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Coagulation efficiency comparison of natural and its blended coagulant with alum in water treatment

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ABSTRACT

The present study was conducted to identify and examine locally available natural coagulant (*Sorghum bicolor* [NC]) and its blended form with chemical coagulant (alum) to treat turbid water. Blended form of NC was prepared by mixing different proportions of NC and alum. NC, alum and blended coagulant (NC_B) were compared with each other to check maximum turbidity removal efficiencies. At optimum doses and pH, turbidity removal efficiencies by alum, NC and NC_B were 97.9%, 93.2% and 98.96%, respectively. Also statistical analysis was performed for validation of results. Further, NC was characterized by Fourier transformed infrared test that confirmed the presence of protein-specific functional groups (medium, small and broad 1° and 2° amines, medium aliphatic amines and small saturated aliphatic groups) responsible for coagulation activity. Floc sizes were also observed through micro-photographic analyses of NC, alum and NC_B were found out to be 19, 39 and 45 μm, respectively. In water treatment, NC_B proved to be the best coagulant for turbidity removal and the coagulation mechanism observed was charge neutralization in it.

Keywords: Coagulation activity; Coagulation mechanism; Functional groups; Turbidity

1. Introduction

Access to drinking water is a fundamental human need for healthy life [1]. Drinking water is treated to reduce influx of anthropogenic contaminants to satisfy water quality guidelines [2]. On the global scale, contribution of ground water volume is less as compared with surface water but it has exceptional benefits such as approachability, less capital investment and reliability outweighs the volumetric access of surface water. Increasing salt contents and decreasing water tables in the pumped groundwater indicate that more expensive and poor quality groundwater will have to be used for drinking purposes in future [3].

The most commonly used water treatment methods for turbidity removal are coagulation and flocculation [4]. A variety of chemical coagulants such as salts of alum and iron as well as synthetic and natural polymers are used for potable water treatment [5]. Alum-based coagulants are most commonly used for conventional drinking water treatment [6]. It is quite evident from the research that alum-based coagulants may lead to severe health problems including neurological illness and Alzheimer's disease [7]. Moreover, the cost of chemical coagulants is very high and many developing countries cannot afford these coagulants for water treatment [8]. Other problems related to chemical coagulants are production of large volumes of non biodegradable sludge, low efficiency of coagulation at low temperature and reduction in pH [9]. Therefore; the need of hour is to replace these coagulants with natural extracts if available locally. These natural extracts are safe, environmental friendly and produce about five times less sludge than that of chemical coagulants [10].

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Seeds of drum stick tree (*Moringa oleifera*) and Nirmali tree (*Strychnos potatorum*) have been reported as very efficient coagulants for water purification [11,12]. Other plant materials such as wood-apple seeds (*Feronia limonia*) [10], avocado seeds (*Persea americana*) [13], peels of orange (*Citrus sinensis*) [14], cactus (*Opuntia dillenii*) [15] and mustard (*Brassica*) [16] seeds have been identified as potential coagulating agents to treat water. Studies report that high amount of protein content is present in seeds of plants which is mainly responsible for the coagulation mechanism [17,18].

Due to lack of financial resources in developing countries, it is essential to find out cost-effective coagulants. The present study was conducted to identify and examine locally available natural coagulant sorghum (*Sorghum bicolor*) to remove turbidity in water and further it was also compared with its blended form with chemical coagulant (alum) to check maximum turbidity removal efficiency. Objectives of the study were identification of protein-specific functional groups in biocoagulant responsible for coagulation, evaluation of optimum dose and pH of coagulants and its comparison with blended form (*Sorghum bicolor* and alum) and coagulation mechanisms for coagulants were also examined.

All the research was carried out from 10th January 2017 to 7th April 2017 at Department of Environmental Engineering, University of Engineering and Technology (UET), Taxila, Pakistan.

2. Materials and methods

2.1. Selection of natural coagulant

A natural coagulant, *Sorghum bicolor* (NC) was selected for this research, brought from a local market of Sawabi, Khyber Pakhtunkhwa (KPK), Pakistan. The NC was examined through Fourier transform infrared (FTIR) test by JASCO FT/IR-4100 to confirm the presence of protein content mainly responsible for coagulation activity.

2.2. Preparation of coagulant solutions

Seeds of NC were neatly washed with water, oven dried at 65°C for 1 h, grinded to get fine powder and sieved to get particles of size up to 300 micron. Coagulant solution for NC was prepared by adding 1 g coagulant powder into 1 L distilled water and then to extract active coagulating agents, the suspension was stirred for 1 h. Further, coagulant solution was filtered and then coagulant doses were prepared from this filtrate [19]. A stock solution of alum (1,000 mg/L) was prepared and then using this solution, different doses for coagulation were prepared. For each experimental run, fresh coagulant solutions were prepared.

A blended coagulant (NC_B) was prepared by mixing different proportions (75:25, 65:35, 50:50, 35:65, 25:75) of optimum doses of NC and alum, respectively.

2.3. Preparation of synthetic water

Synthetic water was prepared by adding 1 g kaolin powder in 1 L distilled water. To get average initial turbidity (130 ± 10 NTU), this suspension was allowed to settle for 50–60 min. For each experiment, fresh synthetic water samples were prepared [19].

Table 1
Important physical and chemical characteristics of synthetic water sample

Parameter	Value
Turbidity, NTU	130 ± 10
pH	8.5
Alkalinity, mg/L as $CaCO_3$	110

2.4. Experimental

2.4.1. FTIR analysis

FTIR test was performed by JASCO FT/IR-4100 in order to examine protein-specific functional groups responsible for coagulation activity.

2.4.2. Optimization of coagulant dose

Coagulation–flocculation–sedimentation studies were carried out for alum, biocoagulant and its blended form using a jar test apparatus (Phipps and Bird BP-900). Doses of coagulants (alum and NC) were varied from 10 to 70 mg/L. Rapid mixing was done at 100 rpm for 2 min following slow mixing at 30 rpm for 20 min, respectively. Samples were then allowed to settle for a duration of 30 min. To simulate plain sedimentation, no coagulant dose was added in first jar. Supernatant from the jars was taken to analyze turbidity removal. Doses of NC_B at different proportions of alum and NC were prepared to get optimum dose. Table 1 shows initial values of turbidity, pH and alkalinity of supernatant taken.

2.4.3. Optimization of pH

To optimize pH, optimum dose of respective coagulants was added in all jars and pH was varied from 4 to 9. To adjust pH, solutions of 1 N sodium hydroxide (NaOH) and sulphuric acid (H_2SO_4) were used.

2.4.4. Microscopic analysis

To observe floc sizes before and after coagulation, micro-photographic analyses of the suspensions were also conducted using Olympus microscope BX61.

3. Results and discussions

3.1. FTIR analysis

FTIR spectrum of NC is presented in Fig. 1. Nine marked peaks in the figure clearly indicate presence of protein-specific functional groups. The spectrum of NC-3 lies between 575.647 and 3,363.25 cm^{-1}. The peak at 3,363.25 cm^{-1} ensures the presence of medium 1° and 2° amines group whereas peak at 1,020.16 cm^{-1} confirm the presence of medium aliphatic amines group in sample. The peak at 1,649.8 cm^{-1} indicates the presence of medium 1° amines group whereas another peak marked at 1,741.41 cm^{-1} indicates the presence of small

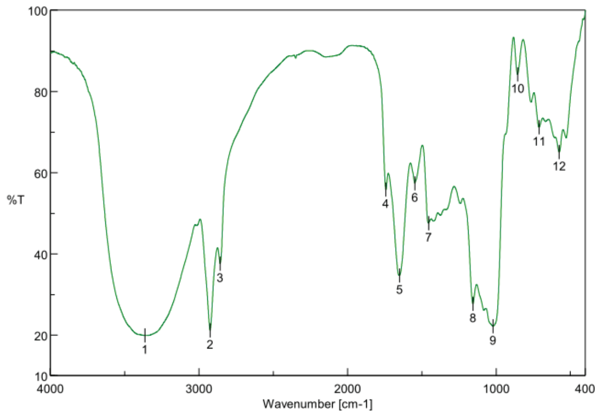

Fig. 1. FTIR spectrum of *Sorghum bicolor* (NC).

saturated aliphatic group. The peak at 855.275 cm^{-1} ensures the presence of small and broad 1° and 2° amines group [20]. So, this analysis confirms the presence of protein content in NC which is responsible for coagulation activity.

3.2. Optimization of parameters for coagulants

The relationship between coagulants (alum and NC) dosage and percentage turbidity removal is shown in Fig. 2. Maximum removal of turbidity (97.1% and 93.2%) from water by alum and NC was observed at a dose of 20 and 60 mg/L, respectively. Further increase in dose of alum decreased the removal efficiency of turbidity and reduced up to 93% at a dose of 70 mg/L while for NC, increase in turbidity removal was observed with the increase in NC dose till 60 mg/L following decrease in turbidity removal. The major reasons behind the reduction in turbidity removal efficiency at higher doses were re-stabilization and over dosing of particles.

After optimization of coagulant doses, pH was also optimized and presented in Fig. 3. For alum, at first removal, efficiency decreased by increasing pH of solution but after pH 5 it started increasing and became maximum (97.9%) at 6.5. After that, turbidity started increasing by increasing pH value. Whereas for NC, by increasing pH levels, turbidity removal efficiency was also improved and reached up to its maximum removal at 8.5 (93.2%). Further increase in pH of NC caused reduction in turbidity removal efficiency. At higher pH levels, the reason behind the reduction in coagulation activity concluded that due to high concentrations of sodium hydroxide, some protein content denatured hence reducing the coagulation activity.

After optimizing doses of alum and NC, different proportions of these were prepared for coagulation with NC_B. Fig. 4 presents turbidity removal efficiencies at different doses of NC_B. Maximum turbidity removal efficiency (98.27%) by NC_B was achieved at proportion of NC and alum doses (75:25). During coagulation by using NC_B, less turbidity removal efficiency was observed at equal proportions of alum and NC doses while, when one of the proportions of alum or NC doses was higher than the other, then removal efficiency of turbidity became better.

To optimize pH of NC_B, coagulation was done at optimum dose of NC_B at different pH levels (4–9) in Fig. 5. At pH 8, maximum turbidity removal efficiency (98.96%) was

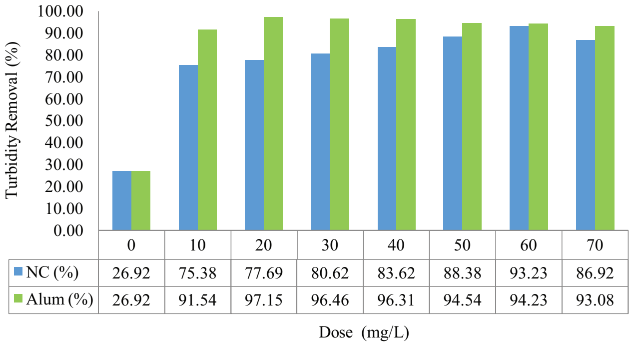

Fig. 2. Effect of dose on coagulation activity of alum and *Sorghum bicolor* (NC).

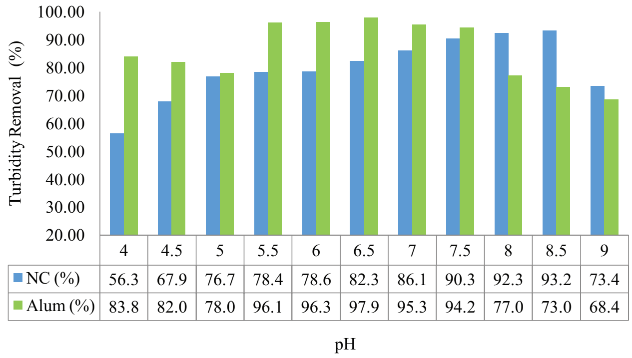

Fig. 3. Effect of pH on coagulation activity of alum and *Sorghum bicolor* (NC).

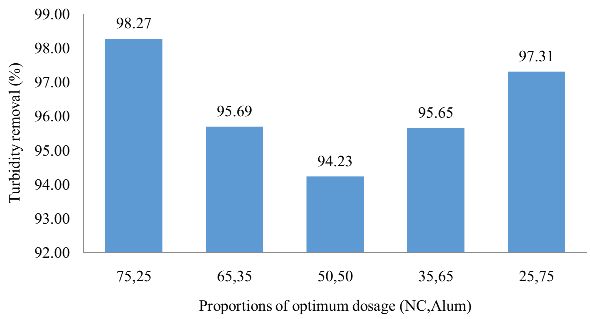

Fig. 4. Effect of different proportions of optimum dosage on coagulation activity of NC and alum (blended coagulant, NC_B).

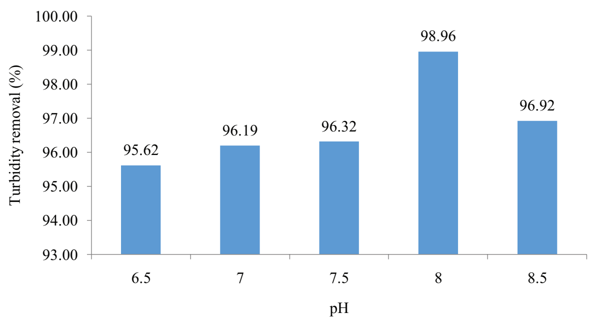

Fig. 5. Effect of different pH on coagulation activity at optimum dose of blended coagulant (NC_B).

observed. As previously observed, the optimum pH of alum and NC was 6.5 and 8.5, respectively, while optimum pH observed for NC_B was 8. It might be due to high proportion of NC as compared with alum in dose of NC_B.

Statistical comparison of coagulants has been shown in Table 2. Comparison analysis of coagulants exhibited that NC_B is the most efficient coagulant based on mean values of percentage turbidity removal, that is, 98.96. In addition, coefficient of skewness (CS) was found to be least for NC, highest for alum, and 1.26 for NC_B coagulant. Based on CS, both alum and NC_B have non-symmetric distribution of percentage turbidity removal with large number of high values in data set which exhibits high efficiency of these two coagulants as compared with NC. Non-linear geostatistical trend has been observed for coagulants NC and NC_B in measured percentages on the basis of coefficient of variation.

Table 2
Statistical analysis of data regarding coagulants

	Alum	NC	NCB
Minimum value (%)	97.6	92.7	97.9
Maximum value (%)	98.5	93.9	99.4
Mean (%)	97.9	93.2	98.9605
Skewness	1.6451604	0.6861883	–1.2602967
Variance	0.0410526	0.1284211	0.1272471
Standard deviation	0.2026145	0.3583588	0.3567171

3.3. Microscopic analysis

Figs. 6(a)–(d) present results of microscopic analysis of synthetic water samples before and after turbidity removal at a resolution (200×). Fig. 4(a) indicates plain sedimentation of synthetic water sample provided 30 min settling. This was done to compare floc sizes of sedimentation with and without coagulant. Sizes of less than 3 μm were observed during plain sedimentation. Fig. 4(b) shows the micro-photograph

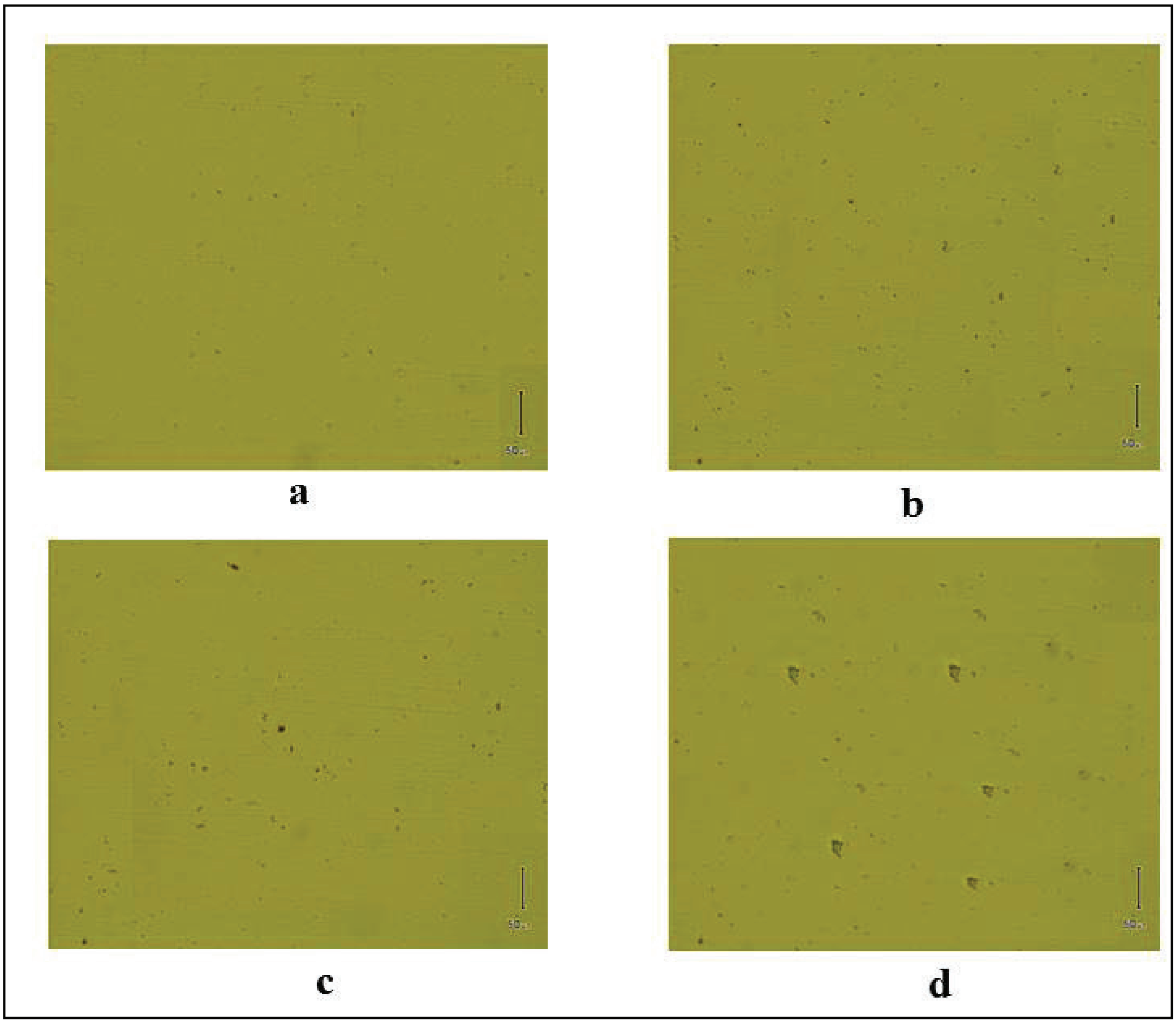

Fig. 6. Microscopic analysis of synthetic water samples before and after jar test at optimum conditions exhibiting: (a) plain sedimentation, (b) destabilized synthetic sample of alum, (c) destabilized synthetic sample of *Sorghum bicolor* (NC) and (d) destabilized synthetic sample of blended coagulant (NC_B).

of flocs produced during the coagulation with NC at optimum conditions. For this suspension, floc sizes up to 19 µm were observed. It can be deduced that particles formed agglomerates after adding NC. Particles examined were well bound and spherical. Floc sizes were reduced on higher dose due to over dosing phenomenon thus showing re-stabilization which confirmed the mechanism of charge neutralization. Fig. 4(c) shows the micro-photograph of flocs produced during the coagulation by using alum at optimum conditions.

Uneven irregular shaped flocs of sizes up to 39 µm were observed representing sizes larger than that of natural coagulant (NC). The dominant coagulation mechanism observed for alum was charge neutralization. However; precipitate formation was also viewed to some extent. Fig. 4(d) shows the micro-photograph of flocs produced during the coagulation with blended coagulant (NC_B) at optimum conditions. Floc sizes up to 45 µm were observed. The phenomenon of coagulation observed in this case was also charge neutralization.

4. Conclusions

Water quality treated by alum, biocoagulant and its blended form was compared. The turbidity removal efficiencies of alum, NC and NC_B were found out to be 97.9%, 93.2% and 98.96%, respectively. The results were also validated through statistical comparison of coagulants. FTIR analysis confirmed the presence of protein content in the form of following functional groups (medium, small and broad 1° and 2° amines, medium aliphatic amines and small saturated aliphatic groups) responsible for coagulation activity. The excellent removal efficiency by NC_B proves that it can be replaced by alum. The phenomenon observed in coagulation by NC_B was charge neutralization with floc sizes of 45 µm. It can be evidenced that the blended coagulant was found out to be excellent among all.

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