Original Research Article

FLOCCULATING PROPERTIES OF A BIOFLOCCULANT PURIFIED FROM *BACILLUS SUBTILIS* ISOLATED FROM THE STREAM SEDIMENTS OF ONYEARUGBULEM MARKET, AKURE, NIGERIA.

Abstract

Soil samples (sediments of stream, its bank and abattoir soil) were collected from Onyearugbulem market abattoir, Akure, Ondo State, Nigeria. Bacteria were isolated from the above soil samples by dilution and pour plate methods. Screening for best bioflocculating bacteria was also performed. Effects of metal ions (such as Mg^{2+}, Ca^{2+} and Al^{3+}), temperature and pH on flocculating activities of the bioflocculant were also determined. Six bacterial isolates producing flocculating substances were isolated and the isolate with the best flocculating property was selected. The identified bioflocculant producing bacteria are *Bacillus anthracis, B. subtilis, B. thuringiensis, B. cereus, Streptomyces griseus* and *S. somaliensis.* The best bioflocculant producing bacterium was *Bacillus subtilis* and the flocculating activity of its bioflocculant was stimulated in the presence of Mg^{2+}, $Ca^{2+}$and Al^{3+}. This bioflocculant was thermostable and retained more than 80% of its flocculating activity after being heated at 100^{o}C for 25 minutes. It had the highest flocculating activity of 85% at pH 6 with optimum bioflocculant dosage of 0.8 mL. This study suggests soil samples from Onyearugbulem market abattoir as a potential source of bioflocculant-producing bacteria with good bioflocculating properties.

Key Words

Bioflocculant, Onyearugbulem stream, pour plate, metal ion, flocculating property, thermostable.

Introduction

Flocculation is a form of chemical reaction that involves the addition of clarifying agents such as Iron (II) sulphate, Aluminium sulphate, and Iron (II) chloride in water treatment which results in the formation of colloids (Vasantharaj *et al.*, 2013). It can also be described as a physical and chemical process used for the removal of the visible sediments and material from water which makes it a colloidal solution. Flocculation can be carried out through agitation or by the addition of flocculating agents (Moghimipour *et al*., 2014). Bioflocculants are microorganism-produced special natural inorganic macromolecule substances that can flocculate suspended solids, cells, colloidal solids etc (Zaki *et al.*, 2011). Several biopolymer flocculating microorganisms have been screened and isolated from activated sludge, waste water, and soil (Zaki *et al.*, 2011). Species of microorganisms that have bioflocculant producing characteristics include bacteria (such as *Bacteroidites, Bacillus* sp., *Bacillus muscilaginosus*, *Bacillus subtilis*) fungi, actinomyces and algae (*Chlamydomonas reinhardtii, Chlorella minutissima Arcobacter*, *Cellulosimicrobium cellulans*, *Aeromobacter xylosidans*,) (Okaiyeto *et al.*, 2013). Bioflocculants stand out among others as they have the advantage of innocuousness, biocompatibility, biodegradability and environmental friendliness, unlike organic and inorganic flocculants which are toxic and whose degradation intermediates are difficult to remove from the environment (Okaiyeto *et al.*, 2015). Besides, organic flocculants such as polyacrylamide and polyethylene imine derivatives have been involved in adverse human health effects (Nwodo *et al*., 2014). Conversely, the enormous advantages associated with bioflocculants motivate its consideration as an alternative, hence the vast interest in the scientific and industrial community worldwide (Nwodo *et al*., 2012).

Materials and Methods

Description of study area

Onyearugbulem abattoir was selected as the study area because of its location in the large expanse of built up area comprising of low medium and high income earners with residential buildings in the north by office complexes and west and east by private schools and ships. The abattoir is about 50 meters off the express (Ilesha-Owo) and covers about 1000m^2 land mass.

Period of study

This research was carried out from October 2016 to September 2017. The first set of soil and water samples were collected in October 2016 which were immediately analysed. Samples were thereafter collected as required based on failure in experimental set up.

Sample Collection

Soil sample from the Onyearugbulem abattoir slaughtering site and stream bank, was collected with the aid of an auger. The soil was dug in a V-shape to a depth of about 0-5cm, thin slices of the soil was removed from the sides and transferred into a clean container. With the aid of an auger, composite sediment was taken upstream where it was maximally free from contaminants (Nontembiso *et al*, 2011). Well water was collected with the aid of a sterilized fetching bucket into a clean 50 liter container. Stream water was collected at three different points (upstream, mid-stream and downstream) together with a clean bowl into a clean 50 L container. Abattoir waste effluent was collected directly from abattoir drainage into a clean 50 L container.

Physicochemical Properties of the Soil and Water Samples

The physicochemical properties (pH, exchangeable magnesium and calcium component, particle size analysis, nitrogen, phosphorus, carbon, sodium, potassium and organic content

determination) of the soil samples used for the isolation of bioflocculant producing bacteria were determined according to Association of Analytical Chemists (A. O. A. C, 1990). Collected water samples were subjected to chemical analysis such as Dissolved oxygen, pH, Electrical conductivity, Total Dissolved Solids, Chloride content, Nitrate, Phosphate, Magnesium content and total hardness before their respective treatment.

Determination of the pH of Soil Samples

Twenty grams of each soil sample was weighed and put in a 100 ml beaker. Twenty milliliters of distilled water was added to the sample. The suspension was left for 2 minutes, with occasional stirring using glass a rod by hand in order to enable it reach equilibrium. The pH of the suspension was determined using a pH meter (AOAC, 1990).

Determination of exchangeable magnesium and calcium component of soil sample using EDTA titration method

One litre standard flask was filled to the half mark with distilled water and 60 ml concentrated acetic acid and 70 ml ammonia solutions were added. The mixture was shaken together and was made up to 1 liter mark with distilled water. This mixture was left to settle overnight. A 10g quantity of soil sample was weighed into beaker and 100 ml ammonium acetate was added and the mixture was stirred and allowed to stand for 1 hour. The mixture was then filtered using whatman filter paper (pore size 2.5µm). The filtrate was collected and bottled. A 50 ml burette, which previously had been washed and dried was filled to the level mark with 0.01M EDTA solutions. The filled burette was placed vertically on a retort stand. 10 ml of the prepared soil sample solution was then pipette and transferred into 250 ml conical flask. Five drops of 2% KCN was then added. A 7 ml volume of concentrated ammonium solution was

added. Three drops of Eriochrome Black T indicator was then added and a wine red colour was obtained. The titration was repeated and the mean values were calculated. To obtain Ca^{2+} alone, 10 sml of the sample was pipette into a 250 ml conical flask. Five drops of 2% KCN, 5 drops of 5% hydroxyl ammonium chloride and 5 ml 20% KOH solution were added respectively. A pinch of calcium indicator was added to the mixture. The resulting solution was then titrated with 0.01M EDTA solution. The titration was repeated and the mean value was found. To determine Mg^{2+} ions in the solution, the value obtained for Ca^{2+} was subtracted from the total value obtained for Ca^{2+}/Mg^{2+} (AOAC, 1990).

Calculation:

$$\%\ Calcium\ (Ca) = \%\ Magnesium\ (Mg)$$

$$\frac{Ca^{2+}}{Mg^{2+}} - Ca^{2+} = Mg^{2+}$$

T = Titre value obtained from EDTA titration

M = Molarity of acid used

V_1= Total volume of initial extracting solution

V_2 = Volume of extracted solution used

W = Weight of soil sample

40 = Atomic weight of calcium

24 = Atomic weight of magnesium

Analysis of Particle size of Soil Samples

This was done using the hydrometer method. Those soil particles (Coarse fragment) that did not pass through the 2mm sieve were weighed and reported as a percentage of the whole weight. 50g of the fine earth fraction (greater than 2mm fraction) were put in a beaker and 100ml of 5% dispersing agent, sodium haxametaphosphate, added. The suspension was mixed with a stirring rod and allowed to soak for 30 minutes before transferring it to the bottled cup. The bottle cup was attached to the stirrer and stirred for three minutes to ensure breakage of soil aggregates. The suspension was poured into cylinder and made up to mark, stirred and both hydrometer and thermometer were inserted at specified time intervals to take readings (40 seconds for silt and clay reading and end of two hour for clay).

The formula below was used in their calculation

a. For an increase in temperature above 20°C

$$\frac{X + 9\ (Y\ x\ 0.36)}{W}$$

b. For a decrease in temperature

$$\frac{X+9\ (Y\ x\ 0.36)}{W}$$

Where X = hydrometer reading at specified time

Y= differences between hydrometer calibrated temperature and the temperature of the solution at specified time.

W = weight of the fine earth fraction used.

Percent silt was derived by subtracting the calculated percent clay from that of silt and clay subtracting percent silt and clay from 100 gives the percent sand. From the texture triangle

diagram, percent clay, silt and sand were used to draw lines parallel to the bottom, left side and right side of the triangle respectively. The area in which these lines intersect gives the class name or texture of the soil. Where the intersecting lines fall on the line between two textual names. The name of the finer fraction was used. The suspension was decanted and the process repeated until the supernatant became clear. The sand fraction was transferred quantitatively into a small beaker and dried in oven at a temperature of 105°C; it was cooled in a dessicator after which the sand fraction was weighed. It was passed through 0.2mm- 0.02mm sieve and the coarse fraction remaining on the sieve was also weighted. The total sand weight minus the coarse and fraction weight gives the fine sand fraction weight. They were expressed in percentage.

Percent clay: (% clay) =

$$\frac{h_x \times 100}{w}$$

Where h_x is the hygrometer reading at 6 hrs 52 mins and w is the weight of sample.

Percent silt: (% silt) =

$$\frac{h_y \times 100}{w} - C(\%)$$

Where C (%) is percentage Clay, h_y is the hygrometer reading at 40 sec and w is the weight of sample.

Percent sand: (% sand) = $100\% - S(\%) - C(\%)$

Where S (%) is percent silt and C (%) is percent Clay.

Determination of available phosphorus of soil samples

Air-dried soil sample (5g) was weighed into a beaker and 35 ml of phosphorus extracting solution, NH_4Cl was measured and added to the content of the beaker. The mixture was well stirred for 5 minutes before filtered using Whatman filter paper No 1 of which 4 ml of the filtrate was pipetted into a test tube and 4 ml of ascorbic acid was also added. The resulting mixture was allowed to stand for 30minutes on a test tube rack for colour development. The color developed was blue and the procedure was repeated for the other samples. The standard was also prepared by measuring 0.5 ml of 100ppm phosphorus standards and adding 4 ml of indicator M and R solution. Twenty five millilitres of distilled water was added. The solution was transferred into another test tube. A blank was prepared by measuring 4 ml of the ascorbic acid reagent and 25 ml of distilled water into another test tube. The available soil phosphorus absorbance was read at 660nm wavelength using the corning colorimeter model 253 (AOAC, 1990).

Determination of total nitrogen content of soil samples

A gram of each of the soil samples, which previously has been ground and sieved in a 2mm wire mesh was weighed and transferred into a 500 ml micro-Kjeldahl flask and 20 ml concentrated $H_2SO_4$was added, the mixture was swirled for a few minutes and was allowed to stand for about 30 minutes. A 20 ml concentrated copper oxide catalyst was added to the mixture. The flask was then transferred to a mechanical heating mantle. The heater was placed in the fume cupboard connected to the electrical outlet socket and was switched. The flask was then left to boil for about 5 hours in the fume cupboard. After the digest has been observed to be clear of H_2SO_4 fumes in the flask, the heater was then switched off. The micro-Kjedahl flask was then removed from the heater and allowed to cool. The digest was then decanted into another flask.

100 ml of distilled was then added to the content of the flask. The micro-Kjedahl flask was then attached to the distillation apparatus. 10 ml of 40% NaOH solution was added through the funnel stop cork of the distillation apparatus. A 50 ml boric acid with indicator solution was transferred into 25 ml conical flask. The flask was then placed under the condenser of the distillation apparatus. The tip of the condenser was positioned such that it was about 4mm above the surface of the boric (H_3BO_3) solution in the conical flask. The digest was then distilled by allowing hot steam pot to pass from the steam pot into the digest in the micro-Kjedahl flask, thereby causing the digest to boil and distill over into boric acid. After about 150 ml of the distillate had been collected in boric acid, the distillation was stopped. The distillate was then titrated with 0.5 M standard hydrogen cholride. The colour change at the end point was from green to pink (AOAC, 1990).

$$\% \text{ Nitrogen} = \frac{M \times T \times 0.014 \times V1 \times 100}{W \qquad V2}$$

M = Molarity of acid used

T = Titre volume

V_1 = Volume of digest

V_2 = Volume of digest used

W = Weight of sample

0.014 = Multiplication factor (i.e. milligram equivalent of nitrogen in ammonia)

Determination of organic carbon content of soil samples

Five grammes of sample was placed in a ceramic crucible and then heated at 350°C overnight. The sample was then cooled in a desiccator and weighed.

$$\text{Organic matter content} = \frac{\text{Initial} - \text{Final Sample Weight}}{\text{Initial Sample Weight}} \text{ x } 100$$

All weights were corrected for moisture water content prior to organic matter content calculation. To convert the organic matter to total organic carbon content, a conversion factor of 1.724 was used based on the assumption that organic matter contains 58% organic carbon (AOAC, 1990).

$$\text{Organic Carbon (g)} = \frac{\text{Organic Matter (g)}}{1.724}$$

Determination of exchangeable sodium and potassium of the content of soil samples using Flask emission Photometry method

Ammonium acetate extracting solution was used for the extraction of Na and K in the soil sample. The procedure was observed for the exchangeable Mg and Ca preparation. A 10g of soil sample was weighed into a baker; 100 ml of the ammonium acetate solution was added. The mixture was then filtered using Whatman filter paper. The filtrate was collected, bottled and labelled. The exchangeable Na and K were determined using the flame photometer according to AOAC, 1990.

Calculation:

$$\text{Sodium (Na) or Potassium (k)} = \frac{\text{R x V x D}}{\text{W}}$$

R = Reading

V = Volume of extracting solution used

D = Dilution factor

W = Weight of soil sample used

Determination of organic matter

1g was weighed and transferred to 250-milliliter conical flask. A 10ml of $K_2Cr_2O_7$ Pottassium hepta dichromate was added and swirled to mix. 20 ml of concentrated sulphuric acid H_2SO_4 was rapidly added, shaken and allowed to stand for 30 minutes. The mixture was diluted with 100 ml of distilled water and five drops of ferroin indicator added, it was then titrated with 0.5N ($FeSO_4$) ferrous sulphate (Carter, 1992).

A blank titration was prepared in the same was (without soil) to standardize the dichromate solution. Percent organic matter was subsequently calculated, using the formula below;

$$\% \text{ Organic Carbon} = \frac{(B-T)x\ M\ x\ 0.003\ x\ 1.33\ x\ 100}{W=\text{Weight of sample}}$$

Correction Factor (CF) = 1.33

M = Molarity of solution x ml of solution used

W= Weight of sample

% Organic matter soil = % organic C x 1.729

Determination of pH for water samples

This was determined as described by Ademoroti (1996). The Jenway 3015 pH meter was first standardized using standard buffer solutions of pH 4 and pH 9. The pH of the sample water was determined by using pH meter on arrival at the laboratory. The electrode was carefully suspended in the sample and allowed to stand until the reading was steady before the reading was finally recorded.

Determination of electrical conductivity (EC)

The samples were thoroughly mixed together thereafter; an aliquot was taken into the meter sample holder. The sample holder was then properly placed into a colorimeter. Immediately the reading knob was depressed, the reading was taken and recorded (Ademoroti, 1996).

Determination of Total Dissolved solids

The sample was first filtered using a whatman filter paper. Fifty millilitres (50 ml) of the filtrate was then transferred into a previously weighed evaporating dish. This was evaporated to dryness on an electric hot plate before drying to constant weight in the oven at 105^{o}C. The weight of the dish was subtracted from the final weight (mg) of the total dissolved solid.

$$Total\ Dissolved\ solid\ \left(\frac{mg}{L}\right) = \frac{Total\ Dissolved\ Solid\ (mg) X\ 1000}{filtrate\ taken\ (ml)}$$

Determination of Chloride

The Mohr method as described by AOAC (1990) was used, 100ml of the sample was measured into a conical flask and a pinch of powder $CaCO_3$ was added. This was following by addition of 2ml of the indicator. The whole mixture was then titrated against standard $AgNO_3$

solution to a permanent reddish-brown precipitate A blank titration was equally carried out by substituting the sample with distilled water.

$Ag^+ + Cl^- \rightarrow AgCl$

$2Ag^+ + CrO_4^{2-} \rightarrow Ag_2CrO_4$

The chloride was expressed as

$$Cl\ \left(\frac{mg}{L}\right) = \frac{(A-B)\ X\ M\ X\ 70{,}900}{ml\ of\ sample}$$

where A= ml of $AgNO_3$ for sample

B= ml of $AgNO_3$ for blank

M= molarity of $AgNO_3$

Determination of sulphate

The turbidity method was employed by using $BaCl_2$ as precipitant as described by Ademoroti, (1996). Ten millimeters (10 ml) of the sample was introduced into 25 ml volumetric flask and 10 ml of distilled water was added. This was following by addition of 1ml of gelatin-$BaCl_2$ reagent. The mixture was made up to mark with distilled water. The mixture was allowed to stand for 30 minutes before the optical density was determined at 420nm.

Calculation

$$SO_4\ \left(\frac{mg}{L}\right) = \frac{mass\ of\ SO_4\ from\ curve\ X\ 1000\ X\ D}{ml\ of\ sample}$$

where D is the dilution factor

$$D = \frac{total\ volume\ of\ mixture}{sample\ volume}$$

Determination of Phosphate

Vanado-Molybdophospheric acid colormetric method as described by Ademoroti (1996) was used. Vanado-Molybdo-Phosphoric Acid Colometric Method: Excessive color of sample was removed by shaking 50 ml portions of each with about 0.2g activated carbon type No 33033 is an Erlenmeyer flask about 5 minutes. It was then filtered through whatman filter paper.

Standard phosphate solution

0.1295g anhydrous $KHPO_4^{3-}$ was accurately weighed with the aid of an analytical weighing balance. It was then dissolved in 1 liter of distilled water. Serial dilution was thereafter prepared from the standard solution.

Calculation

$$\frac{mg}{PO_4^{3-}}\ P = \frac{(reading\ from\ curve\ X\ 1000\ X\ D)}{ml\ of\ sample}$$

Determination of Hardness

The total hardness was determined using titration method (Ademoroti, 1996). A 25 mL of water sample was diluted to 50 mL with distilled water in a conical flask. A milliliter of the buffer 10 solution was added and a pinch of solochrome black T indicator and KCN (for masking) were added and titrated against 0.01M EDTA to the final end point which is blue.

$$Total\ hardness\ (EDTA) as\ \frac{mg}{L}\ \mathrm{CaCO3}\ = \frac{(V\ X\ A\ X\ 1000)}{ml\ of\ sample}$$

Where V = ml titration for the sample

A= mg $CaCO_3$ equivalent to 1ml EDTA titrant

Determination of Alkalinity (Hydroxide, Carbonate and Bicarbonate)

A few drops of phenolphthalein were added to 20ml of water sample in a 50ml conical flask but there was no color change which indicated the absence of hydroxide and carbonate. A 2 drops of methyl orange was added to fresh 20ml of water sample in a 50ml conical flask. The colored solution was then titrated against 0.025M H_2SO_4 till the color changed from yellow to pink. Blank titration was also carried out.

$$HCO_3\ alkalinity = \frac{V\ X\ A\ X\ 1000}{ml\ of\ sample}$$

Where V = methyl orange titration

A= concentration of acid

Determination of Metals

The sample for metal analysis was prepared prior determination 5ml of concentrated HNO_3 was added to 200ml of water sample in a 250cm^3 beaker. The solution was evaporated to near dryness (less than 25 mL). After cooling, the solution was made up 2ml with concentrated HNO_3 and transferred into sample bottles prior analysis (Ademoroti, 1996). The heavy metal (Cd, Pb, Cu, Cr, Ni, Zn, Co) were determined with Atomic Absorption Spectrophotometer (AAS) by using appropriate wavelength for each and the alkali metals (Na and K) were determined by

using flame photometer. The absorbance and the concentration of the metals were thereby obtained.

Separation and Purifiction of Bioflocculants

Purified isolates were introduced into 50ml of bio-flocculant production medium and then incubated for 3days. The culture broth was diluted into two volumes of distilled water and centrifuged at 4,000 rpm for 15 minutes. The supernatant was poured into three volumes of acetone (1:3) and added three times to precipitate the biopolymer flocculant. The precipitate was then centrifuged at 8000 rpm for 20mins and washed by ether. The crude obtained was dialyzed at $4^{o}C$ overnight in deionized water and vacuum dried overnight in a desiccator to obtain pure bio-flocculants (Elkady *et al*., 2011).

Jar test determination of bioflocculant dosage and measurement of Bioflocculaing activity

Different concentrations (0.1 to 1.0 mg/ml) of purified bioflocculant were prepared. Their flocculating activities were measured against 4g/l kaolin clay suspension. A 3.0 ml of 1% (w/v) $CaCl_2$ was added to the different concentrations of the purified bioflocculant and mixed with 100ml of kaolin clay suspension in 500ml beakers. The solution was rapidly mixed at 160rpm for 2 minutes, followed by gradual flocculation at 40 rpm for 2 minutes and sedimentation for 5minutes. After sedimentation, 2mls was gently withdrawn from the upper clarifying phase in order to measure the flocculating activity. The concentration dosage that gave the best flocculating activity was used for subsequent experiment (Elkady *et al*., 2011).

Preparation of dialyisis bag

Ethylene diamine tetraacetic acid (EDTA) (0.27g) was weighed into 100ml of distilled water which was boiled. The dialysis bag was placed in the boiling water and was made to boil.

The bag was removed and rinsed with distilled water. This process aids easy opening of the dialysis bag (Elkady *et al.*, 2011).

The flocculating ability of the bacterium polymer was measured using the equation

$$;Flocculating\ Activity\ (\%) = \frac{(B-A)}{A}\ X\ 100$$

Where A is the absorbance of the sample experiment, B is the absorbance of the control experiment at 550nm. (Cosa *et al*., 2013; Ugbenyen and Okoh, 2013).

Effects of some physicochemical factors on flocculating activity

Jar Test determination of bioflocculant dosage

0.2 to 1.0 mg/mL of the purified bioflocculant was prepared. Their bioflocculating activity was measured against 4 g/L of Kaolin clay suspension. 3.0 mL of 1% weight per volume of $CaCl_2$ was added to the different concentrations of the purified bioflocculant and mixed with 100 mLof kaolin clay suspension in 500 mL beakers. The solution was rapidly mixed at 160 rpm for 2 min, followed by gradual flocculation at 40 rpm for 2 min and sedimentation for 5 min. After sedimentation, 2 mL was gently withdrawn from the upper clarifying layer in order to measure the flocculating activity Agunbiade *et al.*, (2017).

Effect of cations on flocculating activity

According to Agunbiade *et al.,* 2017 the effect of different cations on bioflocculant production was gotten by using Na^+, K^+, Mg^{2+}, Mn^{2+}, Al^{3+} and Fe^{3+} in the place of $CaCl_2$ in the production medium.

Effect of pH on flocculating activity

With the use of 0.1 M HCL and NaOH as buffer solutions in adjusting the pH of the production medium, the effect of pH on the flocculating activity of the bioflocculant produced was gotten. pH range of 3-12 was used in this set up. (Elkady *et al*., 2011).

Effect of temperature on flocculating activity

Heat stability of the bioflocculant was evaluated by incubating the bioflocculant solutions in water bath at a temperature range of 50, 60, 70, 80, 90 and 100^{o}C for 25 minutes. Afterwards, the residual flocculating activity was determined using the protocol of Gong *et al*., (2008) and Agunbiade *et al*., (2017).

Microbial analysis of water samples

Fifth fold serial dilution was carried out on the collected water samples, using pour plate method to determine microbial load. Biochemical identification methods were employed in the identification of the isolated bacteria. Bergey's manual of determinative bacteriology was used in identification to genus level. (Omezuruike, 2008).

Statistical Analysis

Data are presented as mean ± standard error (SE). Significance of difference between different treatment groups was tested using one-way analysis of variance (ANOVA) and significant results were compared with Duncan's multiple range tests using SPSS window 8 version 20 software. For all the tests, the significance was determined at the level of $P<0.05$.

Results and Discussion

Physicochemical parameters of soil and water samples

The abattoir slaughtering site was richer in organic content (75%), organic matter (74%), phosphorus (74%), potassium (43%), sodium (62%) and magnesium (42%) than stream bank and sediment. This indicates that the site of slaughter contains higher organic nutrient than the soils of the stream bank and stream sediment. Soil from the stream sediment is sandier than others (Table 1). Abattoir waste water presented high values of the following: sodium (61%), potassium (64%), iron (45%), copper (46%), zinc (52%), pH (38%), conductivity (95%), soluble solids (37%), dissolved solids (91%), Total Dissolved solids(93%), Dissolved oxygen (99%), Biochemical oxygen demand (97%), alkalinity (97%), chloride (97%), chemical oxygen demand, (99%) hardness (81%), sulphate (91%) and phosphate (99%) when placed side by side with well and stream water from the same environment.Well water had more calcium content than abattoir waste water. Also, stream water contained more lead, cadmium and cobalt than the remaining water samples (Table 2).

Isolation of bioflocculant producing bacteria

Escherichia coli, and *Bacillus cereus* were isolated from the three soil samples, ABSS, SBNK and STSD. Among the isolates from abattoir slaughtering site are *Citrobacter freundii* ABSS, *Bacillus subtilis* ABSS and *Monococcus luteus* ABSS which were not isolated from stream bank and sediment. However, *Staphylococcus aureus* was not isolated from abattoir slaughtering site. *Proteus mirabilis* SBNK was found in stream bank but was absent in slaughtering site and stream sediment. The following organisms were isolated from stream sediment but not found in slaughtering site and stream bank. They are *Clostridium botulinum*, *Shigella dysenteriae*, *Streptomyces somaliensis* and *Salmonella typhi* (Table 3).

Table 1 Physicochemical analysis of soil samples

Soil Sample	ASS	SB	SS
pH	5.16±0.06[a]	5.23±0.06[a]	5.19±0.06[a]
MC	21.55±0.06[a]	34.25±0.06[b]	5.19±0.06[c]
OC	1.55±0.06[a]	0.17±0.06[a]	0.36±0.06[b]
OM	2.67±0.06[a]	0.30±0.06[b]	0.63±0.06[c]
N	0.40±0.06[a]	0.08±0.06[a]	0.06±0.06[b]
P	32.62±0.60[a]	25.20±0.06[b]	16.52±0.06[c]
K	1.26±0.06[a]	0.49±0.06[b]	0.28±0.06[c]
Na	1.30±0.01[a]	0.73±0.01[b]	0.44±0.01[c]
Ca	2.60±0.10[a]	1.50±0.01[b]	3.00±0.01[c]
Mg	1.30±0.10[a]	0.73±0.09[a]	1.00±0.06[b]
Sand	56.80±0.06[a]	52.80±0.06[b]	80.80±0.06[c]
Clay	27.20±0.58[a]	23.20±0.58[b]	11.20±0.58[c]
Silt	16.00±0.00[a]	24.00±0.00[b]	8.00±0.06[c]

Data are presented as Mean ± S.E (n=3). Values with the same superscript letter(s) along the same row are not significantly different ($P<0.05$).

KEY

pH – Hydrogen ion concentration, MC- Moisture Content OC- Organic Content, OM- Organic Matter, MC- Moisture Content, N- Nitrogen, P- PhosphorusK- PotassiumNa-SodiumCa-CalciumMg-Magnesium ASS-Abattoir Slaughtering Site, SB- Stream Bank, SS-Stream Sediments

Table 2 Mineral Analyses of selected water samples

Parameters	Well Water	Stream water	Abattoir waste water
Na	23.80±0.06[a]	32.90±0.90[b]	90.50±0.12[c]
K	13.70±0.12[a]	17.70±0.12[b]	56.50±0.12[c]
Mg	5.53±0.12[a]	5.89±0.12[b]	5.78±0.12[c]
Ca	40.20±0.12[a]	39.90±0.12[b]	11.30±0.12[c]
Pb	0.33±0.12[a]	0.42±0.12[b]	0.38±0.12[c]
Cd	0.012±0.00[a]	0.013±0.00[b]	0.010±0.00[b]
Cr	0.001±0.00[a]	0.001±0.00	0.001±0.00
Fe	0.31±0.00[a]	0.33±0.00[b]	0.52±0.00[c]
Cu	0.02±0.00	0.05±0.00	0.06±0.00
Ni	0.06±0.00	0.08±0.00	0.07±0.00
Co	0.010±0.00	0.012±0.00	0.009±0.00
Zn	0.40±0.01[a]	0.41±0.01[a]	0.86±0.01[b]
pH	6.49±0.34[a]	6.90±0.00[a]	8.30±0.12[b]
Cond	39.80±0.12[a]	755±0.00[b]	14480±0.00[c]
SS	1.42±0.12[a]	1.59±0.12[b]	1.73±0.12[c]
DS	342±0.00	377±0.00	7225±0.00
TDS	179.50±0.12[a]	378.72±0.88[b]	7226.73±0.12[c]
DO	5.49±0.12[a]	5.54±0.1[a]	910.41±0.12[b]
BOD	1.01±0.01[a]	1.40±0.12[b]	82.76±0.01[c]
Alkalinity	139.40±0.12[a]	320.00±0.00[b]	13600.00±0.00[c]
Chloride	73.24±0.06[a]	81.99±0.00[b]	5466.35±0.12[c]
COD	157.00±0.00	168.00±0.00	51200.00±0.00
Hardness	189.20±0.12[a]	201.60±0.12[b]	1680.00±0.00[c]
Sulphate	223.89±0.00[a]	232.01±0.00[b]	4408.35±0.12[c]
Phosphate	11.98±0.00[a]	13.68±0.00[b]	3967.180.00[c]

Data are presented as Mean ± S.E (n=3). Values with the same superscript letter(s) along the same row are not significantly different ($P<0.05$).

Table 3 Frequency of occurrence of bacteria isolated from different soils and water samples obtained from Onyearugbulem market

Suspected Organisms	WLWT	STWT	ABWW	ABSS	SBNK	STSD
1	+	+	+	+	+	+
2	-	-	-	+	-	-
3	-	+	+	-	-	+
4	-	-	-	+	+	-
5	-	-	-	+	-	-
6	+	+	+	+	-	+
7	+	+	+	-	+	+
8	-	-	-	+	+	+
9	+	-	-	+	+	-
10	-	-	-	-	-	+
11	-	+	+	-	-	+
12	-	-	-	-	-	+
13	-	+	+	-	-	+
14	+	-	+	+	-	+
15	-	-	-	+	-	-
16	-	-	-	+	+	-
17	-	-	-	+	+	-

Keys

ABSS- Abattoir slaughter site WLWT: well water STWT: stream water SBNK; stream bank ABWW: abattoir waste water STSD: streamsediments+: isolated or present -: Not isolated or present

1. *Escherichia* sp 2.*Citrobacter* sp 3.*Bacillus subtilis* 4.*Bacillus cereus* 5.*Micrococcus* sp
6.*Klebsiella* 7.*Staphylococcus* sp 8.*Pseudomonas* sp 9.*Proteus* sp 10.*Clostridium* sp 11.*Shigella* sp
12.*Streptomyces* sp 13.*Salmonella* sp 14.*Enterobacter* sp *15.Streptomyces* sp *16. Bacillus* sp *17 Bacillus* sp

Six bacteria with bioflocculating potentials were isolated. They are *Bacillus cereus*, *Streptomyces somaliensis, Streptomyces griseus, Bacillus thurigiensis*, *Bacillus subtilis* ABWW and *Bacillus subtilis* STSD. *Bacillus cereus* had its flocculating activity increase progressively with time, the same was recorded for *Streptomyces somaliensis, Streptomyces griseus and Bacillus thurigiensis*. *Bacillus subtilis* ABWW and *Bacillus subtilis* STSD had their highest flocculating activities at 144hours of production and least flocculating activity at 216 hours. *Bacillus subtilis* STSD had the highest flocculating activity at all times of production. This makes it the bacterium with the best flocculating activity of all the isolates (Figure1).

Flocculating activity increased progressively with increased dosage till it attained 90% at 0.8mg/ml dosage level which is the highest. Thereafter, a progressive decline in the flocculating activities with increased dosage level was recorded (Figure 2).

Na^{2+} had the least effect on the flocculating activity of the bioflocculant followed by K^{+}. Mg2+ had the best stimulatory effect on the flocculsating activity of the bioflocculant produced from *Bacillus subtilis*[b] (Figure 3).

Least flocculating activity was recorded at pH 4 which progressively increased to a peak of 80% flocculating activity at pH8 and steadily decreased with increased pH (Figure 4).

The temperature retaining ability of the bioflocculant shown in figure 5 indicated progressive increase in temperature. Highest flocculating activity was 80% at 100^{o}C and least was 75% at 50^{o}C.

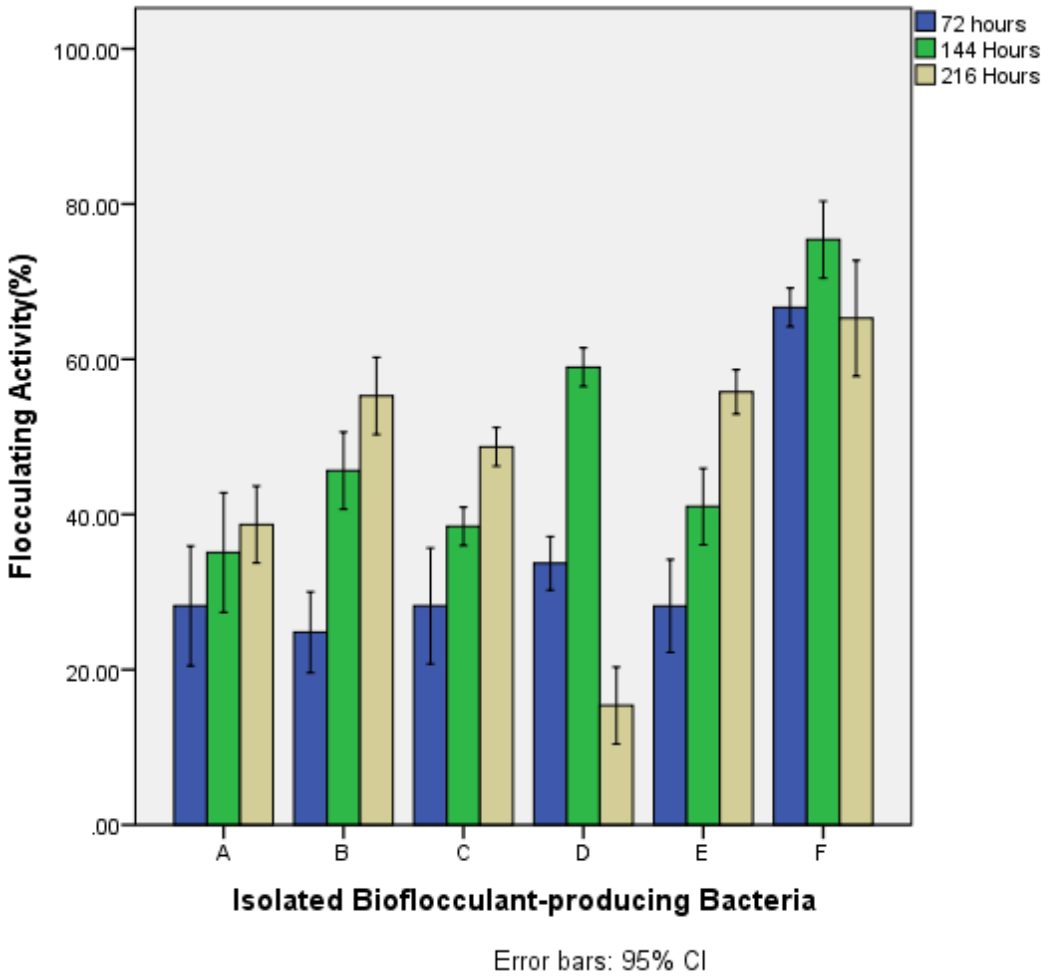

Figure 1 Flocculating activities of isolated Bioflocculant producing bacteria

KEY

A ***Bacillus cereus*** **B** ***Streptomyces somaliensis*** **C** ***Streptomyces griseus***

D ***Bacillus thuringiensis*** **E** ***Bacillus anthracis*** **F** ***Bacillus subtillis***

[Type a quote from the docume . You can position the text box anywhere in the document. Use atting of the pull quote text box.]

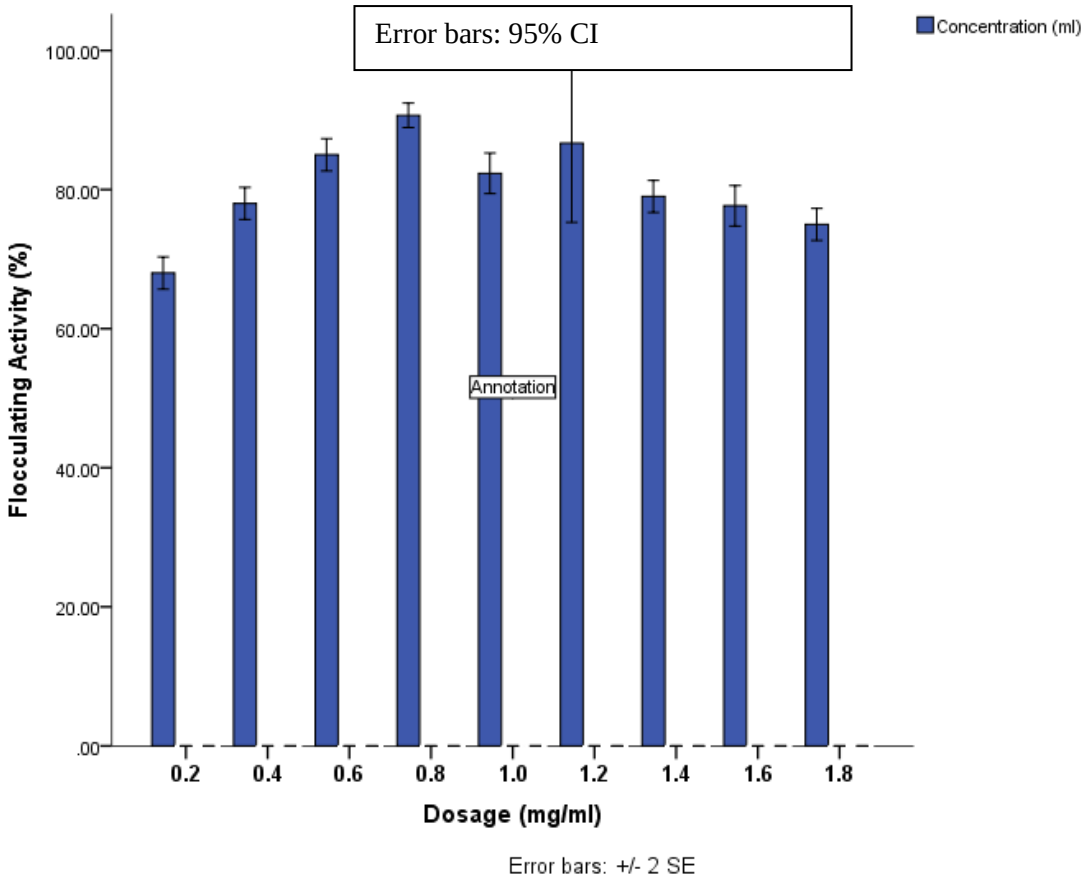

Figure 2 Effect of Treatment dosage on flocculating activity of the bioflocculant purified from *Bacillus subtilis*

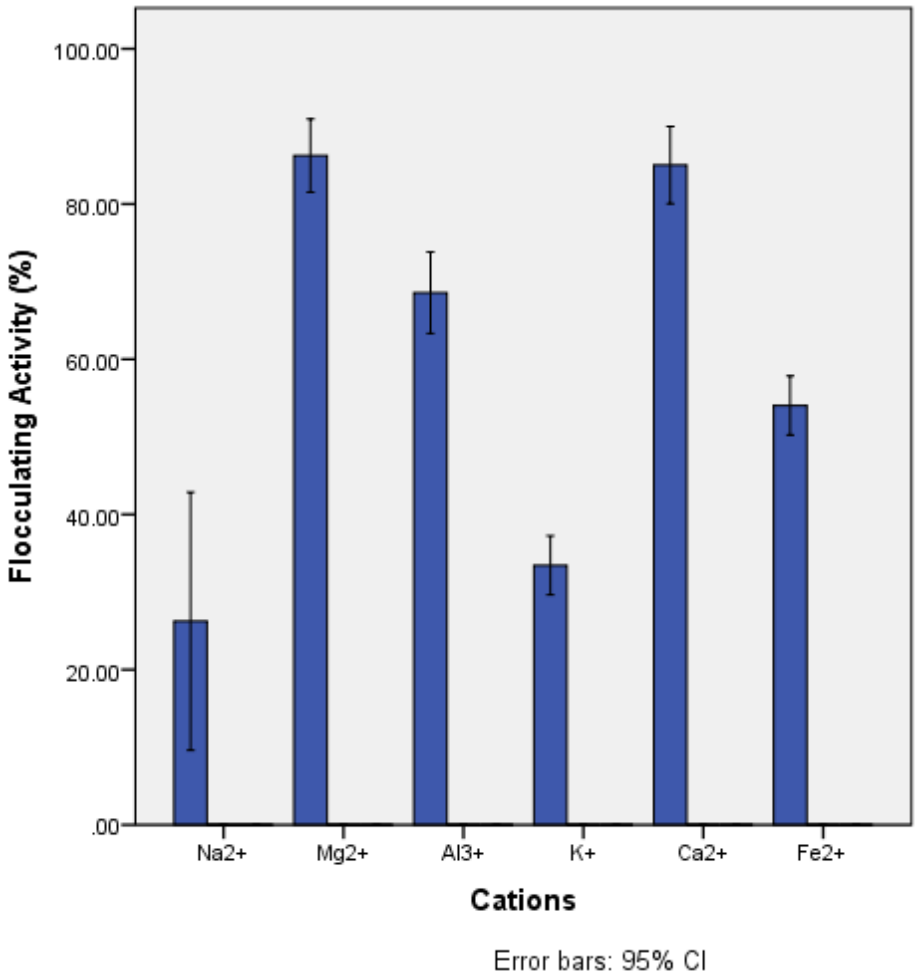

Figure 3 Effect of cations on flocculating activity of the bioflocculant purified from *Bacillus subtillis*

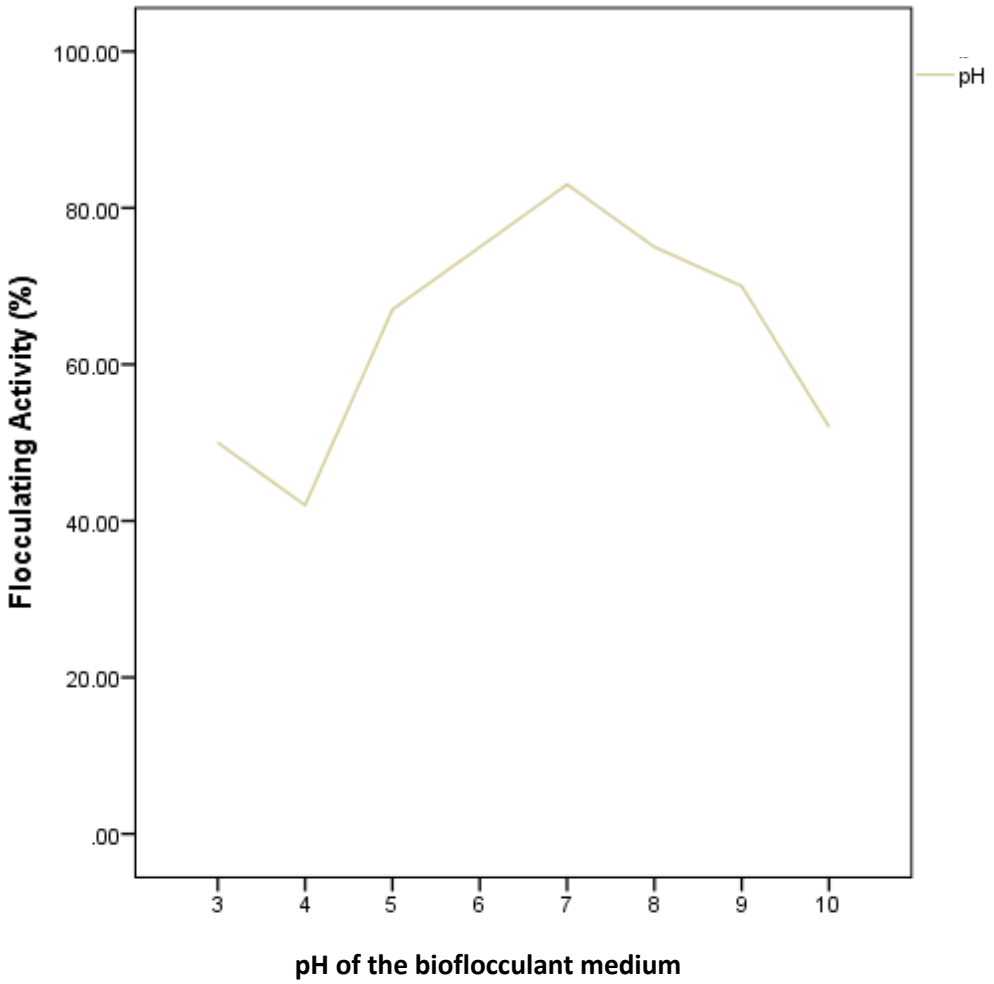

Figure 4 Effect of pH on flocculating activity of the purified bioflocculant from *Bacillus subtilis*

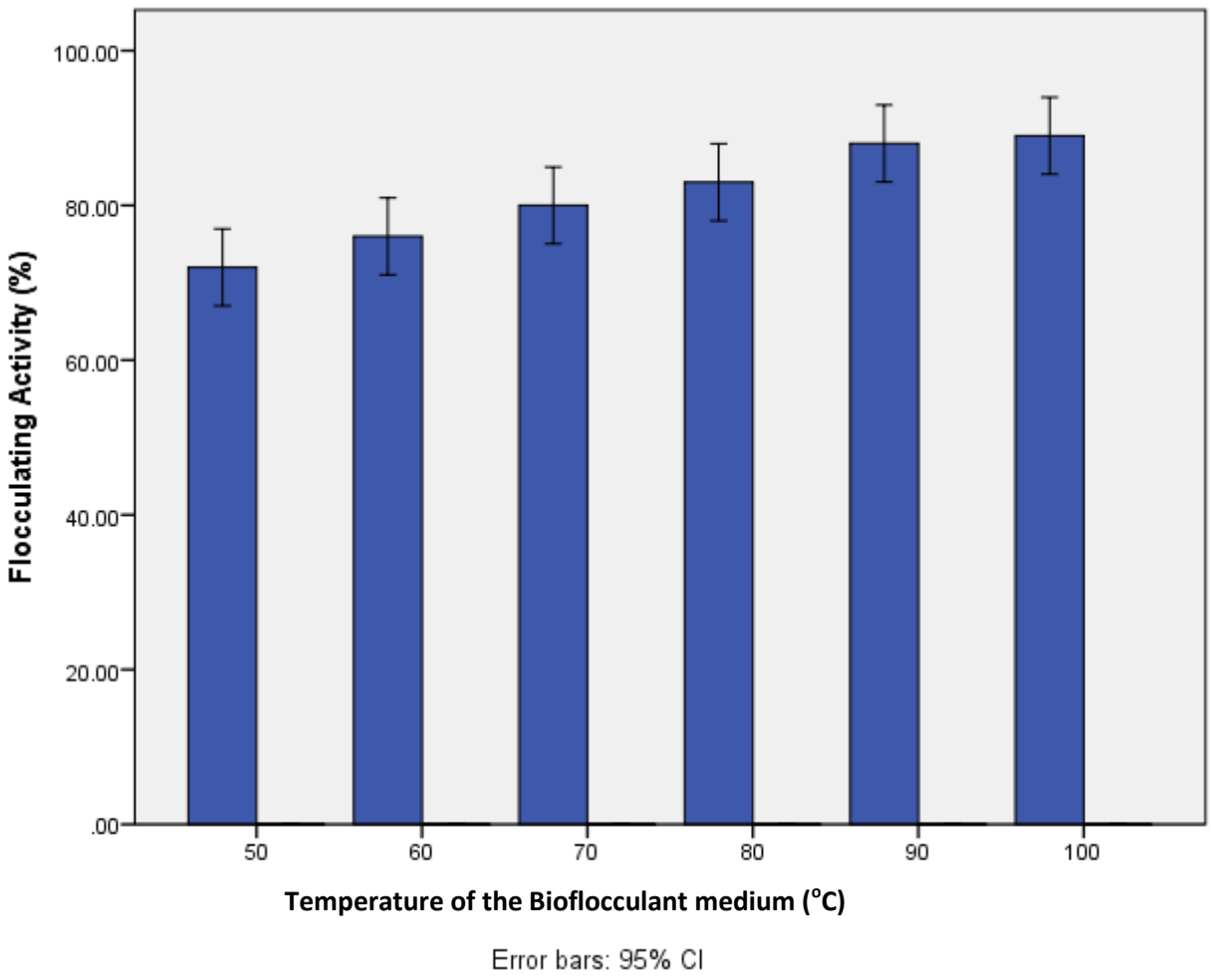

Fig. 5. Graphical representation of temperature retaining ability of the bioflocculant during progressive increase in temperature

The increased value of Abattoir Slaughtering Site than Stream Bank and Stream Sediment suggests the impact of abattoir waste on the surrounding soil. Abubakar and Tukur (2014) revealed that the discharge of abattoir effluent to the surrounding soil had significant effect on some soil chemical properties. Going by the findings of Chukwu and Anuchi (2016), the values obtained above are typical for soil samples located within the vicinity of a slaughter house. It can be deduced from the physicochemical parameters that the pH values of the soil samples were below average, indicating that the soil samples were slightly acidic (Chukwu and Anuchi, 2016). There's a possibility of contamination of the soil samples from abattoir activities (Neboh *et al*., 2013).

Well water samples consist of expected compositions of minerals for typical well water. This can be attributed to the fact that the well water is not located within the vicinity of the abattoir slaughtering site. This water sample serves as a form of control to other water samples. Mineral composition of the stream water is a little above average and this can be associated with the fact that the utensils, containers and bodies of the slaughter men are washed in the stream where the water sample was collected (Adelegan, 2002). The mineral composition of abattoir waste water was extremely high and can be associated with the deposition of fat contents, animal wastes etc., in the abattoir waste water (Teekenah *et al.*, 2012).

During the production of bioflocculant from *Streptomyces griseus*, according to Shimofuruya *et al*., 1996. The bioflocculant was produced by the bacterium in the death phase of its growth. In this research, the highest flocculating activity was achieved at 216 hours of cultivation indicating the production of more bioflocculant at the death phase. The bioflocculant purified from *Bacillus* sp 1-450 was produced during the log phase as reported by Kumar *et al* (2004). *Bacillus* sp isolated in this research had their bioflocculants produced in less than 72

hours of production which increased with time for all at 144 hours but decreased after 216 hours of production in the case of *Bacillus thuringiensis* and *B. subtilis*.

Effect of treatment dosage or inoculum size on the flocculating activity of the purified bioflocculant from *Bacillus subtilis* shows that high flocculating activity of 80% and above was achieved with treatment dosages of 0.8, 0.6, 1.0, and 1.2 mg/ml. At dosage 0.2 mg/ml, the flocculating activity was about 70%; which has the lowest flocculating activity. It can be deduced that the bioflocculant gave its best flocculation at different dosage levels of 0.6, 0.8 and 1.2. Previous studies have shown that inoculum size play important role in cell growth and bioflocculant production (Okaiyeto *et al.*, 2015). Small size inoculum prolong the lag phase, while large inoculum make niches of strain overlap excessively and consequently inhibit bioflocculant production (Okaiyeto *et al.*, 2016, Zhang *et al*., 2007). The quantity of the bioflocculant taken at varying quantities per milliliter reflects its bioflocculating ability (Okaiyeto *et al*., 2016). The biopolymer purified from *Bacillus mojavensis* at a dosage level of 5.2g/l attained very fast sedimentation (Elkady *et* al., 2011). Bioflocculant purified from *Bacillus* sp DP 152 at a dosage of 1mg/l brought about flocculation (Suh *et al*., 1991).

The effect of cations on the flocculating activity of the bioflocculant produced by *Bacillus subtilis* showed that except Na^+ and K^+, which drastically reduced the bioflocculating efficiency of *Bacillus subtilis*, virtually all the metal ions stimulated flocculating activity of the bioflocculant to a level above 50%. This result is in tandem with that of Ugbeyen and Okoh (2014), Okaiyeto *et al*., (2015) where the monovalent ions used completely inhibited the flocculating activity of the bioflocculant used. The variation in the flocculating activity recorded could be as a result of the fact that the bioflocculants being compared (this research, Okaiyeto (2015) and Ugbeyen and Okoh (2014)), were produced from different organisms and this

therefore justifies the disparity in the effect Na^{+} and K^{+} has on the bioflocculating activity. Divalent cations were observed to better stimulate the flocculating activity of the bioflocculant produced by *Bacillus subtilis*. Ugbeyen and Okoh, (2014) had similar finding that divalent cations have good stimulatory effect on bioflocculating activities of bioflocculants. The bioflocculant showed optimum flocculating activity with Mg^{2+} and Ca^{2+} when compared with Al^{3+} and $Fe^{3+.}$ Bioflocculant produced by *Bacillus licheniformis* (CRC 10826) in an aerobic culture medium with citric acid, glutamic acid and glycerol as carbon source had its flocculating activity stimulated by $Ca^{2+.}$ Fe^{3+} and Al^{3+} with a neutral pH (Shih, 2001). *Bacillus* sp Gilbert had its source from Algoa Bay used Mg^{2+} as cation at pH 6.2 (Nontembiso *et al.,* 2011).

Studies have shown that the initial pH of the growth medium required for bioflocculant production varies from one microorganism to the other (Li-Fan and Cheng, 2010; Ugbenyen *et al.,* 2012). Xia *et* al (2008) revealed that the initial pH of the growth medium affects the electric charge of the cell and the redox reaction which in turn affect the nutrient assimilation and enzymatic reaction. The effect of pH on flocculating activity of purified bioflocculant from *Bacillus subtilis* was assessed at concentration of 0.8mg/ml with the pH of the solution ranging from 3-12. The bioflocculant flocculated a kaolin suspension with over a wide range of pH between 3 and 12 at rates above 50% except at pH 4 which is drastically low and is about 20%. From this study, it was observed that bioflocculant production is possible in almost all the pH conditions except pH 4. Optimum bioflocculant production was observed in pH 6 at 65% followed by pH 9 at 60%. This gives an impression that bioflocculant production from *Bacillus subtilis* is possible under weak acidic and alkaline conditions. This finding is similar to that of Liu *et al.* (2010) and Zulkeflee *et al.*(2012). Zheng *et al*., (2008) and Okaiyeto *et al.,* (2015) revealed that an alkaline pH range of 7-12 was more suitable for biofloculant production of

Bacillus sp F19 with its maximum flocculating activity observed at pH 9; bioflocculant production was however inhibited under acidic conditions. The case was however different for bioflocculant produced from *Cobetia sp.,* with its optimum production at pH 6 (Ugbenyen *et al*., 2012).

Effect of temperature on the purified bioflocculant from *Bacillus subtilis*, shows that the bioflocculant purified from *Bacillus subtilis* is thermal stable. This was demonstrated with an increase in the flocculating activity of the bioflocculant with increased temperature. It is understood that bioflocculants rich in polysaccharides are more resistant to heat than those that are mainly composed of proteins or have lesser polysaccharide content (Xia *et al*., 2008; Okaiyeto *et al*., 2015).

Conclusion

Bacillus subtilis isolated from the stream sediments of Onyearugbulem abattoir stream possessed properties capable of forming colloids as a result of flake formation in the macrocromolecule produced by it. This bioflocculant can be exploited further in water treatment.

References

Abubakar, G. A., & Tukur, A. (2014). Impact of Abattoir Effluent on Soil Chemical Properties in Yola, Adamawa State, Nigeria. *International Journal of Sustainable Agricultural Research*, *1*(4), 100-107.

Adelegan. J. A. (2002) Environmental policy and slaughterhouse waste in Nigeria. 228th WEDC conference Kolkota (Culcutta), India.

Adelegan, J. A. (2004). "Environmental Policy and slaughterhouse Waste in Nigeria" *Proceedings of the 28th Water Engineering Development Centre (WEDC) Conference*. Calcutta, India. pp 3-6.

Agunbiade, M. O., Van Heerden, E., Pohl, C. H., and Ashafa, A. T. (2017). Flocculating performance of a bioflocculant produced by *Arthrobacter humicola* in sewage waste water treatment. *BioMedicalCentral (BMC) Biotechnology*, *17*(1): 51.

A. O. A. C. (1990). Official Methods of Analysis.15th edition. Association of OfficialAnalytical

Black, C. A. (1965). Method of soil analysis, part 2, chemical and microbiological properties, American society of Agronomy, Inc, publisher, Mandison, Wisconsin USA. pp. 240-256

Carter, M. R. (1992). Soil Sampling and Methods of Analysis. Canadian Soil Society, Lewis Publishers, London. Chemists.Washington D. C.USA .pp. 110-105.

Chukwu, U.J. and Anuchi, S.O. (2016). Impact of Abattoir Wastes on the Physicochemical Properties of Soil within Port Harcourt Metropolis. The International Journal Of Engineering And Science (IJES) 5(6): 17-21

Cosa, S., Ugbenyen, M. A., Mabinya, L., Vuyani, I. and Okoh I. A., (2013). Characterization of a thermostable polysaccharide bioflocculant produced by *Virgibacillus* species isolated from Algoa bay. *African Journal of Microbiology Research.*7(23): 2925-2938

Elkady, M. F., Farag, S., Zaki, S., Abu-Elreesh, G., & Abd-El-Haleem, D. (2011). Bacillus mojavensis strain 32A, a bioflocculant-producing bacterium isolated from an Egyptian salt production pond. *Bioresource technology*, *102*(17), 8143-8151.

Gong, W. X., Wang, S. G., Sun, X. F., Liu, X. W., Yue, Q. Y., and Gao, B. Y. (2008). Bioflocculant production by culture of *Serratia ficaria* and its application in wastewater treatment. *Bioresource technology*, *99*(11): 4668-4674.

Moghimipour, E., Salimi, A., Rezaee, S., Balack, M., & Handali, S. (2014). Influence of Flocculating Agents and Structural Vehicles on the Physical Stability and Rheological Behavior of Nitrofurantoin Suspension. *Jundishapur journal of natural pharmaceutical products*, *9*(2).

Neboh, H. A., Ilusanya, O. A, exekoye, C. C. and Orji, F. A. (2013). Assessment of Ijebu-igbo Abattoir effluent and its impact on the ecology of the receiving soil and river. *IOSR Journal Of Environmental Science, Toxicology And Food Technology* 7 (5): 61-67

Nontembiso, P., Sekelwa, C., Leonard, M. V., & Anthony, O. I. (2011). Assessment of bioflocculant production by *Bacillus* sp. Gilbert, a marine bacterium isolated from the bottom sediment of Algoa Bay. *Marine drugs*, *9*(7), 1232-1242.

Nwodo, U.U., Agunbiade, M.O., Green, E., Mabinya, L.V., Okoh, A. I., (2012). A Fresh water Streptomyces, isolated from Tyume River produces a predominantly extracellular Glycoprotein bioflocculant. *International Journal of Molecular Science***13**: 8679-8695

Nwodo, U.U., Green, E., Mabinya, L. V., Okaiyeto, K., Rumbold, K., Obi, C. L., and Okoh, A. I. (2014). Bioflocculant production by a consortium of *Streptomyces* and *Cellulomonas* species and media optimization via surface response model. *Colloids and Surfaces Biointerfaces.*116: 257-264.

Okaiyeto, K., Nwodo, U. U., Mabinya, L. V., & Okoh, A. I. (2013). Characterization of a bioflocculant produced by a consortium of Halomonas sp. Okoh and Micrococcus sp. Leo. *International journal of environmental research and public health*, *10*(10), 5097-5110.

Okaiyeto, K., Nwodo, U. U., Mabinya, L. V., Okoli, A. S., & Okoh, A. I. (2015). Characterization of a Bioflocculant (MBF-UFH) Produced by Bacillus sp. AEMREG7. *International journal of molecular sciences*, *16*(6), 12986-13003.

Okaiyeto, K. Nwodo, U. U. Okoli, A. S. Mabinya, L. and Okoh, A.I. (2016). Studiesmon Bioflocculant production by *Bacillus sp*. AEMREG2 *Political Journal of Environmental Study* 25 (1), 241-250

Omezuruike, O. I., Damilola, A. O., Adeola, O. T., and Enobong, A. (2008). Microbiological and physicochemical analysis of different water samples used for domestic purposes in Abeokuta and Ojota, Lagos State, Nigeria. *African Journal of Biotechnology*, *7*(5), 617.

Shimofuruya, H., Koide, A., Shirota, K., Tsuji, T., Nakamura, M., & SUZUKI, J. (1996). The production of flocculating substance (s) by Streptomyces griseus. *Bioscience, biotechnology, and biochemistry*, *60*(3), 498-500.

Suh, H. H., Kwon, G. S., Lee, C. H., Kim, H. S., Oh, H. M., & Yoon, B. D. (1997). Characterization of bioflocculant produced by Bacillus sp. DP-152. *Journal of Fermentation and Bioengineering*, *84*(2), 108-112.

Li-Fan, L. I. U., & Cheng, W. (2010). Characteristics and culture conditions of a bioflocculant produced by Penicillium sp. *Biomedical and environmental sciences*, *23*(3), 213-218.

Liu, W. J. Kai, W. Li,B. Z.Hong, L. Y. Jin, S.Y. (2010) Production and Characterization of Intracellular bioflocculant by *Chryseobacteria dalguense* w_6 cultured in low nutrition medium. *Bioresource Technology* 101: 1044-1048

Luo, Y., Guo, W., Ngo, H. H., Nghiem, L. D., Hai, F. I., Zhang, J., ... & Wang, X. C. (2014). A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. *Science of the Total Environment*, *473*, 619-641.

Teekenah,W.E., Agi, P.I and Babatunde, B.B.(2014. Analysis of surface water pollution from Abattoirs and the interrelationship betweenphysiico-chemical properties (A case study of the new Calabar river). *IORS Journal of Environmental SScience, Toxicology and Food Technology* 10-18 8(5)

Ugbenyen, A., Cosa, S., Mabinya, L., Babalola, O. O., Aghdasi, F., & Okoh, A. (2012). Thermostable bacterial bioflocculant produced by Cobetia spp. isolated from Algoa Bay (South Africa). *International journal of environmental research and public health*, *9*(6), 2108-2120.

Ugbeyen , A. M. and Okoh, A.I. (2013). Flocculating properties of a bioflocculant produced by Bacillus sp. Isolatedfrom a marine environment in South Africa. *Chemical and Biochemical engineering quarterly* 27(4):511-518.

Ugbenyen, A. M., and Okoh, A. I. (2014). Characteristics of a bioflocculant produced by a consortium of Cobetia and *Bacillus* species and its application in the treatment of wastewaters. *Water SA(South Africa), 40*(1):139-144.

Vasantharaj, S., Sathiyavimal, S. and Hemashenpagam, N. (2013)Treatment of municipal waste water with special reference to activated carbon combined with sand. *Archives of Applied Science Research* 5 (3):90-92

Xia, S., Zhang, Z., Wang, X., Yang, A., Chen, L., Zhao, J., ... & Jaffrezic-Renault, N. (2008). Production and characterization of a bioflocculant by Proteus mirabilis TJ-1. *Bioresource technology*, *99*(14), 6520-6527.

Zaki, S., Farag, S., Elreesh, G. A., Elkady, M., Nosier, M., & El Abd, D. (2011). Characterization of bioflocculants produced by bacteria isolated from crude petroleum oil. *International Journal of Environmental Science & Technology*, *8*(4), 831-840.

Zhang, Z. Q., Bo, L., Xia, S. Q., Wang, X. J., & Yang, A. M. (2007). Production and application of a novel bioflocculant by multiple-microorganism consortia using brewery wastewater as carbon source. *Journal of Environmental Sciences*, *19*(6), 667-673.

Zheng, Y., Ye, Z. L., Fang, X. L., Li, Y. H., & Cai, W. M. (2008). Production and characteristics of a bioflocculant produced by Bacillus sp. F19. *Bioresource Technology*, *99*(16), 7686-7691.

Zulkeflee, Z. Aris, A. Z. Shamsuddin, Z.H., & Yusoff, M. K. (2012). Cation dependence, pH tolerance and dosage requirement of a bioflocculant produced by *Bacillus* sp. UPMBB13: Flocculation performance optimization through Kaolin assays. *The Science World Journal* 7