Economical Surface Water Treatment Technique using Acidified Recycled sludge

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Abstract—*Drinking water must be free from all types of impurities such as color, odor, colloidal suspension, microorganisms and others causing adverse health effects. In general, water treatment, especially, adopted for surface waters, which are dominated by colloidal suspensions and microorganisms is carried out using physico-chemical processes. These processes are accomplished by chemical substances, which are potentially harmful to human health, if they are present in water after treatment. In surface waters, the major impurity is very fine particles (Colloids). The colloids are composed of particles having at least one dimension lying within the range of ten angstrom to one micron, i.e., 0.0000001 to 0.0001 cm. The colloids of size, 1.0 micron requires 10 days settling time in one meter deep column. These suspensions are removed by addition of appropriate chemical (coagulant), rapid and intense mixing for obtaining uniform dispersion of the chemical. The coagulation with conventional coagulants results in the production of voluminous sludge that poses difficulty in handling and disposal in the environment. Therefore, the objective of present study was to substitutes of conventional coagulants that produce lesser amount of sludge and treat the water more effectively. Recycle of sludge produced from water treatment plant (Poly aluminum chloride (PAC)) is being acidified with any acid brings forth a product called Acidified Recycled Sludge (ARS). The Acidified recycled sludge (ARS) has been prepared using 1% diluted sludge and 2.5N H_2SO_4 at the rate of 0.02 ml/ml. The samples have been analyzed at room temperature of 23 -26^{0}C for turbidity, total dissolved solids (TDS), alkalinity and total hardness as per procedure Standard Methods of Water and Wastewater Examinations. The batch experiments in Jar Test Apparatus have been conducted for turbidity removal of river Yamuna water collected from Wazirabad barrage water using ARS. The results of treated water with alum and ARS show the 89%, 85% and 57% reduction in turbidity, TDS and alkalinity respectively and also considerable reduction in removal in total hardness as compare to Alum. Comparative cost analysis for effective turbidity removal with alum and ARS has been carried out for batch operations of water treatment. The comparison of cost analysis for alum and ARS for the water treatment shows that ARS is quite cheaper (70%) than that of alum. The results shows that the use of ARS as coagulant for the water treatment instead of conventional coagulant (alum) will economical and environment friendly.*

Keywords: *Colloids, Coagulant, Recycled Acidified Sludge, TDS, Turbidity.*

1. INTRODUCTION

Drinking water used for human consumption must be free from all impurities, microorganisms, and must not cause adverse health effects due to chemical contaminants. The water treatment technique should remove the impurities or inactive potentially harmful substances that may be present in water sources and also ensure that drinking water is aesthetically pleasing and economical. The availability of a water supply adequate in terms of quality and quantity is essential to human existence. Rainfall directly affects the quantity of surface water. As the rainfall is not uniform throughout the year, the quantity of surface water also has large variations. Surface water mostly contains large amount of impurities in suspended, colloidal and dissolved form. According to a 2007 World Health Organization report, 1.1 billion people lack access to an improved drinking water supply, 88 percent of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year. Development of effective water treatment techniques helps to prevent the water borne diseases.

The colloidal suspensions in surface water are considered as one of the significant impurity. The colloidal suspensions are having at least one dimension lying within the range of ten Angstrom to one micron i.e., 0.000,0001 to 0.001cm (McBain et al, 1950). The turbidity in surface waters results from the erosion of colloidal material such as clay, silt, rock fragments and metal oxides from the soil. Vegetable fibers and micro-organisms also contribute to turbidity. The colloidal material associated with the turbidity provides adsorption sites for chemicals that may be harmful or cause undesirable tastes and odors and for biological organisms that may be harmful for human health. Disinfection of turbid water is difficult because of the adsorptive characteristics of some colloids and solids may shield organisms from the disinfectant. The colloids impart turbidity to the water and these are required to remove from water, if the water is to be used for human consumption. The removal of colloids is the main objective and the most difficult aspect in conventional water treatment. A physico-chemical process applied in the water treatment for the settling of colloidal particles.

There are two types of colloids: hydrophilic colloids and hydrophobic colloids. Soap, proteins degradation products, agar-agar, gum arabic, and synthetic detergents in water are the common examples of hydrophilic colloidal systems. Every hydrophilic colloid is characterized by the fact that it possesses and forms a very thin layer of solvent around each particle. The process of formation of such film is called hydration. This property and the slight charge (usually negative) that it possesses prevent the colloid from being coagulated easily, making its removal from aqueous suspension difficult. Hydrophobic colloids are clay and non-hydrated metal oxides. The hydrophobic colloidal system is characterized by the absence of hydration and, therefore, strong affinity between the disperse phase and the dispersion medium. They are irreversible because their dry residue does not form sols on contact with the dispersion medium. Stability of such colloids depends upon the presence of stabilizers, such as ions, molecules and high molecular compounds in the dispersion medium. The ionic stabilization can be explained by the adsorption of ions in the dispersion medium as a result of which all colloids become electrically charged. The charge may be positive or negative depending upon the nature of the sols and the conditions under which the formation of the sol occurs. Since the colloidal particles have similar negative electrical charges and electrical forces to keep the individual particles separate, the colloids stay in suspension as small particles (A. Koohestanianet al.2008).

The time of settlement of such particles takes longer duration in comparison to coarser particles, which is not possible to provide such long detention period for settling. The settling characteristics of discrete suspended particles have been given in table 1

Table 1: Settling characteristics of discrete suspended particles (Biswas, 1985)

Particle size, mm	Settling velocity, mm/sec	Time required to settle 1 m
0.1	15.4	65 seconds
0.01	15.4×10^{-2}	108 minutes
1.0	15.4×10^{-4}	10 days
0.1	15.4×10^{-6}	2.75 years
0.01	15.4×10^{-8}	275 years

It has, therefore, been essential to agglomerate two or more of the colloids to form flocs resulting in the increase of mass-density through physico-chemical process, which makes quicker settlement possible. Agglomeration of the particles depends upon three primary parameters namely, Vander Waals interaction (usually attractive forces bringing the particles together), frequency of collision between particles, and the electrostatic interaction (usually repulsive forces which prevent aggregation or collision) (Puri et al, 1983; Soni, 1968).

Hong -Zhang Wu. et al, (2007) reported that Chemical coagulation is one of the most popular and effective methods for suspended particle and turbidity removal. This approach is usually operated in a two-step procedure.

Coagulation is the process of destabilizing colloidal particles so that particle growth can occur as a result of particle collisions (La Mer et al, 1963). However, the term flocculation is used to describe the process whereby the size of particles increases as a result of particles collisions. In other words, coagulation describes the effect produced by the addition of a chemical to a colloidal dispersion, resulting in particle destabilization. Operationally, this is achieved by addition of appropriate chemical and rapid and intense mixing for obtaining uniform dispersion of the chemical. However, flocculation is the second stage of the formation of settle able particles (or flocs) from destabilized colloidal sized particles and is achieved by gentle and prolonged mixing. In modern terminology, the combination of mixing (rapid) and stirring or agitation (slow mixing) that produce aggregation of particles is designated by the single term flocculation. The exact method by which coagulation is accomplished cannot be determined, there may be one of the four mechanisms thought to occur. These include ionic layer compression, adsorption and charge neutralisation, sweep coagulation and inter particle bridging. The chemicals added to aid coagulation are called coagulants. Aluminiumsulphate (alum), Ferric Chloride, Ferrous sulphate ,etc are some of the coagulants used in coagulation process.

The jar test is the most practical method for determining the chemical conditions required for coagulation. Reagents may exert a negative impact on health as applied to drinking water treatment because they leave harmful monomer aluminum, and unwanted side products in effluent, especially for excessive usage (Srinivasan and Viraraghavan, 2002). Even though they possess good particle removal efficiency, these coagulants may contaminate drinking water via aluminum residue, which has been recognized as a factor in Alzheimer’s disease (Mclachlan, 1995). The coagulation with conventional coagulants can easily remove colloidal suspensions but the major drawback of the process is the production of voluminous sludge, which poses difficulty in handling and disposal to environmental engineers. According to environmental protection regulation we need to minimize the waste production. Oftentimes, the costs of handling the enormous quantities of waterworks sludge can account for a significant part of the overall operating costs of water treatment works. Therefore, the substitute of conventional coagulants, which produces lesser amount of sludge and treats the water more effectively, was the major area of research for environmental scientists. Acidification of the sludge and using it as coagulant for the treatment of surface water reduces the sludge volume and treatment cost. This helps to recycle the coagulants and decrease the sludge production. This reduces the disposal costs too. Acidification of sludge using sulphuric acid from water treatment plant is used as coagulant. The aluminum recovery efficiency by acidification was affected by the type of sediments in the water sources. The coagulation mechanism is the combination of floc sweeping and physical adsorption (Babatundeet al. 2007). The aluminum recovery efficiency by acidification for poly aluminium chloride-based sludge is higher than that of aluminum sulphate-based sludge. Sludge from clay-based sediments has higher aluminum recovery efficiency than sludge from sand-based sediments after acidification. (Y.J. Chen et al. 2011).

The coagulation with conventional coagulants can easily remove colloidal suspensions but the major drawback of the process is the production of voluminous sludge, which poses difficulty in handling and disposal to environmental engineers. According to environmental protection regulation, it is required to minimize the waste production. Therefore, the substitute of conventional coagulants, which produces lesser amount of sludge and treats the water more effectively, is the major area of research for environmental scientists. Therefore, use of produced sludge should be recycled and reused as far as possible. Acidification of sludge produced from water treatment plant by any acid is used as coagulant for surface water treatment in laboratory in batch operations.The aluminum recovery efficiency by acidification for poly aluminium chloride-based sludge is higher than that of aluminum sulphate-based sludge (Y.J. Chen et al. 2011).The aluminum recovery efficiency by acidification was affected by the type of sediments in the water sources. The coagulation mechanism is the combination of floc sweeping and physical adsorption (Babatundeet al.2007).

In this paper the water samples of river Yamuna collected from Wazirabad barrage is analyzed at room temperature of 23 - 26^0C for total dissolved solids, turbidity, pH and alkalinity as per procedure Standard Methods of Water and Wastewater Examinations. The Acidified recycled sludge (ARS) has been prepared using 1% diluted sludge and 2.5N H_2SO_4 at the rate of 0.02 ml/ml. The turbidity removal study have been conducted using conventional jar test. A comparative cost analysis for effective turbidity removal with alum and ARS has been carried out for batch operations of water treatment.

2. MATERIALS AND METHODS

Collection of Surface water from river Yamuna

The sampling water has been collected near Wazirabad Barrage, river Yamuna through grab sampling. Frequent water samples have been collected in non-adsorbing PVC containers. Then, the collected samples have been preserved using suitable preservatives as described in Standard Methods of Water and Wastewater Examinations.

3. PREPARATION OF ALUM REAGENT

The alum reagent of normality 1N has been prepared by dissolving 1000 mg alum in 100 ml distilled water and diluted it to 1000 ml using distilled water. In this way, one ml of alum reagent is made equivalent to 1 mg alum. Thereafter, this alum reagent has been used as a coagulant for the removal of colloidal suspensions in batch operations.

4. DETERMINATION OF OPTIMUM COAGULANT DOSE

The conventional jar test apparatus has been used for the determination of optimum coagulant dose. The doses of alum reagent ranging from 5 ml/l to 30 ml/l with an increment of 5 ml/l have been added. The Jars containing water, 1000 ml each have been placed on Jar test apparatus. Initially, the samples have been allowed to flash/rapid mixing for two minutes and then, slow mixing for 20 minutes. Thereafter, jars have been kept standstill for 30 minutes to settle down the flocs. The supernatant from each jar has been taken and tested for turbidity through Nephelo turbidity meter. The minimum turbidity indicates the optimum dose of alum to treat Yamuna water. The optimum coagulant dose has been observed as 25 ml/1000 ml with the turbidity removal efficiency of 84% as shown in Table 4

Preparation of H2SO4 of Variable Normality

Sulphuric acid of variable normalities have been prepared from concentrated H_2SO_4 having normality 36N and 98% pure. The concentrated H_2SO_4 has been diluted with distilled water for preparation of variable normal acids. Similarly 1N, 1.5N, 2N, 2.5N, 3N, 3.5N and 4N normal acids have been prepared in the laboratory.

Preparation of Acidified Recycled Sludge as coagulant (ARS)

Water treatment sludge has been collected from Chandrawal Water treatment plant of Delhi Jal Board for recycle and reuse in treatment of surface water. Sulphuric acid of different normality 1N, 1.5N, 2N, 2.5N, 3N, 3.5N and 4N has been prepared as per the standard practice. The sulphuric acid of required normality is added at the rate of 0.02ml/ml of water treatment sludge and mix swiftly and allowed to stand for 40minutes. The Acidified Recycled Sludge (ARS) is ready for use as coagulant. Following this procedure ARS is prepared for 1N, 1.5N, 2N, 2.5N, 3N, 3.5N and 4N. ARS is added in the conventional jar test to find out the optimum dose of coagulant.

Colloidal suspension removal using jar test

One litre of synthetic dairy water sample was collected in a 2000ml jar and added 5ml to 30ml of WTS of 1N with an increment of 5ml to each beaker respectively. After a flash mixing of 2 minutes and then 20 minutes of slow mixing the sample containing coagulant were allowed to kept undisturbed for another 30 minutes to settle the flocs formed. The turbidity of the supernatant has been measured using digital Nephlo Turbidity Meter to find out the colloidal suspension removal from water. Perform the jar test for 1.5N, 2N, 2.5N, 3N, 3.5N and 4N also.

The percentage turbidity removal can be evaluated by the expression

$$\text{Percentage turbidity} = \frac{(\text{Initial} - \text{Final})}{(\text{Initial Turbidity})} * 100$$

Determination of Total Dissolved Solids (TDS) and Total Suspended Solids TSS

The characteristics parameters of the synthetic dairy waste water have been analyzed using standard methods. Total Dissolved solids are the portion of solids that passes through a nominal pore size under specified conditions.Suspended solids are the portion retained on the filter. Gravimetric method is used for determination of TSS and TDS. The procedure is as follows. Take initial weights of Whatman filter paper no 44 or 41 and crucibles. Take 50 ml of sample and filter the sample through filter paper. Keep the filter paper with residue in oven at 105^0Cfor 24 hours. Measure the volume of filter water and transfer it to empty crucible. Keep the filled crucible in oven at 180^0C for 24 hours.After 24 hours measure the weight of dried filter paper (FP) and crucibles.

$$\text{TSS (mg/l)} = \frac{(\text{Final FP weight} - \text{Initial FP weight}}{\text{ml of sample used}} \times 1000$$

$$\text{TDS(mg/l)} = \frac{(\text{Final weight, crucible} - \text{Initial weight, crucible}}{\text{ml of sample used}} \times 1000$$

5. RESULTS AND DISCUSSION

The Yamuna river water has been tested for turbidity, TSS, TDS and Alkalinity. The tested results are presented below in table 2:

Table 2: Raw water characteristics of Yamuna River

S. No.	Sampling location	Parameters	Initial Concentration
1	Wazirabad barrage	Total dissolved solids	447 mg/l
2		Turbidity	55 NTU
3		pH	6.8
4		Alkalinity	177 mg/l
5		Total hardness	181 mg/l

Turbidity Removal by Environmental Friendly Coagulants

a) Acidified Recycled Sludge (ARS): Conventional Jar test was performed to examine turbidity removal efficiency from surface water using ARS and Alum. The test are carried out in the Environmental Engineering Laboratory of Jamia Millia Islamia University, New Delhi. ARS of different normality applied for to determine the optimum dose for effective and efficient removal of turbidity. ARS prepared from sulfuric acid of 1N to 4N normality doses started from 5 ml/L to 30 ml/L with an increment of 5 ml/l was applied in jar test and results presented in Table 3.

Table 3: Turbidity Removal from surface water using ARS of different Normalities

ARS Dose ml/l	Turbidity removal, % by							pH
	1 N	1.5 N	2 N	2.5 N	3 N	3.5 N	4 N	
5	9.2	8.9	22.1	51.2	72.3	60.3	33.6	6.8
10	11.4	13.1	31.5	61.3	81.2	68.1	41.4	7.1
15	15.9	17.3	38.9	67.8	83.8	71.4	44.2	6.9
20	22.4	23.1	45.2	72.5	85.4	75.6	47.1	7.2
25	29	26.3	55.2	77.6	89.4	77.4	48.9	6.8
30	33.6	23.9	57.9	81.4	86.2	72.6	42.6	7.1

The all test are performed at normal pH condition. According to the results the maximum turbidity removal efficiency from Yamuna river water was observed at 25ml/l (ARS 3N) dose with 89.4 %. of ARS 3N normality and same is reflected in the Fig. 1 below:

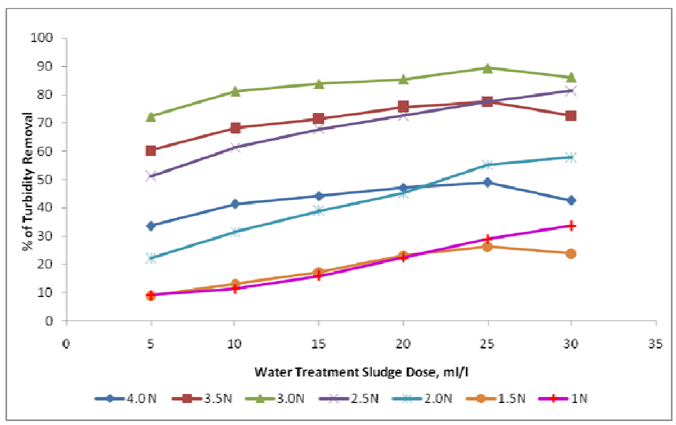

Fig. 1: Turbidity Removal by ARS

b) Turbidity removal by Alum: The river water has been treated with both alum and ARS in batch operations. The variable dosage of alum ranging from 0.0 mg/l to 40mg/l with an increment of 10 mg /l has been added in water samples and optimum dose of alum has been obtained. At optimum coagulant dose, the reduction of various water quality parameters, as discussed above have been experimentally measured after treating the water by jar test and presented below in table 4:

Table 4: Turbidity removal with Alum

S. No.	Alum dose, ml/l	pH	Turbidity removal, %
1	5	6.9	25
2	10	7.1	48
3	15	6.8	63
4	20	6.4	80
5	25	6.9	84
6	30	7.2	72

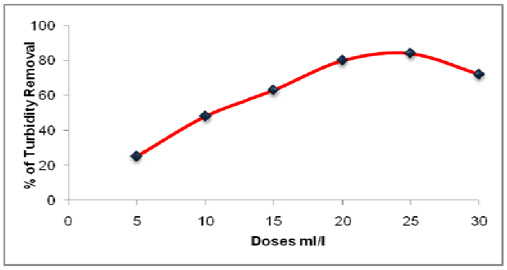

Fig. 2: Turbidity Removal efficiency by Alum

From the above results it has been observed that ARS is more efficient in removal of turbidity as compare to Alum.

TSS and TDS Removal

TSS, TDS and Alkalinity has been checked of raw surface water and treated water by alum and ARS in the laboratory in batch scale. The output of test results has been presented below in Table 5.

Table 5: TSS, TDS Alkalinity and Total hardness in raw surface Water and treated water

S. No	Sampling location	Parameters	Initial Concentration	% removal after treatment with alum	% removal after treatment with ARS
1	Wazirabad barrage	TSS	376mg/l	70%	77.1%
2		TDS	447 mg/l	50.34%	84.8%
3		Alkalinity	177 mg/l	89 mg/l	76 mg/l
4		Total hardness	181 mg/l	139 mg/l	121 mg/l
5		Turbidity	55NTU	83%	89%
6		pH	6.8	6.8	6.5

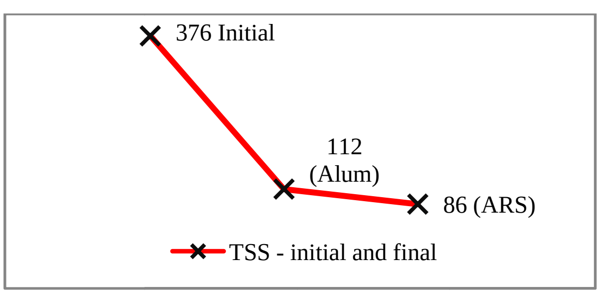

Fig. 3: Removal of TSS by Alum and ARS

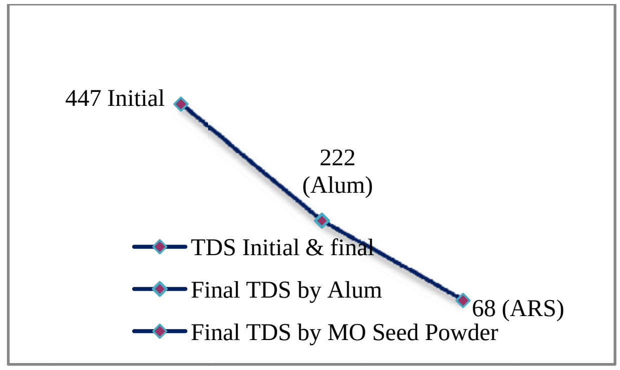

Fig. 4: Removal of TDS by Alum and ARS

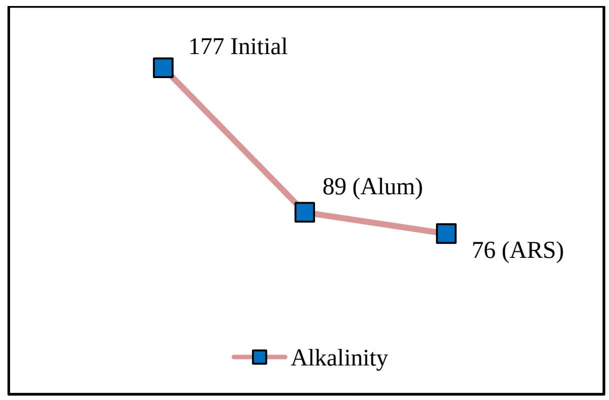

Fig. 4: Removal of Alkalinity by Alum and ARS

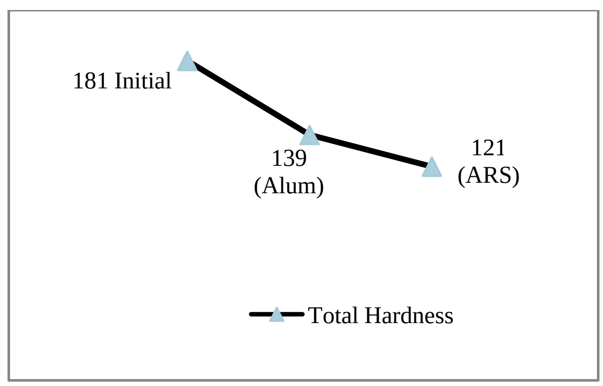

Fig. 4: Removal of Total Hardness by Alum and ARS

6. COST ANALYSIS

The cost analysis for alum and ARS shows that ARS is quite cheaper than alum in the removal of colloids in batch operations. The analysis has been worked out for current cost of chemicals used for both alum and ARS.

Quantity of Alum

The experimental results show that the optimum dose of alum required for the removal of turbidity up to 84% is 25 mg/l.

Therefore, for the treatment of 50 MLD turbid water, the total alum requirement is

Alum Required = 25 mg/l x 50,00,00,00 l/day x 1 kg/1000000 mg

= 1250.00 Kg/day

@ the rate of Rs. 410 per kg

Total cost of alum per day = 1250.00 x 300.00

= Rs. 5,12,500.00

Quantity of Sulfuric Acid

Sulphuric acid of 3N has been used for the acidification of sludge, i.e. for the preparation of ARS. The normal sulphuric acid of 3N has been added in sludge at the rate of 0.05ml/ml. The quantity of sulphuric acid consumed has been evaluated as follows:

Quantity of ARS (3N)

The results show that 25 ml/l dose of ARS is required for the removal of ~95% turbidity. Therefore, the ARS required for the treatment of 50 MLD turbid water is

= 25 ml/l x 50, 000,000 l/day x 1l/1000 ml

= 12,50,000 l

Sulphuric Acid

3 Normal Sulphuric Acid Required = 0.02ml/ml x 12,50,000 l

= 25,000 l

Total Quantity of Concentrated Sulphuric Acid required

= 2083.33 l ~ 2083 l

Market rate of Sulphuric Acid per liter = Rs. 75.00

Total cost of Sulphuric Acid per day

= Rs. 75.00 x 2083

= Rs. 1,56,225.00

4.8.7 Chemical's Cost Comparison

The comparison of cost analysis for alum and ARS for the treatment of 50 MLD shows that ARS is quite cheaper than that of alum. By using ARS one can save the chemical cost up to 70%. The analysis has been carried out on the basis of batch experiments conducted in the laboratory.

7. CONCLUSIONS

The results show that the ARS is more efficient than Conventional coagulant alum in terms of removal of turbidity, TSS, TDS, Alkalinity and Total Hardness from surface water. Water treatment sludge disposal problem can be easily handled by recycling of sludge and use as coagulant for treatment. ARS prepared from recycling of water treatment sludge which is also safe to the environment by recycling. Sludge handling problems can be sorted out by reuse of water treatment sludge. This will be an alternative to conventional and expensive coagulants.

8. ACKNOWLEDGEMENTS

I wish to thanks the Civil Engineering Department, Jamia Millia Islamia for support my research work.

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