Environtropica, August 2013, Vols 9&10, 60-72 ISSN 1597-815X

Snail Shell as a Biocoagulant Aid for the Precipitation of Colloidal Particles in Aqua Medium

[1]Adelagun, R.O.A, [2]Oladoja N.A, [2]Ololade I.A, [3]Berezi E.P, [1]Dina O.F, [2]Bello H.A
[1]Chemistry Department, Wesley University of Science and Technology, Ondo
[2]Chemistry Department, Adekunle Ajasin University, Akungba Akoko, Ondo
[3]Chemistry Department, Bayelsa State College of Education, Brass Island, Bayelsa
Correspondence: jemiruth2009@yahoo.com Tel: 08065709024

Accepted on July 9, 2013

Abstract

Associated health and environmental problems with the use of conventional coagulants in water and wastewater treatment necessitated the need for alternative cost effective and environmentally acceptable coagulant. The ability of Snail Shell (SS) to act as a biocoagulant aid in the alum precipitation of colloidal particles in aqueous system was evaluated. Physico-chemical characterisation and mineralogical assemblage of the SS were evaluated. Synthetic turbid water of varying turbidities (50,100,300 NTU) was prepared by clay dispersion in deionised water. Both alum and SS were used separately to determine optimum dosages for the coagulation in different turbid wasters in a continuous variation in a jar test experiment. Effects of some process variables (coagulant/coagulant aid dosages and flocculation time) were also determined. The use of SS as a coagulant aid with alum precipitation showed that treated waters of lower residual turbidities were obtained from synthetic waters of high initial turbidities. Studies on the effects of flocculation time showed an optimum flocculation time of 30mins and redistribution/dispersion which was a normal phenomenon with the use of alum as coagulant did not occur when SS was used as a coagulant aid with alum.

***Key words**: Alum, Biocoagulation, Snail shell, Surface Water, Turbidity,*

Introduction

The development of innovative clean-up technologies remains a challenge as current procedures have many limitations such as being expensive, disruptive and only efficient for certain concentrations. The primary purpose of water and wastewater treatment is to remove the suspended and soluble organic constituent. Currently, the most widely used remediation techniques are based on physical-chemical processes including filtration, chemical precipitation, ion –exchange, adsorption, electro-deposition and membrane system for water treatment (Olayinka *et al.*, 2009). River water is a widely used but often unappreciated source of water. In rural and suburban areas 90-95% of the drinking water comes from river water. Other functions of rivers include removal of effluent discharges from industrial plants and sewage works as well as recreational roles and fishing (Dix 1981). Surface water contains many contaminants; organic and inorganic in nature as well as suspended particles from municipal, industrial and agricultural wastes (Ademoroti, 1986). Various types of suspended solids discharged into surface water usually undergo slow biodegradation and cause a reduction in the dissolved oxygen in water. Such suspended particles make water turbid and reduces light penetration, photosynthesis and restrict plant growth. Turbidity also reduces visibility in the water thereby limiting food capacity of many fishes. Fish and invertebrates also have their respiratory efficiency reduced because of their gills surfaces have become clogged with suspended matter (Horsfall and Spiff 1998). Coagulation- flocculation is one of the simplest and most cost effective unit operations in the treatment of water and wastewater. It involves the use of a coagulant for the removal of dissolved and suspended colloidal particles from the system (Oladoja and Aliu 2008). The efficiency of the coagulation- flocculation process varies; depends on the physical and chemical characteristics of the water and the operating conditions. Aluminium salts have being used (Diaz *et al.*, 1999) and it is by far the most widely used coagulants in water and wastewater treatment. However, several serious disadvantages of using Aluminium salts including Alzheimer's and similar health related problems associated with residual Al in treated waters have been identified (Yoko *et al.*, 1995, Pan *et al.*, 1999). Synthetic organic polymer have been used as effective coagulant aid in drinking water purification system (Bratby 1980), however, organic polymers contain contaminants such as residual monomers and other reactant and reaction by-products from the manufacturing process that could potentially negatively impact human health (Kawamura 1991; Bolto1995; Lee 1998,Ozacar and Sengil 2002).This therefore necessitates the need to develop coagulant and coagulant aid from natural sources. Coagulant aids are used in coagulation- flocculation operations, mainly to improve the efficiency of the primary coagulant and to reduce cost. The choice of a material as a coagulant is premised on the particular physical or chemical property of the colloidal particulates of the water on which the operation is to be performed (Oladoja and Aliu 2008). Owing to inherent drawbacks associated with the use of conventional coagulants, research recently focuses on the use of biocoagulants and bioflocculants (Chem *et al.*, 2003, Strand and Varumik 2003,Tripathy *et al.*, 2001). Some of the coagulants and flocculants of biological origins that have been used include chitosan (Roussy *et al.*, 2004), tannis (Ozacar and Sengil 2002), moringaoleifera (Ndabingengesere and Narasiah1998), plantain peelings ash (Horsfall and Spiff 1998), extract of okra and Nirmali seeds (Al-Samawi and Shkralla1996).

The use of calcium-rich materials in the water industry have been studied and reported by different researchers. Traditionally, limestone is used as coagulant – aid (an adsorbent weighting agent) in the treatment of low turbid water (Jessey and Sydney 1971). In addition, it provides alkalinity to its adsorbent –weighting action. The use of limestone (calcite) e.g. sludge from fuller –earth production, blast furnace slag, fly ash etc has been reported as coagulant aid in the treatments of petroleum refining wastewater (Dermici *et al.*, 1991) and phosphate removal from aqueous medium (Vigneswaran and Visvanathan1995, Moon *et al.*, 2007). In the present study, the shell of Africana Land Snail, calcium- rich material is being proposed as a coagulant aid in the alum precipitation of colloidal particles from aqua medium. Gastropod (snails and slugs) is a class under phylum mollusc. The African Land snail is classified as Achatinaachatina. The snail shell (SS) has the same basic construction as other mollusc shells. Basically, the SS consists mainly calcium carbonate $CaCO_3$ as well as various organic compounds (Oladoja and Aliu 2009; Oladoja *et al.*, 2010). The present investigation studied the ability of the Africana Land SS to act as a coagulant aid in the alum precipitation of colloidal particles in aqueous medium. In order to achieve this, we tested the ability of alum and SS to act as coagulant separately. After confirming the coagulant abilities of both alum and snail shell separately, SS as a coagulant aid with alum the primary coagulant was then investigated. The effects of some process variables such as coagulant and snail shell dosage and flocculation time were also studied to optimize parameters in the coagulation process and the settling characteristics of the sludge produced were investigated using the Sludge Volume Index (SVI).

Materials and Methods

SS preparation and characterization

The SS was obtained after the snail has been removed in boiled water. The snail shell was first washed with tap water then rinsed thoroughly with deionized water. It was dried in the oven before it was ground in a wooden mortar and pestle. The ground SS was finally made into powder using laboratory grinding machine and sieved with a laboratory sieve of known mesh size. The $pH_{solution}$ of the SS was determined using a laboratory pH meter (Hanna, pH211 microprocessor). The bulk density, particle size distribution and the proximate chemical composition of the SS were also determined. The presence of selected metal ions in the digested SS sample was determined using atomic absorption spectrophotometer (AAS).The point of zero charge (PZC) was determined using the solid addition method (Horsfall and Spiff 1998) viz: to a series of 100 ml conical flasks, 45 ml of 0.1M KNO_3 solution was transferred. The pH_o values of the solution were roughly adjusted from 2 to 12 by adding either 0.1M HNO_3 or NaOH. The total volume of the solution in each flask was made exactly to 50 ml by adding the KNO_3 solution. The pH_o of the solutions were then accurately recorded. SS (1 g) was added to each flask and securely capped, immediately. The suspension was then manually agitated. The pH values of the supernatant liquid were recorded. The difference between the initial and final pH (pH_f) values ($\Delta pH = pH_0 - pH_f$) was plotted against the pH_0. The point of intersection of the resulting curve at which $\Delta\Delta pH$ gave the PZC. The stability of the SS was assessed by dispersing 2 g of SS, in different aqueous solutions [acidic (0.1M HCl), neutral (distilled water) and basic solutions (0.1M NaOH)]. The mixture was agitated, intermittently, for a period of 120 min. Thereafter, the mixture was filtered and the residue was dried to a constant weight. The magnitude of the difference in weight of the SS before and after soaking in different aqua medium was used as a measure of the stability of the SS in the different solutions.

Synthetic Turbid Water

Stock of the synthetic turbid water sample was prepared by adding a known quantity of pulverized clay to a known volume of deionized water. The mineralogy and geochemistry of the clay sample was studied using a Diano 2100 E-X-ray diffractometer and an AAS respectively. Synthetic water of different turbidities (50, 100, and 300 NTU) were prepared from the stock by dilution with deionized water.

Alum Solution

An accurately weighed quantity of alum [$Al_2(SO_4)_3.18H_2O$] (Merck) was dissolved in distilled-deionized water to obtain a final alum concentration of 0.1 g of alum per mL. A fresh alum solution was prepared daily for reliability of results.

Coagulation Experiment

The different studies concerning the coagulation and flocculation of the synthetic turbid water were conducted using the jar test method. The conventional jar test procedure with a six-unit multiple stirrer system was used. The optimum alum dosages ranging from 1.0

mg/L to 5.0 mg/L for the coagulation of different turbid waters (50, 100, and 300 NTU) was determined. The ability of SS to act as a coagulant in the treatment of water with low alkalinity was also assessed at varying dosages (1-7g/L) to determine the optimum SS dose. Each experiment was conducted in duplicate and the results were reproducible within values of 0.1 to 0.5 NTU. The experiment was conducted in a system containing six rectangular pales (75 x 25 cm). Briefly, the experiment involved the addition of the coagulants and/or coagulant aid to turbid water (500 mL). This was followed by rapid mixing of the mixture (i.e., coagulant plus turbid water) for 2 minutes at 200 rpm and slow stirring for 20 minutes at 45 rpm. The mixture was allowed to settle and samples were withdrawn from a 3-cm depth after 20 minutes for turbidity and pH determinations. Optimization of the coagulation process was performed by the method of continuous variations of two reaction conditions for the different turbid waters at the optimum dosage of alum, SS and alum/SS combination ratio and flocculation times (10, 20, 30, 60, 90 min).

Sludge characterization

In order to observe the settling characteristics of the sludges produced from the use of the alum–SS combination and SS alone, the Sludge Volume Index (SVI) measurements were determined over time for the sludges produced from the two processes.

Results and Discussion

Snail shell characterization

The results presented in Table 1 are the physicochemical characteristics of the SS.

Table 1.Proximate physico-chemical characteristics of SS.

Physico-chemical characteristic	Value
pH solution	8.01
Bulk density (g/cm3)	1.33
PZC	7.90
Volatile matter (%)	4.14
Ash (%)	93.76
Moisture (%)	2.10
Ca (%)	99.74
Mg (%)	0.0002
Na (%)	0.0008
K (%)	0.0009
Cu (%)	0.00002
Pb (%)	0.0005

The results of the proximate chemical composition revealed a very high inorganic fraction of the SS (ash content = 93.76%) with predominance of calcium (99.74%) amongthe selected metal ions determined. The other metal ions determined were present at trace quantities. The pH solution of the SS was 8.01, while the bulk density was 1.33 g/cm. In order to ascertain the mineral phases present in the SS matrix, it was subjected to XRD analysis. The point of zero charge of the SS surface was determined to assess and understand the influence of pH on the turbidity removal by the SS. Interaction of cations with the surface of a material is favoured at pH>pHPZC whereas the interaction of anions is favoured at pH <pHPZC. The result of the point of zero charge (PZC) of the SS was

7.9. This shows that at pH less than 7.9 the surface of the SS is dominated by positive charges, whereas at pH greater than 7.9 the surface is dominated by negative charges. The ability of the SS to function effectively and remain whole in different aqueous medium (i.e. acidic, neutral and basic medium) was assessed by dispersing 2 g of SS in different aqueous solutions (0.1 M HCl, deionized water, 0. M NaOH). The mixture was agitated intermittently for a period of 120 min. Thereafter the mixture was filtered and the residue was dried to a constant weight. The difference in weight was highest for the sample dispersed in acidic solutions (0.49 g). The difference in weight of samples dispersed in neutral and basic solutions were infinitesimal. The appreciable loss in weight observed in the sample dispersed in the acidic medium could be ascribed to the reactivity of $CaCO_3$, the main constituents of the SS in acidic medium which led to the evolution of CO_2.

Clay Characteristics

An X-ray diffractometer (Diano 2100*E) was used for the clay mineralogical analysis. A copper anticathode ($\lambda = 1.54A^o$) was used. XSPEX version 5.41 software was used in the interpretation of the diffractogram. The results obtained revealed the presence of the following clay minerals: kaolinite (27.68%); smectite (7.55%); illite (16.43%); mixed layer (i.e., smectite/ illite mixed layer) (8.48%); and quartz (39.86%). Geochemical analysis of the different clay samples was performed using AAS after the clay samples were digested in a polypropylene bottle using a mixture of HF, HCl, and $HClO_4$. Ten major elements were determined. The geochemical analysis showed the abundance of the presence of SiO_2 (50.11%), Al_2O_3 (17.00%), and structural (H_2O) (5.01%). This revealed the hydrated aluminosilicate nature of this material. The percentage oxide compositions of the other elements present was: Fe_2O_3 (1.42%); MgO (78%); CaO (6.01%); Na_2O (1.61%); K_2O (1.02%); TiO_2 (0.21%); MnO (0.001%); and P_2O_5 (0.01%).

Optimum Alum Dose Determinations

An overview of the results obtained when alum was used alone as the primary coagulant to determine the optimum alum dosage carried out in a Jar Test Experiment for each turbid water (50,100 and 300 NTU) is shown in Table 2.

Table 2: Optimum Alum Dose Determination

Alum Dose (mg/L)	300NTU	100NTU	50NTU
1.2	60	40	36
1.6	58	34	22
2.0	46	26	15
2.4	40	20	18
2.8	38	18	20
3.2	35	22	22
3.6	68	30	28
4.0	88	40	33

The turbidities of the different turbid waters decreased with increasing alum dosages. The reduction in the turbidity values continued until a minimum turbidity value was obtained, thereafter an increase in the turbidity value was observed. The smallest doses that gave optimum turbidity removal for the different turbid waters varied with the initial turbidity of the water. The higher the initial turbidity, the higher the value of the optimum alum dose used (3.2 mL/L for 300 NTU, 2.8 mL/L for 100 NTU, and 2.0 mL/L for 50 NTU). Higher residual turbidities were obtained for waters with lower turbidities than for waters of higher turbidity in the experimental runs. The observed difference in the value of the percentage turbidity removal in the different turbid waters could be ascribed to the different mechanisms of coagulation, as proposed by Ozacar and Sengil (2002). At higher turbidities, the predominant mechanism for coagulation of colloidal particles was "sweep coagulation." The large quantity of $Al(OH)_3$ precipitate was capable of sweeping the fine colloidal particles from the water. The $Al(OH)_3$ adsorbed on the surface of the colloidal particles therefore reduces the negative charge with its slightly positive charge. Coagulation is most effective with highly turbid water (300NTU) and a decrease in the pH of the residual turbidities was also observed. The initial solution pH is one of the important factors that is given higher consideration in the use of coagulation-flocculation in the water industry. This could be understood from the reported speciation of alum in water. Alum dissociates in water to give Al^{3+}, SO_4^{2-} and various alum complexes such as $Al(OH)^{2+}$, $Al(OH)_3$, and $Al(OH)_4^{\ -}$, depending on the pH of the medium. The various positively charged species that are formed may combine with negatively charged colloids to neutralize part of the charge on the colloid particles (Ademoroti 1996). The colloidal materials then come together and become incorporated into masses that can be readily precipitated. It is noteworthy that the pH of the water plays a prominent role in the determination of the hydrolysis species that is predominant in the aqueous medium. Lower pH value favours the species with higher positive charge on them. At pH below 5.0, the OH is insufficient to precipitate Al^{3+} completely, so that $[Al(OH)^{3+}]$ and $Al(OH)^{2-}$ occur. The positively charged Al attracts the colloidal particles and forms loose flocs which are not dense enough for easy macroflocformation and subsequent sedimentation. When the optimum dose is exceeded, the aggregated particles can re-disperse and this disturbs particle- settling (Chan and Chiang 1995). This has been attributed to an increase in the repulsive energy between the coagulant and the colloidal particles which causes hindrance in floc formation (Mishra *et al.*, 2004).

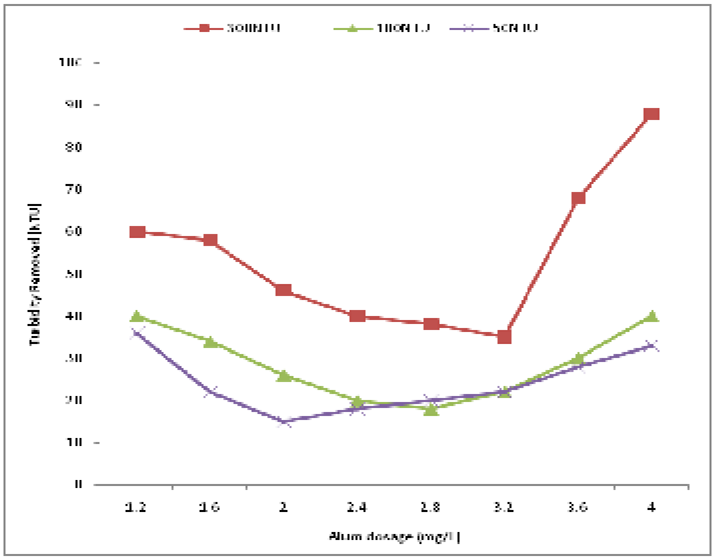

Figure 1: Determination of optimum Alum dose

Determination of optimum SS dose

In this study, a coagulation experiment was performed to examine the role of SS as the primary coagulant. Different dosages of ground SS (1-7g) were used as a primary coagulant. Results obtained are shown in Table 3 which is expressed as percentage of the turbidity removal from the aqueous system. Optimum SS dose was between 4-5 g/L.

Table 3: Optimum Snail Shell (SS) Determination

SS Dose (g/L)	300NTU	100NTU	50NTU
1.0	40	33	30
2.0	35	35	32
3.0	43	38	35
4.0	54	40	39
5.0	50	36	37
6.0	46	34	35
7.0	44	30	32

The percentage removal of colloidal particles increases with increasing SS dosage for each turbidity concentration. It was also observed that the percentage of the turbidity removed increases with increasing initial turbidity concentration. From the result obtained for the bulk density of the SS of 1.33 g/cm^3 shows that SS is denser than water (1.00g/cm^3). This implies poor solubility of $CaCO_3$ in aqueous medium, thereby making it difficult to substantiate on the mechanism of reaction of the SS. However, proposed mechanism is that of adsorption of the colloidal particles on the large surface area of the SS.

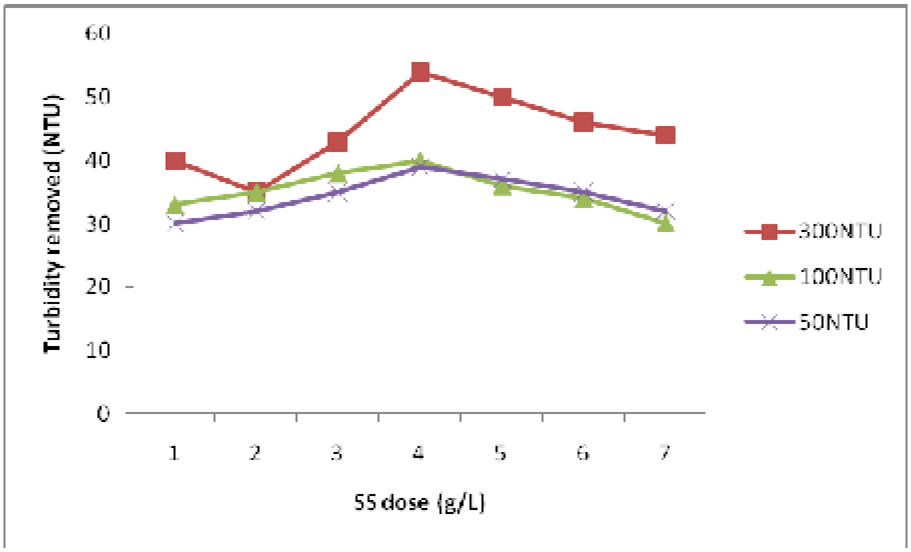

Fig 2: Determination of optimum SS dose

Studies on the use of SS as a Coagulant Aid

The results presented in Fig. 3 showed the effect of the addition of SS as a coagulant aid on the residual turbidities of the treated waters. The values of the residual turbidities of the treated synthetic waters were lower with the addition of SS than when alum was used alone.

The water with the initial highest turbidity value (i.e., 300 NTU) produced water with the highest value of percentage turbidity removal (93.33%, Table 4). This could be ascribed to the high colloid concentration in the medium which promotes interparticle bridging and macrofloc formation.

Table 4: % Turbidity removal at optimum alum dose with SS as a coagulant aid

SS Dose (g/l)	300NTU	100NTU	50NTU
1.0	68	64	45
2.0	75	76	62
3.0	80	78	68
4.0	94	91	80
5.0	84	80	75
6.0	80	75	73
7.0	75	73	69

At relatively low colloid concentrations (i.e., 100 and 50 NTU) an improvement in the value of the residual turbidity was also recorded. The results obtained from these studies compared very well with some of our past studies (Horsfall and Spiff 1998, Oladoja and Aliu 2009, Oladoja *et al* 2010). It should be noted however that despite the observed improvement in percentage turbidity removal at 100 and 50 NTU when the SS was used as a coagulant aid, the percentage turbidity removal was relatively low when the results were compared with synthetic water of 300 NTU. The relatively low initial turbidities of the waters could inhibit the rapid formation of flocs as the rate of interparticle contact is too slow to utilize destabilization by charge neutralization.

Our findings revealed that the pH of the treated water when alum was used alone was lower than the initial pH of the turbid water than when SS was used as a coagulant aid in all the studies carried out (i.e., water of different turbidities). When SS was used with the coagulant aid, the pH values of the treated waters were higher than the respective initial pHs (fig. not shown). The observed pH elevation increased with an increase in SS dosage. Proposed mechanism for this observation is that the dissolution of alum in water furnishes the aqua medium with H^+, which decreases the pH of the medium. When alum is used with the SS, the SS used acts as a reservoir of OH^- ions, thereby reducing the effect of the H^+ ion generated by the dissolution of alum, and the acidity effect is reduced thereby increases the pH. The removal could be ascribed to the alkaline nature (pH 8.01) and the neutralizing ability of the coagulant aid (SS) used. The SS served as the reservoir of alkalinity and help to neutralize the acid produced from the hydrolytic chemistry of aluminium ion. Solution pH during coagulation affects the chemistry of the coagulant. The traditional coagulants, alum and ferric salts, undergo a hydrolysis reaction upon their addition to water, forming a series of products, e.g.

Monomeric aluminium species	($Al(OH)^{2+}$, $Al(OH)^{2+}$ and $Al(OH)_4^-$)
Dimmer Aluminium species	$(Al_2(OH)_2^{4+}$
Trimmer Aluminium species	$(Al3(OH)_4^{5+}$
Tridecamer Aluminium specie	$(Al_{13}O_4(OH)_{24}^{7+}$
Amorphous precipitate	$(Al(OH)_{3(am)}$

Yan *et al.*2008, Oladoja and Aliu 2009 studied the hydrolysing behaviour of $AlCl_3$ and found that the minimum solubility was obtained at a pH of 6.3. Therefore, at a pH higher than 6.3, the hydrolysis products of alum are high molecular weight polymer or sols, which efficiently remove particles through bridging or sweeping flocculation; at a pH slightly lower than the minimum solubility pH of the coagulant, the hydrolysis products of alum are mainly medium polymer or monomers, which have a high ability to remove dissolved organic carbon by complex adsorption, charge neutralization or co-precipitation (Oladoja and Aliu 2009).

Naturally, the hydrolytic chemistry of aluminium ion causes a decrease in the pH of the treated water and makes floc formation difficult but the SS created an enabling environment for floc formation and confirmed the neutralizing ability of the coagulant aid used, aside its role as a weighting agent (Horsfall and Spiff 1998; Oladoja *et al* 2010). In addition to the role of SS, identified above, their large surface areas also confer adsorbent properties on it. Owing to the predominance of $CaCO_3$ in the coagulant aid used, the hydrolysis reaction of calcite ($CaCO_3$) could be used to elucidate the surface reaction of the SS at different pH values. The measurement of the PZC of the SS showed that the PZC occurs at about pH 7.9. From the results of the PZC it could be inferred that the colloids would be chemically adsorbed onto SS at pH values greater than the pH of PZC. For pH between 7 and 8.2, the adsorption seems to be due to both electrostatic and chemical interactions (Karageorgiou *et al.*, 2007).

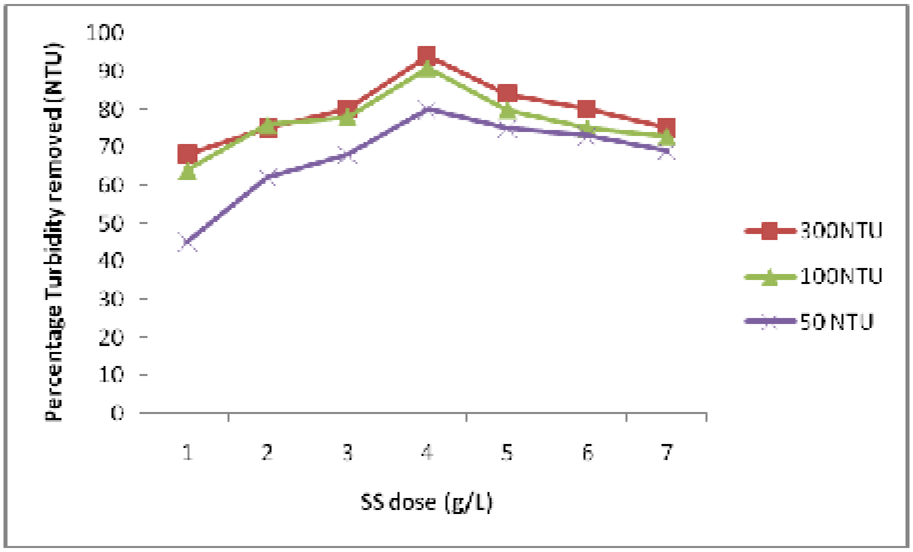

Fig 4: Effects of SS as a coagulant aid at optimum alum dose

Effect of time

Flocculation time is one of the paramount factors considered in the coagulation/flocculation process. The effect of flocculation time was studied at the optimum alum/SS ratio and varied between 10-90 minutes. The results obtained are presented in Fig 5. Past works (Mishra et al., 2004) have reported an optimum flocculation time of 30 minutes when natural polyelectrolyte, alunite and tannin were used, respectively as coagulant and coagulant aid in water treatment. The increase in the residual turbidity after the optimum time has been ascribed to the possibility of redispersion and restabilisation of flocs at higher flocculation time (Sengil 1995). This phenomenon of redispersion and restabilisation was not observed when the SS was used as coagulant aid with alum; instead a reduction in the value of the residual turbidity was recorded over the entire period of studies (90 min).

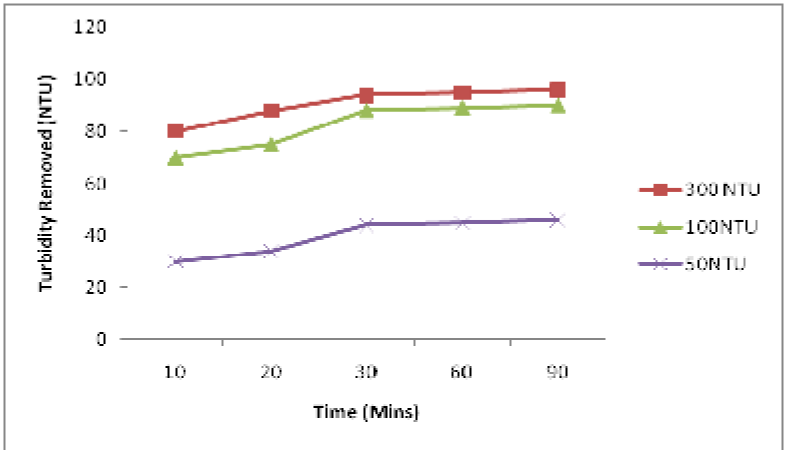

Fig 5: Effect of flocculation time on residual turbidity

Settling characteristics of sludge

The settling characteristics of the sludge produced from the use of SS/alum combination and SS alone were determined using the sludge volume index (SVI). The SVI was measured over time for the two modes of treatment processes and the results obtained are presented in Fig. 6. A good sludge should have an SVI less than 80 mg/g and a very good one around 50 mg/g. An SVI greater than 120 mg/g indicates poor settling characteristics (Gray1999). An overview of the results obtained from the two processes showed that the SVI of the sludge produced from the use of SS only was better than the SVI of the sludge produced from the SS/alum combination in the first 10 min of study. At 30 min of study, a reverse in trend of the SVI of the two sludge produced was noticed and the SVI of the sludge produced from the alum/SS combination was < 80 mg/g while the SVI of the sludge from SS only was > 80 mg/g. At 120 min the SVI of the sludge from SS/alum combination was < 50 mg/g while the SVI of the sludge from SS alone was just < 80 mg/g.

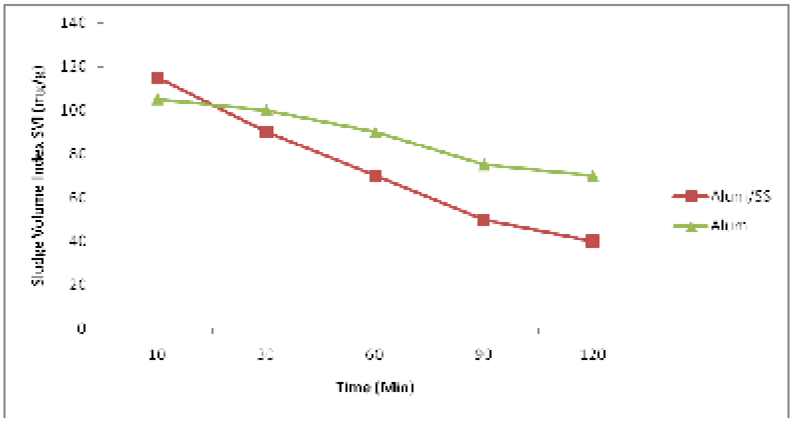

Fig 6: Determination of sludge characteristics over time

Conclusion

Apart from the aesthetically displeasing appearance that high turbidity impart to water, it also provides site for biological organisms growth and interferes with disinfection during water treatment. The maximum turbidity of 1NTU is allowable in drinking water (USEPA1991). Alum is a widely used coagulant in wastewater treatment, however as already stated medical reports have indicated that Al might induce Alzheimer's disease while residual Al concentration in drinking water can also impose health problems apart from the production of large amount of sludge (Buthelezi et al., 2009), therefore the use of high concentration of Al in the treatment of water must be avoided. In this study, the use of Snail Shell (SS) as a coagulant aid in the alum precipitation of colloidal particles was studied and the effects of some process variables (Coagulant/coagulant aids dosage and flocculation time) were optimized by the method of continuous variation. Precipitation of colloidal particles in aqueous medium via alum with the use of SS as coagulant aid can be enhanced. Restabilisation and redistribution which is normally encountered in the sludge precipitate obtained during alum coagulation was not experienced when flocculation time was optimized in this study. Also the alum sludges apart from being voluminous are gelatinous, acidic and difficult to dewater and dispose in the environment (Al-Samawi and Shkralla1996). The SVI (mg/g) monitored over time showed that the sludge obtained from the alum/ SS combination had better settling properties than the sludge obtained when alum was used alone.

References

Ademoroti C.M.A *1996 Environmental Chemistry and Toxicology* 1996, Foludex Press, Ibadan, Nigeria

Al-Samawi A.A, Shkralla E.M1996 An investigation into indigenous natural coagulant, *J EnvSc Health*,143 1881-1897

Bolto, B.A. 1995. Soluble polymers in water purification Programme *Poly Science*, **20:** 987-1041

Bratby, J. 1980 *Coagulation and Flocculation* Upland Press, England

Buthelezi S.P, Olaniran A.O, Pillay B 2009 Turbidity and microbial load removal from river using bioflocculants from indigenous bacteria isolated from wastewater in South Africa. *African Journal of Biotech* **8** (14) 3261-3266

Chan W.C and Chiang C.Y 1995 Flocculation of clay suspensions with water-insoluble starch grafting Acrylamide/sodium allysulfonated copolymer powder, *App. Poly Sci.***58**:1721-1726

Chem L. Chen D, Wu C 2003 A new approach for the flocculation mechanism of chitosan. *J.Polym Environ***11** 03) 87-92

Dermici S, Edorgan B, Ozcimder R 1991 Wastewater treatment at the petroleum refinery, Kirkale, Turkey , Using some coagulants and Turkish clay as coagulant aids *Water Res***32** (11) 3495-3499

Diaz A, Rincon N, Escorihuela A, Fernandez N, Chacin E, Forster C.F 1999 MoringaSeed and Pumice as alternative natural materials for drinking water treatment .*Process Biochem***35**:391-395

Dix H.M 1981 *Environmental Pollution* VaitBallon Press Inc, New York, USA

Gray N.F 1999 *Water Technology: An introduction for scientist and engineer*, Arnold, London.

Horsfall M, Spiff A.I 1998 *Principles of Environmental Chemistry.* Metroprints Ltd, Port Harcourt , Nigeria

Jessey M.C, Sydney A.H 1971 *Coagulation and flocculation in water quality treatment: A handbook of public water supply*, America waterworks Association Inc.

Karageorgiou K, Paschelis M, Anastassaki G.N, 2007 Removal of Phosphate species from solution by adsorption onto calcite used as natural adsorbent. *J. Hazard Mat***139B** 447-452

Kawamura S 1991 Effectiveness of natural polyelectrolyte in water treatment. *J. Am Water Assoc***83**:88-91

Lee J.F, Liao P.M, Seng D.H, Wen P.T 1998 Behaviour of organic polymers in drinking water purification . *Chemosphere***37** 1045-1061

Mishra A, Yadav M, Agarwal B, Rajani S 2004 Use of polyacrylamide-grafted*Plantagopsyllium*mucilage as a flocculants for treatment of textile wastewater. *Colloid Polymer Sci.***282**;722-727

Moon Y.H, Kim J.G, AhnJ.S , Lee G.H, Moon H.S 2007Phosphate removal using sludge from fuller's earth production. *J. Hazard Mat***143** 41-48

Ndabingengesere A. and Narasiah K.S, 1998 Quality of water treated by coagulant using moringaoleifera seeds.*Water Res***32** 781-791

Oladoja N, Aliu D 2009 Snailshell as coagulant aid in the alum precipitation of malachite green from aqua system. *J. Hazardous Mat.***164**, 1496-1502

Oladoja N, Aliu D, OfomajaA. E 2010 Evaluation of snail shell as a coagulant aid in the alum precipitation of aniline blue from aqueous solution.*Env Tech***32** (6) 639-652

Oladoja N.A, Aliu Y.D 2008 Evaluation of plantain peelings Ash Extract as coagulant aid in the coagulation of colloidal particles in low ph aqua system. *Water Quality Res***43** (2/3) 231-238

Olayinka O.K, Oyedeji O.A, Oyeyiola O.A 2009 Removal of Cr and Ni from aqueous solution by adsorption on modified coconut husk. *African Journal of Sc. and Tech,* **3** (10) 286-293

Ozacar M, Sengil I.A, 2002 Effectiveness of Tannis obtained from valonia as a coagulant aid for dewatering of sludge, *Water Res***34** (4) 1407-1412

Ozacar M, Sengil I.A,2002 Enhancing phosphate removal from wastewater using polyelectrolyte and clay injection *J. Hazard Matter***100**: 131-146

Pan R.J, Huang C, Chen S, Chung Y.C,1999 Evaluation of modified Chitosan biopolymer for coagulation of colloidal particles. *Colloid Surfaces A.***147:**359-364

Roussy J, Vanvonpren M, Guibal E, 2004 Chitosan for the coagulation and flocculation of minerals colloids. *J. DisperSc. Tech* **25** (5) 663-677

Sengil I.A 1995 The utilisation of alunite ore as a coagulant aid. *Water Res* **29** (5) 1988-1992

Strand S.P, VarumikOstgaard K, 2003 Interactions between Chitosan and bacteria suspension-adsorption and flocculation. *Colloids Surface B* **27**(1), 71-81

Tripathy T, Bhagat R.P, Singh R.P 2001 The flocculation performance of grafted sodium alginate and other flocculants in relation to iron ore slime suspension. *EurPolym J.***37** (1) 125-130

United State of America Environmental Protection Agency (USEPA) 1991 Is your drinking water safe? (WH-550) *EPA 570/9-91-005* Washington DC.

Vigneswaran S and Visvanathan C 1995 *Water treatment processes: simple options*, CPR Press Inc, New York pp 215

Yan M, Wang D, J.N, J. Qu, CWK Chow and H. Liu 2008 Mechanism of natural organic matter by polyaluminium chloride: effect of coagulant particle size and hydrolysis kinetics *Water Res* **42**:3361-3370

Yoko H, Natsuda O, Hirose J, Hayshi S, Takasati Y, 1995 Characteristics of biopolymers flocculants produced by Bacillus Sp. PY-90. *J. Ferm Bio Eng* **79**:378-380