−55.56	0.00	42.86	−26.33
6c	47.51	96.45	10.00	0.69	−20.83	−55.56	0.00	42.86	−26.33
6d	47.51	95.74	70.00	20.55	−20.83	−55.56	0.00	42.86	−26.33
7a	48.45	91.84	70.00	20.26	−20.83	−55.56	0.00	42.86	−26.33
7b	47.51	91.49	60.00	15.43	−20.83	−55.56	0.00	42.86	−26.33
7c	48.45	94.68	40.00	21.70	−20.83	−55.56	0.00	42.86	−26.33
7d	47.51	98.94	30.00	22.12	−20.83	−55.56	0.00	42.86	−26.33
8a	44.68	92.20	70.00	1.59	−20.83	−55.56	0.00	42.86	−26.33
8b	43.74	88.30	60.00	23.36	−20.83	−55.56	0.00	42.86	−26.33
8c	44.68	89.01	40.00	22.68	−20.83	−55.56	0.00	42.86	−26.33
8d	43.74	92.20	80.00	23.09	−20.83	−55.56	0.00	42.86	−26.33

TDS total dissolved solids, TH total hardness, MH magnesium hardness

Fig. 4 Sludge weight (mg/l) obtained from water treated with blended coagulant (alum + chitin + sago)

Figure 4 demonstrates the sludge obtained from the treatment, and it is observed that the sludge concentration was mostly high in 1:3 ratio.

Discussion

From the above results, it can be observed that the efficiency of blended coagulants in removal of various physicochemical parameters from the waters was better when compared to individual coagulants. Parameters like conductivity, hardness and alkalinity which are increased when treated with

individual coagulants have shown removal even at less percentages when treated with blended coagulants.

Conductivity removal which was negative when treated with individual coagulants, except for chitin which has shown up to 35.71% removal, was removed successfully by blended coagulants. All the three types of blended coagulants were successful in removing electrical conductivity. Though alum and chitin combination has shown highest removal with 58.85%, it was only with some precise doses of the blended coagulant, while the combination of alum, chitin and sago was most stable at all pH ranges and coagulant doses with 48.45% removal of electrical conductivity.

The order of removal efficiency of electrical conductivity is alum + chitin > alum + chitin + sago > alum + sago.

The parameters like hardness and chlorides that have increased more than 50% and 99% have shown lesser increase or lower negative reduction. The order of negative removal of hardness (− 20.83%) and chlorides (− 10.53%) is as follows: alum + chitin = alum + chitin + sago = alum + sago and alum + chitin > alum + sago = alum + chitin + sago for hardness and chlorides, respectively.

Turbidity removal was exceptionally virtuous with blended coagulants (between 86 and 99%) when compared to individual coagulants (between 70 and 80%). The removal of total and dissolved solids was negative with individual coagulants, whereas with blended coagulants it was observed to be between 0 and 40%. Alkalinity reduction was very good with individual coagulants, whereas with blended coagulants it was recorded to be 42.86% for all the three blended coagulants.

Effect of dose of coagulant

Overdosing results in the saturation of the polymer bridge sites and causes re-stabilization of the destabilized particles and hence would also disturb particle settling (Muyibi and Evison 1995). This phenomenon happens if the mechanism of turbidity removal is through adsorption and bridging. Overdosing may also lead to charge reversal and subsequent re-stabilization of destabilized particles if the mechanism of turbidity removal is linked with adsorption and charge neutralization. This evidence is different from those reported by Katayon et al. (2006), as they documented that the optimum dosage of *M. oleifera* increased with increasing initial turbidity. This difference might be due to unlike experimental setups, namely, the type of water used. The present study was performed with natural surface water, while the previous one was conducted on synthetic water made up of kaolin. Surface water characteristics, type and size of particles, alkalinity and other process variables may vary from river to river, which clearly affects the performance of coagulants, unlike synthetic water samples.

Plant coagulants were even slightly more efficient than alum as reported from the first two objectives. Such result is possible and in agreement with previous work using extracts of *C. arietinum*, where natural coagulant also outperformed alum (Diaz et al. 1999; Leones and Martinez 2019).

Effect of pH

When dissolved in water, the aluminum ions are hydrolyzed and it lowers the pH by increasing the concentration of H^+ . Most likely, the naturally occurring coagulants from plant materials possess a buffering property. The study conducted by Ndabigengesere et al. (1995) and Marobhe

(2013), Muthuraman and Sasikala (2014) indicated that water treated with *M. oleifera* and *V. unguiculata* did not alter pH of water, whereas pH of a water sample augmented with increasing doses of *M. oleifera* and *J. curcas* (Marobhe 2013). Thus, using plant extracts for water treatment may have an enormous advantage by omitting the need for application of lime or bicarbonate to subsequently raise the pH, and hence, it provides extra cost savings (Pritchard et al. 2009; Choy et al. 2014; Marobhe 2013; Šciban et al. 2009; Kaji et al. 2019). Among the tested blended coagulants, efficiency of removal of physicochemical parameters can be given as alum + chitin + sago > alum + sago > alum + chitin.

It was apparent that the coagulation efficiency was enhanced due to the use of combined coagulants. It should be noted that the optimum dosage of blend coagulants was found to be approximately half that of the single coagulants, which shows additional advantages for using blend coagulants. In other words, it might be possible to reduce the amount of sludge after completing coagulation and sedimentation processes by using the blend coagulants.

Conclusions

Coagulants and polymers are obtained from many natural sources, when applied as coagulants primary or auxiliary coagulation/flocculation present as viable and inexpensive alternatives for the replacement or reduction in the dosage of the coagulant metal employed in the process of treating water, and respective drawbacks are associated with these salts.

This study investigated the advantage of blended coagulants with alum and natural coagulants chitin and sago and attempted to optimize operational conditions for applying it in a coagulation process. To accomplish this goal, we evaluated the variation in physicochemical properties and turbidity to find affecting factors such as ratio of blended coagulants, coagulation pH and dose and compared the coagulation efficiency of single coagulants with that of the combined coagulants. The turbidity removal efficiency in such combined coagulants applied in this study was found to be 90%, higher than that of single coagulants. It appeared the optimum blend ratio was 1:1 and 1:3. The coagulation efficiency in blended coagulants was found to be better than that of single coagulants for all pH conditions. The floc size in blend coagulants was larger than that of single coagulants. The data obtained in this study indicated the coagulation efficiency could be enhanced by using the blend coagulant.

In general, these products have efficiency in removal of turbidity of water, comparable or superior to that achieved by metal coagulants, spending a lower dosage. These products proved not dependent on temperature or pH correction and alkalinity of the water to work efficiently. In terms of

action on the physicochemical characteristics of the clarified water, the natural polymers and coagulants show little variation in pH, alkalinity, conductivity and concentration of cations and anions. Being from natural sources, these compounds can generate value-added products, presenting itself as a new source of income. However, despite all the associated benefits, natural coagulants and polymers should be effectively applied to the process of water clarification in scale only after undergoing tests certifying its non-toxicity, biodegradability and viability.

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