International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 12 (2017) pp. 3253-3262

Efficiency of PAC in Water Treatment Plant & Disposal of Its Sludge

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Abstract

In this project an attempt has been made to study the efficiency of Alum and Poly Aluminium chloride popularly known as PAC in purification of water. Though PAC is widely used in other countries its use in India for water purification is not appreciable. The optimum dosage level of the chemicals is governed by the reduction of turbidity. Hence artificially various ranges of turbidities have been created in the laboratory and the optimum dosage levels for the various range of turbidity has been studied. Simultaneously the volume of sludge generated has been recorded. A comparison of the reduction in generation of sludge as a part of management of water treatment Plant sludge has been analysed Samples from actual sludge generated in a water treatment plant with river Cauvery as a source has been taken and analysed for its characteristics to find out its suitability for brick marking.

The results recorded indicated that PAC could be considered as one of the best alternative chemical to Alum for coagulation which has both the advantage of lesser optimum dosage and less sludge generation. Though the unit cost of PAC is more than unit cost of Alum considering the capital cost required for establishment of facilities for Alum storage and use, PAC could be still preferred as a alternate chemical. In a larger perspective the contribution of pollutant through discharge of water treatment plant sludge into the aquatic environment could be substantially reduced.

Keywords: Efficiency of Alum, Coagulants, PAC, sludge generation, treatment plant

INTRODUCTION

Water treatment plants are designed to process raw water in order to produce the final treated and disinfected water satisfying the standards laid down under IS for drinking water requirements. The extend of turbidity of the raw water is an indication of quality of the water. The chemical requirements are decided based on the optimum dosage required to bring down the turbidity level to our requirements. The fine suspended particles which are organic in nature contributes turbidity. The extent of dissolved solids contributes to colour. The very fine particles suspended in water is termed as Total Suspended Solids which will not settle down easily. In other words they will not settle within a reasonable period of time if left undisturbed.

With the addition of chemicals they are made to settle within a shot period of time. These chemicals are called coagulants. Coagulants are chemicals that induce curdling or congealing. Coagulation and flocculation are part of the treatment process whereby the colloidal mater in the form of suspended solids is made to agglomerate and settle down at the bottom of the basins as flocs. This mechanism enables to remove the suspended matter within a short period of time and reduce turbidity. The mechanism involved in this process is that negatively charged particles present in the water are attracted by the positively charged coagulants which ultimately settle at the bottom under gravity. For the same turbidity the chemical dosage required may vary widely because of other factors such a pH, temperature, alkalinity etc also influence the dosage.

Coagulants are classified as being inorganic or organic. Inorganic coagulants include those commonly used chemicals that relay on aluminium or iron. Organic coagulants include the so called poly DADMAC (polydiallydimethyl ammonium chloride) range of polymer. These are special and expensive chemicals that are sometimes used in direct filtration plants when the low dose required making their use appropriate. Alum is widely used as a coagulant in most of the water treatment plants in spite of its limitations on the temperature, turbidity, pH. Inorganic polyvalent Aluminium salt has been used as a coagulant for treatment of water worldwide.

When dose to raw water, inorganic coagulatns decrease its alkalinity. Hence the pH of the chemically dosed raw water will decrease. In certain cases this indicates that supplemental alkalinity in the form of lime, soda, ash, caustic soda or some other alkali will have to be added. Aluminium chlorohydrate (ACH) and polyaluminium chloride (PAC) do not have as great an effect as that of alum in respect of water alkalinity and pH. Organic coagulants generally do not effect the raw water alkalinity and pH.

All coagulants produce sludge in the form of the metal hydroxide together with coloured and colloidal mater removed from the raw water in the treatment process. But not all the inorganic coagulants behave in the same way. ACH and PAC produce less sludge than alum when dosed at equivalent levels.

Organic coagulants produce very little sludge. Inorganic coagulants will increase the total dissolved solids (TDS) concentration of the treated water. When alum is used sulphate levels in the treated water will increase.

Depending on the pH after the coagulant is added, two possible reactions will generally occur. With the Aluminium based coagulants the metal ion is hydrolysed to from aluminium hydroxide floc as well as hydrogen ions. The hydrogen ion will react with the alkalinity of the water and in the process decrease the pH of the water.

The hydrolysis reactions typically take place at a dosed water pH in the range of 5.8 to 7.5. Within this pH range colour colloidal matter is removed by adsorption within the metal hydroxide hydrolysis products that are formed. If an excess alum is added so that the dosed water pH is less than 5.0 then the metal ions (Al^{3+}) directly neutralized the negatively charged organic compounds and colloids in the raw water. This allows the organic molecules to contribute to floc formation. This is often practiced to boost the removal of disinfection by-product precursor. Coagulating at such a low pH requires attention to potential corrosion problems as well as the need for post treatment pH adjustment / alkalinity adjustment to ensure that the treated water is not corrosive.

Iron based coagulants such as ferric sulphate are more expensive than alum. They also consume more alkalinity than alum and hence tend to depress pH of the dosed water more dramatically. Ferric based coagulants are extremely corrosive and produce highly blood/rust coloured stains when there are chemical spills and leaks. Poly DADMAC's are not as good as inorganic coagulant which is used together with alum or PAC the total chemical dose required to achieve the same finished, water quality can be less than if each chemical is used on its own. Alum or ACH in combination with a cationic poly DADMAC polymer will work extremely well on highly coloured water which also have a low pH and alkalinity. When using dual coagulants the inorganic coagulant dose can be reduced by 50% compared to when its used on its own.

PAC AS AN EFFECTIVE COAGULANT

Subsequent to the various coagulants, the advantages of using PAC over alum are, PAC works well with pH range of 6-9 where as alum works better between pH 6.5-7.6, since, PAC works even at temperature below 10^{D}C, so, it can be used during winter season. Also, quality of treated water is good, and possesses greater reaction speed due to its liquid state. Further, it works at all turbidities and contains lower residual aluminium content. Polyaluminium coagulants are typically twice the price of liquid alum on per kilogram aluminium basis. However, lower doses of the coagulant and lower pre- and post-treatment alkali doses can still make its use economical. Polyaluminium chloride solution (10% A1203) is stable for 4 to 5 months when stored at less than 50°C and is so ideal for bulk storage and dosing installations. In Grampians Water Supply scheme, Victoria, PAC is currently being used at three of six recently constructed in-filter/DAF water treatment, based on cost comparison; for the alum option, total chemical costs amount to $76.8/ML, whilst for ACH $63.5/ML; there will be a saving of approximately 17%. This example illustrates that how lower operating costs can be realized when using ACH coagulant compared to alum. Superior quality treated water is also produced with respect to TDS, CCPP and SO_4.

OBJECTIVES

The vital objectives are to assess the efficacy of Poly aluminium chloride (PAC) over Alum in coagulation-flocculation process and to characterize the sludge produced for its future application.

SCOPE OF THE PRESENT STUDY

Following are the scope of present investigation

- Preliminary investigation on turbidity removal by alum and PAC
- Laboratory experimentation pertaining to the assessment of PAC over Alum as an effective coagulant
- Studies and comparison on the effect of turbidities, pH and the effect of dosages (concentration) for alum and PAC on raw water sample
- Analysis of the physicochemical parameters of the treated water and the volume of sludge generates with respect to both the coagulants
- Characterization of the treatment plant sludge (alum and PAC) and suggests its suitability of futuristic application

MATERIALS

Coagulants

Coagulants like Aluminium Sulfate (Alum), and Poly aluminium chloride (PAC), of LR grade were obtained from Merk Chemicals, Mumbai and National Chemicals, Gujarat, respectively. The chemical properties and heavy metal composition of PAC are shown in Table 3.1.

Table 3.1

S.No	Properties	Result
1	Appearance	Transparent Liquid
2	Density(gm/cm3) at 20^0C	1.35±0.05
3	Viscosity(Nm/s) at 20^0C	55-65
4	Colour	Amber
5	Odour	Neutral
6	pH at 20^0C	0.9-1.1
7	Freezing Point	-15^0C
8	Stability	Minimum 6 months in normal storage and 1 year in sealed containers
Heavy Metals Composition		
1	Iron	22.2 mg/l
2	Arsenic	ND
3	Manganese	0.14
4	Chromium	0.04
5	Mercury	0.007

CHEMICAL PROPERTIES AND HEAVY METAL COMPOSITION OF PAC.

Chemicals

All chemicals and reagents used for Physicochemical parameters analysis were of LR grade, obtained from Loba Chemicals, Mumbai and prepared by using pyrogen-free doubly-distilled water prepared in the Environmental Engineering Laboratory, Civil Engineering Department, CIT, Coimbatore, (by Quartz bi-distillation unit, Lab-sil Instruments Lab. Pvt. Ltd., Bangalore).

Water

All experiments were conducted both in distilled water and tap water (Bhavani water). The Bhavani water had average physicochemical parameters shown in Table 3.2.

Table 3.2

S.No.	Physicochemical Parameter	Result*	
		Distilled water	Tap water (Bhavani water)
1	pH	6.60	7.57
2	Turbidity, NTU	Nil	≤ 1
3	TDS, mg/l	10	50
4	Conductivity, µmho/cm	10	25
5	Alkalinity as $CaCO_3$, mg/l	Nil	34
6	Hardness as $CaCO_3$, mg/l	≤ 1	30
7	Calcium as Ca^{2+}, mg/l	Trace	6
8	Magnesium as Mg^{2+}, mg/l	Trace	3.68
9	Sodium as Na^+, mg/l	Nil	10
10	Chlorides as Cl^-, mg/l	Nil	30
11	Sulphates as SO_4^{2-}, mg/l	Nil	21

(* - average of six periodical results)

PHYSICOCHEMICAL PARAMETERS OF PYROGEN-FREE DOUBLY-DISTILLED WATER AND BHAVANI WATER.

Bentonite Clay

The turbidity is artificially created using Bentonite clay procured from (local market). About 10 g dissolved in 1 liter of Bhavani water gives a turbidity of 100NTU which was diluted for further to create various turbidities. The specifications of the Bentonite clay are given in Table 3.3.

Table 3.3: Specifications of the Bentonite clay.

Sl.No.	Parameter	Characters / Composition	
1	Color	Light gray to off-white	
2	Odor	Flat	
3	Mesh Size	US #200 Mesh	
4	Moisture	7.8%	
5	pH	8.3 - 9.1	
Mineral Content			
Silica- 61.4% Magnesium- 1.7% Titanium- 0.02% Iron- 3.5%		Aluminum- 18.1% Sodium- 2.3% Calcium- 0.04% Potassium- 0.01%	

ANALYSIS OF TURBIDITY

The turbidities (NTU) of water samples at the initial and final (after treatment) were analysed using Nephlometer (CL 52D),

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 12 (2017) pp. 3253-3262

Elico, India in glass cuvets using standard turbid solutions of 100NTU and 400NTU and distilled water for zero setting. An experimental error was observed in between 0.5 and 3% in all experiments.

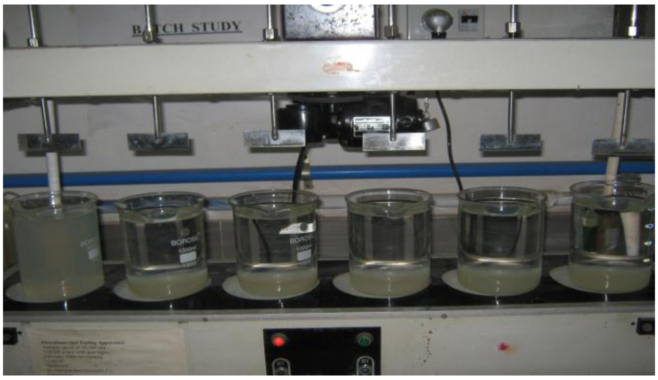
PRELIMINARY COAGULATION-CUM-FLOCCULATION STUDIES

All coagulation studies (either preliminary or any other study as specified later) were conducted in Jar test apparatus, by using tap water, under room temperature. Jar test apparatus (Secor Laboratory Instruments, India) having 6 flat blade stirrers (each 7.6 × 2.5 cm^2) driven by 0.05 HP motor with an induced speed range of 10 to 400 rpm was used to assess Alum and PAC in coagulation of colloidal and dissolved particles. Borosil[R] glass beakers of 1 lts capacity were adopted for all the experiments. The field conditions were simulated in laboratory in Jar test apparatus with 2 min for rapid mixing of coagulants with raw water, 20 min for coagulation-cum-flocculation, and 30 min for sedimentation of flocs.

EFFICACY OF ALUM AND PAC IN TURBIDITY REMOVALS.

In order to assess the potentiality of alum and PAC in coagulating or removing turbidities, 100 NTU turbid samples were taken and five different doses of alum and PAC say 20, 40, 60, 80, 100 mg/l were added to it. The contents were stirred and allowed to flocculate and settle down at room temperature 28°C, and the efficacy of alum and PAC were determined by their respective turbidities removals. Fig. 3.1 and 3.2 are the photographs showing the removal of turbidity at different dose levels of alum and PAC using Jar Test Apparatus.

Photograph Showing the Removal of Turbidity at Different Dose level of Alum Using Jar Test Apparatus.



Photograph Showing the Removal of Turbidity at Different Dose of PAC Using Jar Test Apparatus.

EFFECT OF COAGULANT DOSAGE ON WATER CLARIFICATION

Different dosages of alum and PAC say 5, 10, 20, 30, 40, 50, 60, 70, 80 mg/l and 1 to 8 mg/l respectively were tried for maximum water clarification at different turbidity levels.

EFFECT OF TURBITIES ON WATER CLARIFICATION

Different turbidities were created by bentonite clay say 150, 250, 512, 712, 950, NTUs on Bhavani water and the efficiency of alum and PAC in coagulation was assessed based on their respective turbidities removal.

EFFECT OF PH ON ALUM AND PAC

Conventional metal coagulants (Alum, Iron salts, etc.) are very sensitive to pH and Alkalinity. If the pH of after to be treated is not in proper range, clarification is poor and iron or aluminium may be solubilized causing problems to water user including health hazards. Because of this neutralization by adding chemicals is required if pH is beyond the optimum range. At a dose of alum and PAC of 0.5 mg/l of Al, for medium turbid water, over wide range of pH from 4, 5, 6, 7, 8, 9, experiments were conducted. The initial and final turbidities after the treatment were measured based on supernatant optical density at 750 nm in spectrophotometer.

EFFECT OF TAP WATER (BHAVANI WATER) ON COAGULATION PROCESS

In order to simulate coagulation-cum-flocculation of colloidal and dissolved solids by alum and PAC in raw water, and also due to time and distance constraint for the experiment, tap water (Bhavani water) contacted with bentonite clay (artificial turbidity creator) was taken into consideration. However, same experimental conditions were stimulated and maintained as in field with Jar test apparatus in laboratory at room temperature and pressure (atmospheric conditions).

ANALYSIS OF PHYSICOCHEMICAL PARAMETERS OF TREATED WATER

The treated waters were characterized based on typical physicochemical parameters such as pH, TDS, Cl^-, acidity, alkalinity, hardness, turbidity, and others; and were analysed in Environmental Engineering laboratory, Dept of Civil Engg, C.I.T, Coimbatore and few NPK contents were analysed in the Water Analysis laboratory, SITRA, Coimbatore for reliability and accuracy of results, appropriate analytical techniques (gravimetric / titrimetric / instrumental) were adopted based on Standard Methods for the Examination of Water and Wastewater (APHA *et al*, 1998). The analytical results had an error band between 3 to 5%. The Borosil^R glassware was used in regular laboratory procedures.

MEASUREMENT OF SLUDGE GENERATED

The contents of beaker are drained leaving a small volume of sludge which are measured in ml and filtered through rough filter paper, dried in hot air oven and weighed to get dry weight of sludge.

FIELD STUDIES

Inorder to conform the laboratory studies in field application, few onsite experiments were conducted at the New Tirupur Combined Water Treatment Scheme to investigate the efficiency of coagulants in treatment application.

EVALUATION OF OPTIMUM COAGULANT DOSE (OCDS) OF PAC IN ACTUAL TREATMENT PLANT FOR DIFFERENT TURBIDITIES

For turbidities of raw water (Cauvery water) at the treatment plant, say 1 to 70 NTUs, PAC of dose ranging between 0.5 to 30 mg/l were added in clariflocculators and the performances of it were assessed based on treated water turbidities, pH, alkalinity, and filter bed performances.

ALUM AND PAC SLUDGE CHARACTERIZATION

Sludges generated by alum and PAC at the treatment plant were taken from clariflocculators, and were given for analysis of metals like Mg^{2+}, Al^{3+}, K^+, TKN, Silica, Phosphorus, Calcium carbonates as $CaCO_3$, at Water Analysis Laboratory SITRA, Coimbatore.

UTILISATION OF SLUDGE FOR MANUFACTURING OF BRICKS

Materials and Methods

The water treatment plant sludge used in this study is the coagulant sludge which is withdrawn from the tube settlers of Tirupur Water Supply and Sewerage Project in which alum is used in the coagulation process. The raw water source for this plant is surface water of river Cauvery. The Liquid sludge drained from the tube settlers are collected in a sludge holding tank. The solid consistency of the sludge is about 4% .The consistency has been brought to 20% in the sludge thickener tanks. The sludge from this tank is then centrifuged in a 20cum/hour capacity centrifuge and the resultant solid sludge has been obtained.

Since the raw water characteristics of the river Cauvery over a major period of time in a year are not varying much except on days of heavy rainfall samples from the stocked sludge has been taken for investigation. The sludge analysis is done at Tamilnadu Agricultural University, Coimbatore for its suitability for agricultural purpose. The test results are as follows:

ALUM SLUDGE FOR CONCENTRATION VALUE.

S.No.	Parameters	Unit	Concentration
1	Organic content	%	4.85
2	Total Nitrogen	%	0.38
3	Total phosphorus as P2O5	%	0.12
4	Total potassium as K2O	%	0.30
5	Calcium	Mg/kg	410
6	Magnesium	Mg/kg	36
7	Sodium	-	528
8	Chloride	Mg/kg	780
9	Sulphate	Mg/kg	310
10	Lead	Mg/kg	13.25

Results of the samples tested during 2008 and 2009 indicated that the silica content is 200 to 300 mg/kg.The aluminium content is around 2300 mg/kg.

Preparation of specimen

The alum sludge in the form of graduals are made in to power form by grinding. Commercial Portland pozzolon cement of 43 grade has been used for preparation of specimen. One part by volume of cement and 2 parts by volume of the alum sludge have been mixed thoroughly with water to get a consistency suitable for moulding. The size of the mould used is 20cm x 10 cm x 8 cm. Similarly cement and sludge in the ratio of 1:3 has been mixed in to brick cast. Again instead of cement, clay and sludge are mixed in the ratio of 1:2 and 1:3.

The above said bricks are exposed to direct sunlight after 2 days of casting without removing mould. After drying for 3 days the mould is stripped off. No shrinkage has been observed. After drying for 7 days' the specimens are kept in the oven for 48 hours and then the moisture content is calculated. The weight of the specimens before and after taking out from the oven are recorded and the results are as follows:

Dry Weight of Specimen

S.No.	Specimen no.	Weight before keeping in the oven kg	Weight after removing from the oven (kg)	% moisture
1	Cement: sludge 1:2	2.173	1.738	20.01
2	Cement: sludge 1:3	1.842	1.634	11.30
3	Clay: sludge 1:2	2.013	1.784	11.37
4	Clay: sludge 1:3	2.371	1.920	19.02

The unit weight of the alum sludge is found to be 1105 kg/cum. Because of the low unit weight the weight of the brick Cast is very much less compared to the commercial brick available in the market. Since the percentage of aluminium present in the sludge is more the water absorption characteristics of specimen are more than which resulted higher % of moisture content on the oven dried specimens.

Strength of Stress in Bricks

The bricks are tested in the laboratory for assessing its compressive strength. The results are as follows:

S.No.	Specimen description	Breaking load in kg	Stress in the bricks (kg/sqcm)
1	Cement: sludge 1:2	1000	5.0
2	Cement: sludge 1:3	300	1.50
3	Clay: sludge 1:2	520	2.60
4	Clay: sludge . 1:3	200	1.0

Normal commercial bricks are suitable to withstand a load of 12 to 15 T/brick. The silica content in the sludge is much less and hence the bricks cast did not have enough hardness. The presence of higher concentration of aluminum requires higher sintering temperatures. As the quality and strength of the bricks are governed by these two properties, the alum sludge lacks very much in these aspects.

To conclude that, the alum sludge generated at this treatment plant is not suitable for brick making. This can be used as a filler materials for road portions. The concentration of N,P,K also discourages its use for agricultural purpose.

Breaking the Bricks

RESULTS AND DISCUSSION

Preliminary Coagulation Studies

Before understanding the coagulation of colloids and dissolved particles, few preliminary studies were undertaken to appropriately analyze the efficacy of PAC over alum, to study the effect of dosage and turbidities on coagulation-cum-flocculation process. The behavior of alum and PAC were studied in the tap water system.

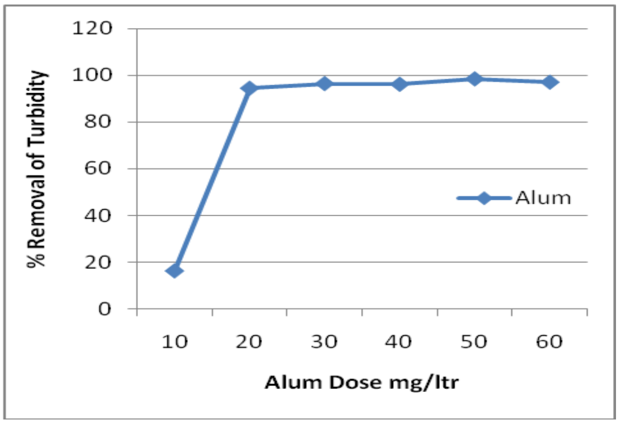
It is seen that there is considerable reductions of Turbidity in PAC treated Jars than Alum. The removal efficiency of PAC from 150 to 7.9 NTU is around 94.7% for higher turbidities, where as in case of Alum treated Jars the removal efficiency (150 – 130.7) is lower than that off.

This is because of the fact that coagulation occurs at slightly negative zeta potential where as in case of alum when too much is added. The colloidal particle surface will be become possible and will be Re-dispersed back, resulting in low removal efficiency of turbidity.

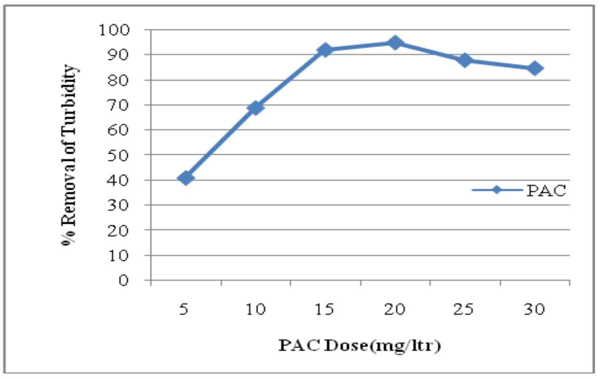
The two parameters pH and TDS were monitored as shown in the Table 4.2. The initial level of pH 6, 8 at a concentration of Alum dose 10 mg/l. The reduction pH was 5.85 with respective dosage of alum. For initial level of TDS was 40

PPT (Parts per Trillion). These were no significant reduction at dosage of Alum 10 mg/l.

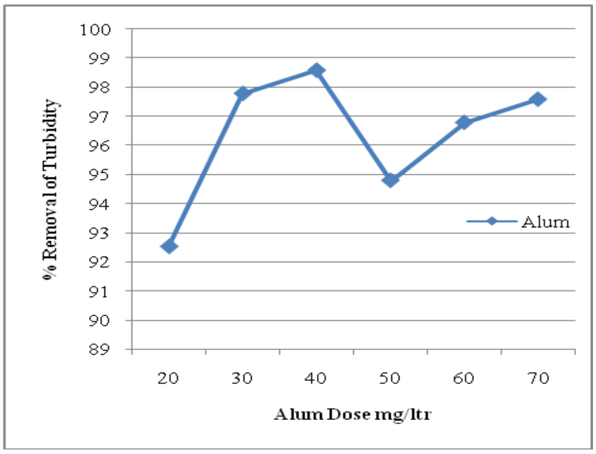
For PAC the initial level of pH was 6.46 at a dosage of 10 mg/l. The reduction level of pH was 5.95 with respective dosage. In TDS there was no significant reduction. It was inferred that the sludge generated was about 0.5582 g/l for Alum for PAC the sludge generated was about 0.1739 g/l.



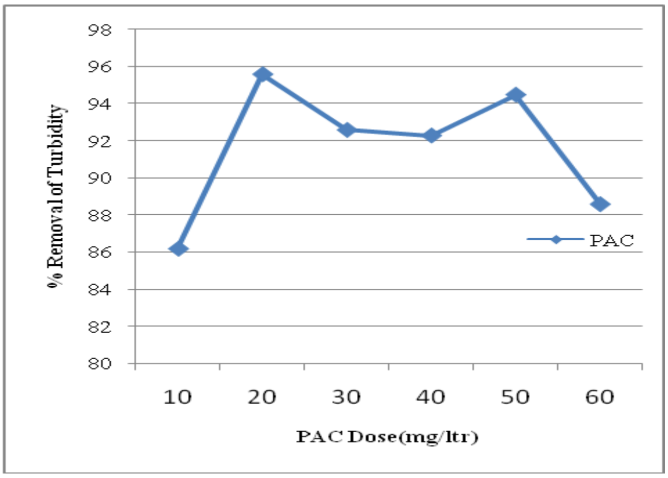
Graphical representation of % Removal of Turbidity at 150NTU (ALUM)



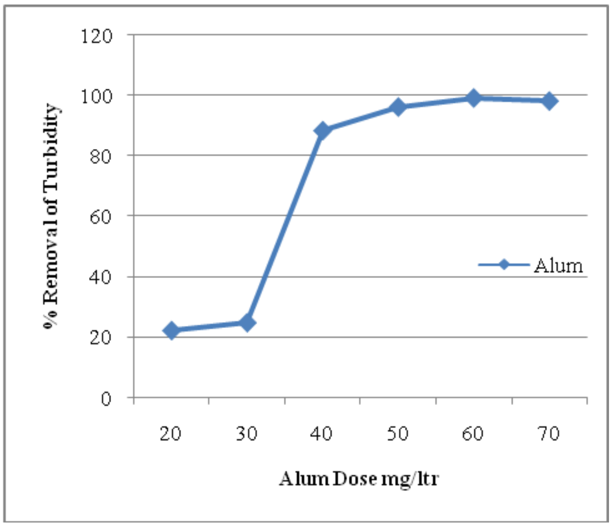
Graphical representation of % Removal of Turbidity at 150NTU (PAC)



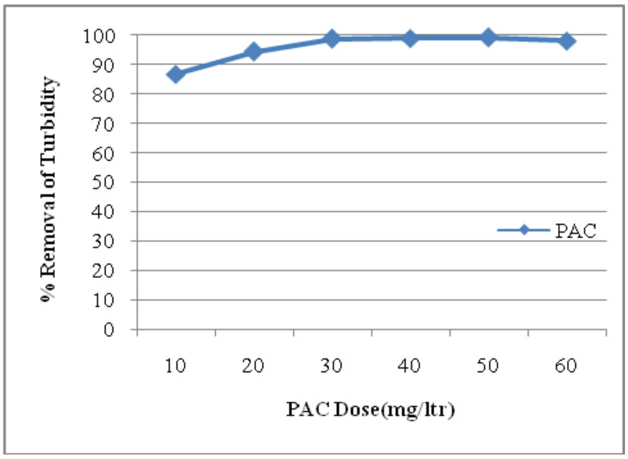
Graphical representation of % Removal of Turbidity at 250NTU (ALUM)



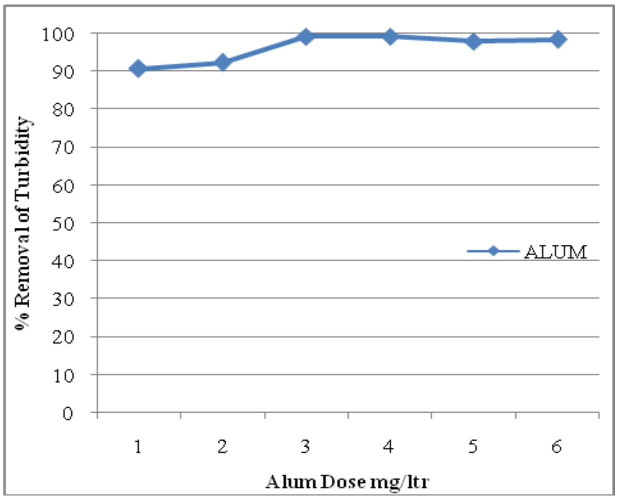
Graphical representation of % Removal of Turbidity at 250NTU (PAC)



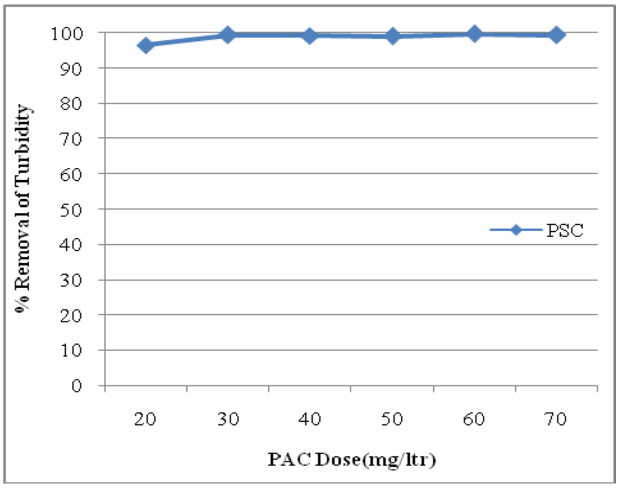
Graphical representation of % Removal of Turbidity at 512NTU (ALUM)



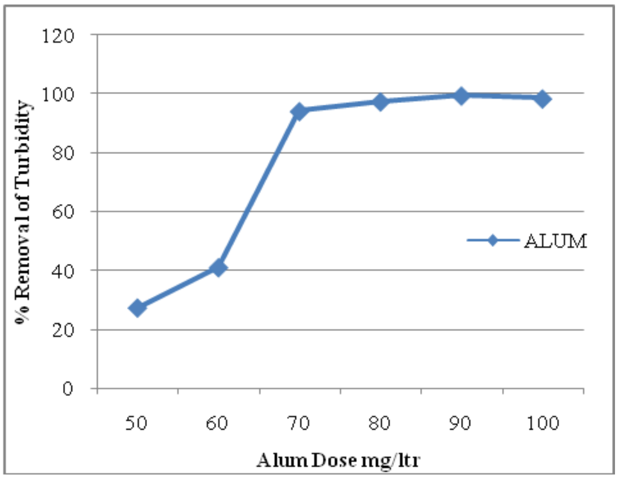
Graphical representation of % Removal of Turbidity at 512NTU (PAC)



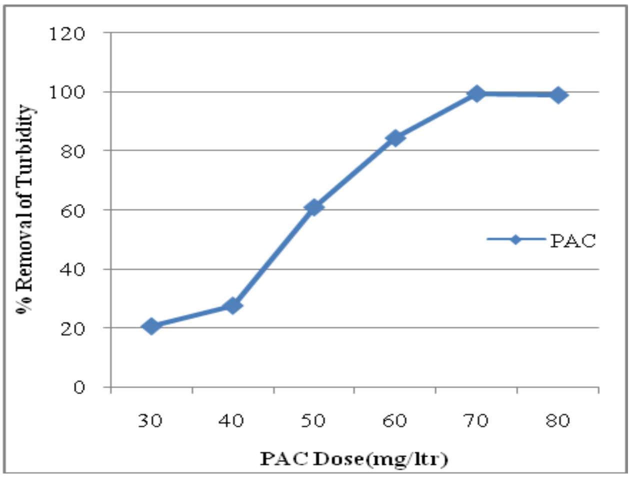
Graphical representation of % Removal of Turbidity at 712NTU (ALUM)



Graphical representation of % Removal of Turbidity at 712NTU (PAC)



Graphical representation of % Removal of Turbidity at 950NTU (ALUM)



Graphical representation of % Removal of Turbidity at 950NTU (PAC)

CONCLUSIONS

Based on the investigation pertaining to the coagulation-cum-flocculation of particles by alum and PAC, the following conclusions are drawn.

1. PAC is a good and an effective coagulant than alum in eliminating turbidity from raw water.
2. PAC works well with all turbidity levels and wide pH range from 7 to 8 than alum.
3. The consumption of PAC is much lower than alum and hence the treatment cost gets reduced.
4. The physicochemical parameter of treated water shows only slight deviation from the initial after the PAC treatment when compared with alum.
5. As PAC causes minimum drop in pH, the need of lime for neutralization can be avoided/minimized. So, the sludge generation at the source itself is reduced.
6. In case of PAC, which is available in markets as both solids and liquids, there is no need of agitators for mixing, which reduces power consumption and also do not require unlike alum.
7. The removal efficiency of PAC is around (80% efficiency) 30 times higher than alum at various turbidity levels.
8. The amount of sludge generated by PAC is lower than alum at the treatment plant.
9. The results of laboratory studies correlate with field studies. Hence replacement of alum by PAC can be done.
10. Based on sludge characterization results, N, P,K and metal values are higher. Further detailed studies have to be done in order to find the suitability of its application.

11. At high turbidities, the application of alum is cost effective than PAC and at low turbidities PAC seems to be cost saving.

MANUFACTURING OF BRICKS

1. Normal commercial brick are suitable to withstand a load of 12 to 15 T/brick. The silica content in the sludge is much less and hence the bricks cast did not have enough hardness.
2. The presence of higher concentration of aluminum requires higher sintering temperatures. As the quality and strength of the bricks are governed by these two properties, the alum sludge lacks very much in these aspects.
3. To conclude that the alum sludge generated at this treatment plant is not suitable for brick making. This can be uses as filler materials for road patricians. The concentration f N, P, K also discourages its use for agricultural purpose.
4. The capital cost required for establishment of facilities for Alum storage and use, PAC could be still preferred as a alternate chemical.
5. In a larger perspective the contribution of pollutant through discharge of water treatment plant sludge into the aquatic environment could be substantially reduced.

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