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Evaluating the Potentials of Local Soil Samples and Alum in Removing Color from Slaughterhouse Wastewater by Coagulation and Filtration

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Abstract: A large quantity of slaughterhouse wastewater (SWW), containing many pollutants, is generated during the slaughtering and cleaning process and needs to be treated before discharge to protect the environment. Slaughterhouse effluent treatment by filtration using soil/sand media, which is cheaper and more affordable than most advanced technologies that are not affordable in developing countries, is scarce in the literature. In this study, coagulation and filtration, carried out independently, were used to remove the color from SWW. Local alum (coagulant), gravel, sand, and soil were used for treating the wastewater. The physico-chemical parameters of raw SWW and treated SWW were determined. SWW concentration, reactor volume, and coagulant dose were used to evaluate the batch coagulation process, while soil type, soil/sand mixtures at different bed heights, SWW initial pH, SWW concentration, and backwashing of the column were used to evaluate the filtration process. The local alum used is mainly composed of SiO_2 (2.17%) and Al_2O_3 (67.12%). At the end of this study, 0.2 g of local alum was chosen as the optimum dosage, and it was concluded that local alum is as good as commercial alum in the treatment of SWW. Results also show that coagulation efficiency increases with an increase in the volume of SWW (maximum value 87.61%) and the concentration of SWW (maximum value 86.79%). The % of soil/sand mixture, bed height, pH, concentration, and backwashing have an effect on filtration efficiency. A bed height of 30 cm, having 25% soil and 75% sand, gave the best color removal (with a mean filtration efficiency of 74.22 ± 7.78%) in SWW. Filtration efficiency increases as pH increases, decreases as wastewater concentration increases, and increases with backwashing. Combined coagulation and filtration using local soils and sand produced improved SWW with properties close to the World Health Organization drinking water standards, reducing biological oxygen demand (BOD) by 98.26% and chemical oxygen demand (COD) by 98.89%.

Keywords**:** alum, coagulation, filtration, slaughterhouse wastewater, soil/sand media

1. Introduction

The increasing world population particularly in developing countries is increasing the need for different industries for the purpose of job creation and general economic development. One of these industries is the meat industry where the demand for animal products is constantly on the rise due to an increase in population, improved economic status, and the need for better diet quality particularly rich in protein. Unfortunately, increasing meat production results in

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serious environmental pollution problems because for every cow and pig processed, respectively 700 and 330 liters of wastewater are generated.[1,2] These wastewater quantities are generated from the different stages of the meat industry such as slaughtering, processing, and preservation, and are likely to increase by 25% if further processing is necessary to convert to edible products. Reports show that the meat processing industry consumes 29% of the total freshwater used by the agricultural sector worldwide.[3-5] This quantity will keep increasing because worldwide production of beef, pork, and poultry meat doubled in the past decade and is estimated to grow linearly until 2050.[6] The main constituents of slaughterhouse wastewater are: diluted blood, protein, fat, and suspended solids which are responsible for the high organic and other nutrients levels in it.[7] Most of these constituents are partially solubilized, causing a high contamination effect in riverbeds and other water bodies if discharged without prior treatment.[7] So, large amounts of organic matter or suspended solids, liquid waste, and odor generation are the major environmental problems originating from slaughterhouse wastewater.[1,2] Surface and groundwater have been contaminated by slaughterhouse effluents due to the fact that blood, fat, manure, urine, and meat tissues are lost to the wastewater streams during the slaughtering process.[7] The major dissolved pollutant in slaughterhouse wastewater is blood, and it is estimated that if the blood from a single cattle carcass is allowed to discharge directly into a sewer line, the effluent load would be equivalent to the total sewage produced by 50 people on an average day.[1,2] This blood is mainly responsible for the intense coloration of the slaughterhouse effluent so eliminating the color will significantly reduce the pollution load of this effluent. Therefore, there is a need to remove color from this wastewater before discharge and in a low-cost process using local materials that are easily affordable.

While several methods can be used for treating this effluent,[3] coagulation and filtration can offer significant advantages as they can be operated without electricity and using local materials that are easily available. However, coagulation using chemical coagulants has to be properly optimized to minimize secondary contamination. Tsamo et al.[4] treated slaughterhouse wastewater using corn cob biochar in batch and filtration mode. Kundu et al.[7] investigated a laboratory-scale sequencing batch reactor (SBR) aerobic-anoxic sequential mode for simultaneous removal of organic carbon and nitrogen. Bazrafshan et al.[8] used combined chemical coagulation and electrocoagulation process to treat slaughterhouse effluent. Ng et al.[9] in their review has presented the following processes for slaughterhouse wastewater treatment: membrane processes, cogulation using moringa oleifera, ime, alum, ferrous sulphate, calcium acetate, and anionic polyelectrolyte, acid precipitation, and oxidation, electrocoagulation in continuous flow mode, coupling electrochemical oxidation with a combined biological process, a combination of electrocoagulation, ultrafiltration, and photochemical processes and biological treatment methods. Ahmad et al.[10] used a combination of sedimentation, filtration, and coagulation methods. Awodi et al.[11] used green synthesized iron oxide nanoparticles as a Fenton-like catalyst for the reduction of physico-chemical parameter. Tanatti and Sezer[12] compared electrocoagulation (EC), dissolved air flotation (DAF), and anaerobic treatment in poultry slaughterhouse wastewater (PSW) treatment. From the reviews presented, slaughterhouse effluent treatment by filtration using soil/sand media which is cheap and affordable to replace mostly advanced technologies that are not affordable in developing countries is scarce in the literature. This paper is therefore aimed at improving the physico-chemical properties of slaughterhouse wastewater by decolorizing it in batch mode with alum and in column mode using soil mixed with sand. In Cameroon, a recent Household Budget Survey (HBS/ECAM II) report shows that beef is the second meat consumed in the country (8.61 g/day/average per individual) after poultry (9.81 g cooked/day) and that in certain parts of the country like Maroua, the daily consumption of beef is estimated at 133 g/per capita, which is 10 times higher than the worldwide average meat consumption.[13] Unfortunately, Cameroon has only two modern slaughterhouses located in the biggest cities of the country (Yaoundé and Douala). As of 2019, an average of 213 cows were slaughtered in fifteen traditional slaughterhouses of fifteen local council areas of the three northern regions of Cameroon per day sending all their wastes to scarce surrounding water bodies.[4] So the fact that most of the operators in Cameroon are in the informal sector indicates the risk posed by slaughterhouse effluent to humans and the environment.

2. Experimental section

2.1 *Slaughterhouse water sampling and preliminary treatments*

Wastewater was collected from the Bamenda III council slaughterhouse located in mile 4 Nkwen, North West

Region, Cameroon. Wastewater was collected on a Saturday at 7:00 am, which is the peak period of slaughter within the week. Samples were collected in polyethylene bottles, which were washed with detergent then with distilled water, 2 M nitric acid, then deionized water again, and finally with the slaughterhouse waste water to be sampled. Electrical conductivity, pH, and temperature were determined in-situ using a pH meter APERA PC 60 pH/cond./sal. Tester. After collection, the wastewater was brought to the laboratory in a cooler and kept at 4 °C. It was then later filtered into a 1,000 mL beaker through Whatman filter paper No. 1 to intercept the fats, hairs, undigested food materials, loose meat, and other suspended solids. The filtered wastewater was kept in an open space for 24 hours under the influence of sunlight and oxygen for aeration and allowed to settle. The process can lead to a reduction of biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), and total Kjeldahl nitrogen (TKN) with removal efficiencies of up to 14%, 29%, 64%, and 33%, respectively.[8] After settling, the clarified supernatant at the top was separated from the concentrated sludge at the bottom by decantation. The clarified supernatant with negligible solid particles was used for the determination of physico-chemical properties and for coagulation and filtration treatments.

2.2 *Coagulation test*

Coagulation was accomplished by using locally made alum (a locally kaolin made alum used in this study was bought from a local market where it is used locally to extract snail flesh from its shell)[14] and commercial alum. The chemical composition of the local alum determined in our previous studies[15] is SiO_2 (2.17%), Al_2O_3 (67.12%), Fe_2O_3 (0.34%), CaO (0.60%), SO_3 (0.2%), Na_2O (0.26%), K_2O (0.22%), P_2O_5 (0.219%), and MgO (0.05%). Our previous study[14] also showed that the fourier transform infrared (FTIR) spectroscopy curve of this alum is dominated by the siloxane group Si-O-Si which is responsible for its efficiency in water treatment. The commercial alum was bought from a local water supply company. The commercial alum has formula $Al_2(SO_4)_3 \cdot 14H_2O$ with only 17.2% of Al_2O_3.[16] The locally made and commercial alums were each converted to powder forms by crushing, sieved through a sieve with pore size > 0.5 mm and stored in airtight polyethylene bottles for usage. Prior to coagulation, the wastewater was scanned in the wavelength range of 400 to 650 nm using a Ultraviolet (UV)-visible Spectrophotometer (Model UV752(D)) to determine the wavelength at which maximum absorbance occurs. Absorbance is directly proportional to concentration from Beer Lambert's law, $A = \varepsilon lC$, where A: absorbance, ε: the molar absorption coefficient, l: the width of the cuvett and c: concentration. Maximum absorbance occurred at 400 nm from this analysis and so all color concentrations before and after treatment were determined at 400 nm and used to evaluate the efficiency of the coagulation process. The first step of the coagulation process was to determine which of the two alums had the best color removal efficiency, so use that sample for further experiments. Accordingly, 100 mL of wastewater (with determined absorbance representing the color intensity or concentration of wastewater) was mixed with commercial or local alum (0.1-1.0 g each) in 250 mL beakers and stirred for 10 minutes and the solutions were allowed to stand for 4 hours for the clogs to settle. The clear supernatants were extracted by decantation and the absorbances were determined by UV-visible Spectrophotometer. In addition to the adsorbent dosage, the slaughterhouse wastewater initial concentration and the initial volume of slaughterhouse wastewater used were studied. For the latter two parameters (concentration and volume), local alum was used as there was no significant difference in removal efficiency between the local and commercial alum. For the initial volume of raw slaughterhouse wastewater, the following volumes were used; 25 mL, 50 mL, 75 mL, 90 mL and 100 mL, and absorbances were determined. For the effect of wastewater initial concentration, 25 mL, 50 mL, 75 mL, 90 mL and 100 mL of stock solution (or raw) of slaughterhouse wastewater were added respectively to 75 mL, 50 mL, 25 mL, 10 mL and 0 mL of tap water for a total reactor volume of 100 mL in each case followed by measuring the corresponding absorbances. All the experiments were done in triplicates. The efficiency of coagulation in all the cases was evaluated using equation (1).

$$\text{Coagulation eff} = \frac{\text{initial absorbance} - \text{final absorbance}}{\text{initial absorbance}} \times 100 \tag{1}$$

From equation (2),[15] it can be seen that some factors that influence the removal of pollutants from wastewater are concentration, reactor volume, and mass of material used. This justifies why in this study, the effects of the mass of alum, initial volume, and initial concentration of wastewater on the removal of color from slaughterhouse wastewater were investigated.

$$\text{Amount removed } (q_e) = \frac{(C_i - C_f)V}{m} \tag{2}$$

C_i and C_f are the initial and equilibrium concentrations respectively; V is the volume of the solution, m is the mass of material used; q_e is amount removed.

2.3 *Filtration test*

The experimental setup used for filtration was done using a polyvinyl chloride (PVC) pipe suspended vertically using clamps and stands as filtration column (Figure 1). The pipe was 50 cm long with a diameter of 3.76 cm. The bottoms of the columns were sealed with cotton cloth. A cotton material was fitted at the bottom of the pipe to act as a sieve during filtration. Local materials; sand, soil and gravel were used. Sand, soil and gravel were washed with tap water and oven dried at 105 °C for 24 hours prior to use. Wastewater was fed from the top of the column under gravity. 20 mL of effluent was collected and the time to collect it was recorded for the purpose of evaluating the flow rate and time at which the system clogs. The absorbance of the effluent was measured at each time using a UV-Visible spectrophotometer and used to calculate the filtration efficiency (equation 1). Filtration was stopped when clogging occurred (water was not flowing).

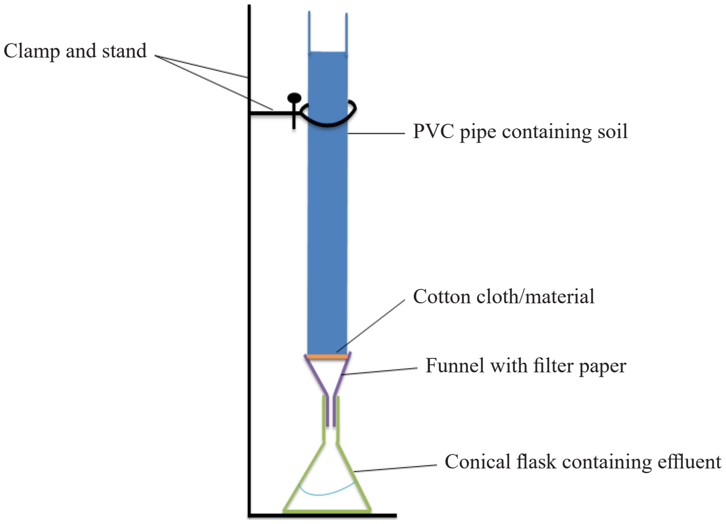

Figure 1. Experimental setup for filtration

The effects of several factors on filtration efficiency were studied. They include the following.

2.3.1 *Effect of soil types*

Three soil types were tested (described as SS1, SS2, and SS3). Soil samples were collected from Bambili village, Tubah council, North West Region, Cameroon. SS3 is the soil from an automobile repair shop (SS3); SS2 is the soil from a waste dump site and SS1 is the soil from a swampy agricultural site. The properties of these soils are given in the study by Tsamo et al.[17] The column was 30 cm occupied with materials; the height of 20 cm occupied by a mixture of sand (100.8 g) and soil (11.2 g) from the bottom and above it 10 cm height of gravel (76 g), the rest by water. Soils have good surface properties for water treatment but can't be used alone in filtration because clogging will easily occur. Soil samples were collected using a shovel at a depth of 30 cm to represent the ploughing zone. For each location, 3 samples were collected, mixed to homogenize, parcelled in polyethylene bags, and labelled using tape and marker. The samples were taken directly to the laboratory, dried in the open air for 15 days, then in an oven at 105 °C for 24 hours, ground to a fine powder, and sieved using a 0.5 mm sieve. The sand used was collected from a construction site in Bambili, washed with distilled water to remove debris and other impurities, dried for 15 days, and sieved using a 0.5 mm sieve.

2.3.2 *Effect of soil percentage*

The accumulation of adsorbate in the fixed-bed column is greatly depended on the quantity of material inside the column.[18] Three bed heights each having three different soil/sand mixtures were tested. The bed heights tested were 10 cm, 20 cm, and 30 cm. Each of these bed heights had the following soil/sand mixtures (%) 10/90, 20/80, and 25/75 corresponding to 11.2 g/100.8 g, 22.4 g/89.6 g, and 28 g/84 g respectively. 3 cm of gravel was added in each case at the top to keep the materials intact.

2.3.3 *Effect of wastewater pH*

0.1 M solutions of H_2SO_4 and NaOH were prepared and used to modify the pH of the wastewater before filtration. The pH of all solutions was measured using a high accuracy pen-type pH meter with a measurement range of 0.00-14.00 pH and an accuracy of ± 0.1 pH. The effect of pH was studied at pH of 4 and 9. Water was then filtered using a 30 cm bed height with a soil sand mixture of 10 : 90% based on studies from the effect of soil percentage.

2.3.4 *Effect of wastewater concentration*

A stock solution containing 4 L of tap water and 400 mL of raw wastewater was prepared. Serial dilution of a stock solution comprising stock solution/tap water; 250 mL/750 mL, 500 mL/500 mL, 750 mL/250 mL, 900 mL/100 mL were prepared, their initial absorbances recorded and then each filtered at a bed height of 30 cm comprising of soil/sand mixture of 10 : 90%.

2.3.5 *Effects of backwashing*

A filtration column of 30 cm bed height containing 10% soil, and 90% sand already used in filtration was cleaned by pouring tap water into the column under gravity to destabilize the clogs. Tap water was passed through the already blocked column 3 times to properly rinse the column. Poured water was collected each time until no flow was observed before the next pouring was done. The fresh wastewater was then filtered until clogging occurred and the efficiency of the column before and after backwashing was compared. Backwashing was done only for one cycle.

For convenience slaughterhouse wastewater will be denoted as SWW.

2.4 *Physico-chemical analysis*

Raw slaughterhouse wastewater (SWW) and coagulated/filtered water were analyzed for different physico-chemical parameters to assess the level of pollutant reduction. Analysis was done using standard methods for analyzing water quality proposed by the American Public Health Association (APHA) 1998[19] and APHA 2012.[20] Parameters determined were: pH, temperature, conductivity, alkalinity, iron, sulphate, nitrite, hardness, bicarbonate ions, nitrate, phosphates, nitrogen, aluminum, chlorine, turbidity, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5).

2.5 *Data analysis*

All statistical analysis was done with the help of Excel 2016 and Origin Pro Lab 9. T-test at 95% confidence level to test for significant difference between the means of 2 paired or unpaired variables. Analysis of variance (ANOVA) was also used to test for differences in means of unequal samples. A post hoc analysis was carried out where necessary at a 95% confidence limit to detect where the difference in means truly existed. The ranking was also carried out by comparing the means of 2 or more groups to determine the highest and lowest.

3. Results and discussion

3.1 *Coagulation*

3.1.1 *Comparing coagulation efficiencies of commercial alum and local alum*

Figure 2 shows the coagulation efficiencies of commercial and local alum for color removal. As observed from Figure 2, there is a general decrease in coagulation efficiency as mass of coagulant increases with optimum discoloration occurring at 0.2 g for the two alums with removal efficiency of 77.76% for commercial alum and 78.56% for local alum. Al-Mutairi et al.[21] reported that the coagulation efficiency of slaughterhouse wastewater increased substantially as the alum (as coagulant) dosage was increased, however, this was not the case in this study. This may be due to easy agglomeration of sites on natural coagulant or the force of mixing was not enough to ensure maximum occupation of treatment sites. However, the trend obtained in this study is similar to those of Ha and Huong,[22] who removed color from swine slaughterhouse wastewater using commercial alum ($Al_2(SO_4)_3 \cdot 18H_2O$-14.5% Al_2O_3). They reported that the color removal rate rises from 87% to 90% when the dosage increases from 400 to 450 mg/L and at pH 7, but when the dosage was increased further, the removal rate dropped slightly. According to them, the reduction was due to the "breaking" of the flocs causing a dramatic reduction in the efficiency of eliminating color. The difference in their results (87-90% removal efficiency) and those obtained in this study (77-78% removal efficiency) is due to the pH of wastewater during coagulation. Their study did the coagulation at a pH of 7 while this study conducted the process at a pH of 5.84. Removal efficiency is favourable at a pH of 7 because of the formation of $Al(OH)_3$ in a neutral environment, which coagulates the pollutants.

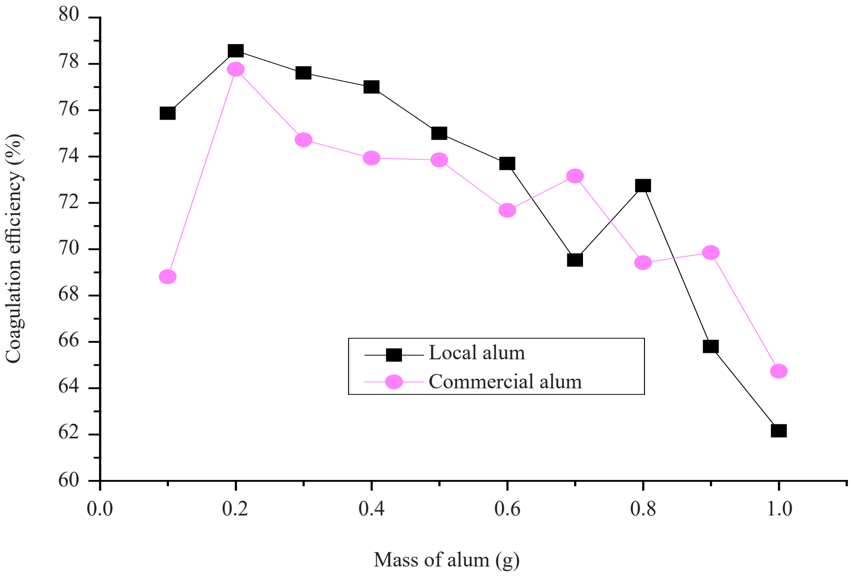

Figure 2. Comparing the effectiveness of local alum and commercial alum in SWW treatment

3.1.2 *Effect of initial concentration of SWW*

Results of the effect of SWW initial concentration on color removal by local alum are presented in Figure 3. The coagulation efficiency increases steadily and reaches a maximum at 0.969 absorbance units of SWW with about 90% removal efficiency. The coagulation decreases sharply and reaches its lowest value of 78% at 1.129 absorbance. Hence the concentration of wastewater is significant in the wastewater treatment process. The results obtained in this work are similar to those of other authors[15] who reported the removal of color from wastewater resulting from the production of a local scrap iron tannery made dye using alum. The removal efficiency of color was 52% for an initial absorbance of = 0.048 and decreased to 24% when absorbance increased to 0.244. According to Khandegar and Saroha,[23] pollutant removal efficiency decreases with increasing wastewater concentration due to the fact that during coagulation the metal hydroxides formed are insufficient to react with the pollutant molecules.

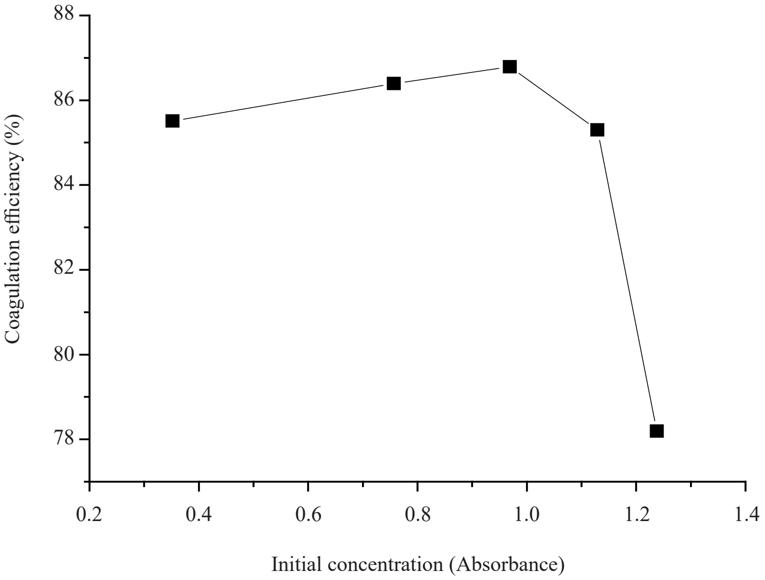

Figure 3. Effects of SWW initial concentration on color removal efficiency (mass alum = 0.2 g, temperature 25 °C)

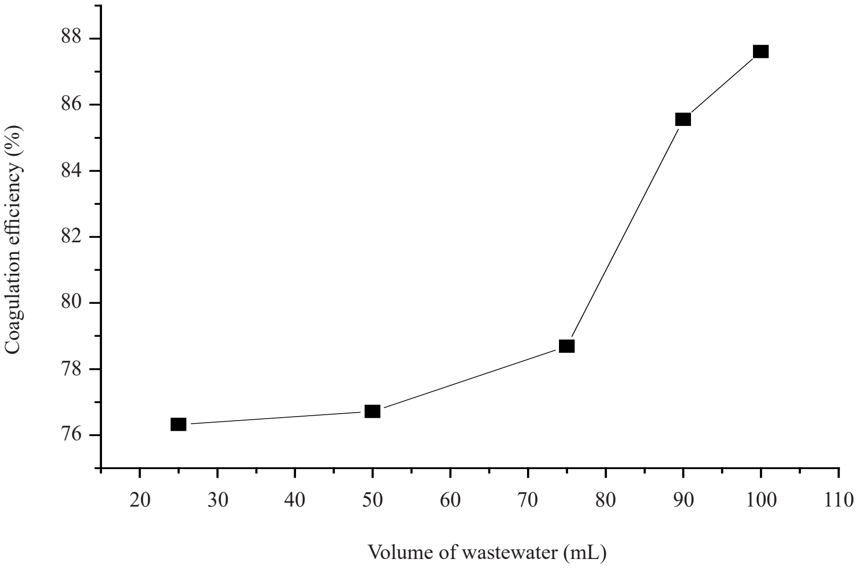

Figure 4. Effects of volume of SWW on coagulation efficiency (mass alum = 0.2 g, temperature 25 °C)

3.1.3 *Effect of volumes of SWW*

In varying volumes of wastewater with a constant local alum mass (0.2 g), it can be observed that the coagulation efficiency increases as the volume of wastewater increases (Figure 4). This may imply that at smaller volumes, there is less diffusion of SWW molecules to the surface of the alum; hence, most sites cannot be accessed. However, at higher volumes, the surface of the alum is easily accessed, and there is enough surface area for reaction. Volume is an important aspect to consider when designing a treatment system, it helps to maintain a flow rate, increase loading capacity, and avoid overcrowding of the system.[24] These results are in accordance with the findings of Weirich et al.,[25] who conducted a statistical analysis of four years of discharge monthly report (DMR) data from 210 operating wastewater treatment facilities to determine the effect of capacity utilization on effluent BOD, TSS, ammonia, and fecal coliforms concentrations. Their findings showed that facilities smaller than 40,000 m^3/d had significantly higher relative effluent concentrations for BOD, TSS, and ammonia, while it was observed that in those with a capacity greater than 40,000 m^3/d, there was an established trend indicating that increasing facility size correlates with decreasing effluent constituent concentrations for BOD, TSS, and ammonia.

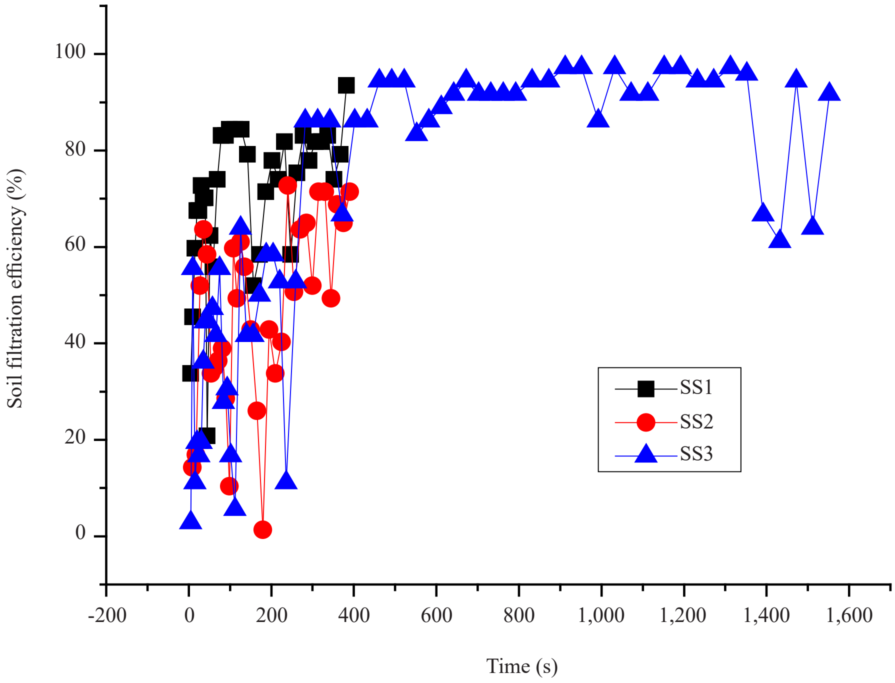

Figure 5. Effects of various soil types on filtration efficiency

3.2 *Filtration*

3.2.1 *The effect of different soil types on filtration efficiency*

Figure 5 shows the filtration efficiency of the three soil samples over the cumulative time of filtration. SS2 showed the least filtration efficiency and the lowest cumulative time, with a mean and standard deviation (SD) of 48.01 ± 18.80%, followed by SS1, with a mean and SD of 67.76 ± 29%. SS3 with mean and SD of 70.66 ± 15.53%, showed the highest filtration efficiency and the longest cumulative time. SS3 had the highest filtration efficiency with a maximum value of 97.22% and a minimum value of 2.78%. This trend is likely due to the porosity of the tested soils as Tsamo et al.[17] reported that SS3 and SS1 have high porosity with the highest sand and gravel contents. Meanwhile, the high content of clay and silt in SS2 suggests a more compact soil with reduced porosity. Also, an ANOVA test shows $P < 0.05$, which indicates there is evidence that the sample filtration efficiency differs across the various soil types. This implies strong evidence of differences in means of filtration efficiency across various soil types. Between 0-500 s, all soil types were very effective in filtration, but SS1 and SS2 blocked within this time. Meanwhile, SS3 continued to about 1,600 s. The longer residence time obtained in SS3 is similar to those of Oladoja et al.,[26] who used the combination of clay and stone-pebbles to treat brewery wastewater in columns mode, and showed that brewery wastewater had longer residence time in non-fortified clay than in fortified clay. SS3 also had 97% pollutant removal efficiency similar to the results of Oladoja et al.,[26] who observed that mixtures of clay/stone-pebbles with the highest proportion of clay (3:1) gave the highest pollutant reductions (78.15%-95.98%), while combinations with a smaller amount of clay (1:3) gave the least pollutant reductions (69.41%-83.92%).

3.2.2 *The effect of soil percentage on filtration at different bed heights*

Figure 6(a) shows the filtration efficiency of three soil sand mixtures at 10 cm bed height. For soil/sand mixtures 10/90% the mean and SD were 67.26 ± 22.29%, for 20/80% the mean and SD were 71.27 ± 7.64%, for 25/75% the mean and SD were 72.20 ± 17.25%. From the graph, 25% soil composition had the highest filtration efficiency with a maximum value of 98.50% and minimum value of 41.79% but had the lowest filtration time of 800 s. This might be due to the fact that more soil treats the wastewater effectively but clogs faster than the other two compositions. The filtration efficiency for 10/90% soil-sand composition ranged from 50-85% and had the highest filtration time of more than 1,500 s followed by 20/80% composition with a filtration time of 1,200 s. However, an ANOVA test indicated that $p > 0.05$, which shows that there is evidence that the sample filtration efficiency does not differ across the various soil compositions when the bed height is 10 cm.

Figure 6(b), shows the filtration efficiency of three soil sand mixtures at 20 cm bed height. The filtration efficiency of 20/80% composition shows the longest flow time followed by 25/75% and lastly 10/90%. The 25/75% soil-sand composition had the highest mean and SD of 85.96 ± 14.01%, seconded by 20/80% composition with 74.90 ± 5.89% and lastly by 10/90% composition with 73.61 ± 10.20%. It can also be observed from Figure 6(b) that 25/75% composition had the highest filtration efficiency with a maximum value of 96.25% and minimum value of 35.00%, followed by 10/90% with a maximum value of 93.67% and minimum value of 49.36%, and then 20/80% with maximum and minimum values of 83.54% and 53.16%, respectively. The ANOVA analysis indicates that there is evidence that the sample filtration efficiencies differ across the various soil/sand mixtures when the bed height is 20 cm ($p < 0.05$). This implies strong evidence of differences in means of filtration efficiency across various soil/sand mixtures. A post hoc test indicated that 25/75% soil/sand mixture is different from 20/80% and 10/90% soil/sand mixtures but 20/80% and 10/90% soil/sand mixtures are not different from each other.

Figure 6(c) shows the filtration efficiency of three soil sand mixtures at 30 cm bed height on the SWW filtration process. The 25/75 soil sand composition flowed for the longest time followed by 10/90 composition and then 20/80. The 20/80 soil sand composition started at a lower filtration efficiency of < 30% but increased throughout the lifespan of the filtration column to a highest value of 98%. 25/75 soil sand composition remained in the same filtration efficiency range of 60-98%. 10/90 showed a lower filtration efficiency of < 10% but increased to about 94.5%. Meanwhile, the mean and SD of 20/80 soil sand composition is 58.67 ± 17.44%, 25/75 soil sand composition is 74.22 ± 7.78%, and 10/90 composition is 48.09 ± 16.14%. 20-80 and 10-90 soil sand composition took a relatively short time to clog and had a maximum value of 95.45% and 25/75 soil sand composition had the longest filtration time. An ANOVA test carried out to find out if there is a statistical difference between the mean groups showed $p < 0.05$ which indicates there is evidence that the sample filtration efficiency differs across the various soil/sand mixtures when the bed height is 30 cm. This implies strong evidence of differences in means of filtration efficiency across various soil compositions.

From the results obtained in this study, 25/75% of soil/sand mixtures gave the best results for all three bed heights. This conclusion is similar to that of Btatkeu-K et al.,[27] who optimized the removal of methylene blue from water using Fe°/sand filtration systems and concluded that 25/75% was the optimal volumetric ratio because increase of Fe° clogs the filtration process. These results are contrary to those of Oladoja et al.,[26] where 75/25% of clay/stone-pebbles had the best removal efficiency as the clay. The difference between these two studies is likely due to the composition of clay which is mainly kaolinite compared to the clay used in this study which is rich in silt (24-32%).[14]

An ANOVA test was carried out on the mean groups which indicated that $p < 0.05$ implying there is evidence that the sample filtration efficiency differs across the various bed heights. A post hoc tests was conducted to determine where differences in filtration means truly exist amongst bed heights. There was no significant difference when comparing mean filtration efficiencies between bed heights of 10 cm, 20 cm, and 30 cm. Furthermore, in terms of ranking, a bed height with 30 cm shows the highest differences in means thus indicating to be the highest bed height in terms of mean differences between groups and ranked first. This may be due to the fact that at bed height of 10 cm the wastewater does not stay long enough in the filtration column and hence the contact time is small. Similar results were obtained by other authors,[28] who investigated the efficiency and pollution reduction potential of sand intermittent filtration technology for wastewater treatment. In all their experimental setups, a maximum percentage reduction of contaminant was observed at a 30 cm filtration bed. An increase in bed height is associated with an increase in adsorption capacity and saturation time. Meanwhile increase in bed height, not only leads to an increase in surface area of adsorbent with more binding sites, but also there is an increase in residence time of wastewater inside the column, thus permitting more diffusion of wastewater particles into the interior of the adsorbent hence more adsorption.[4,29]

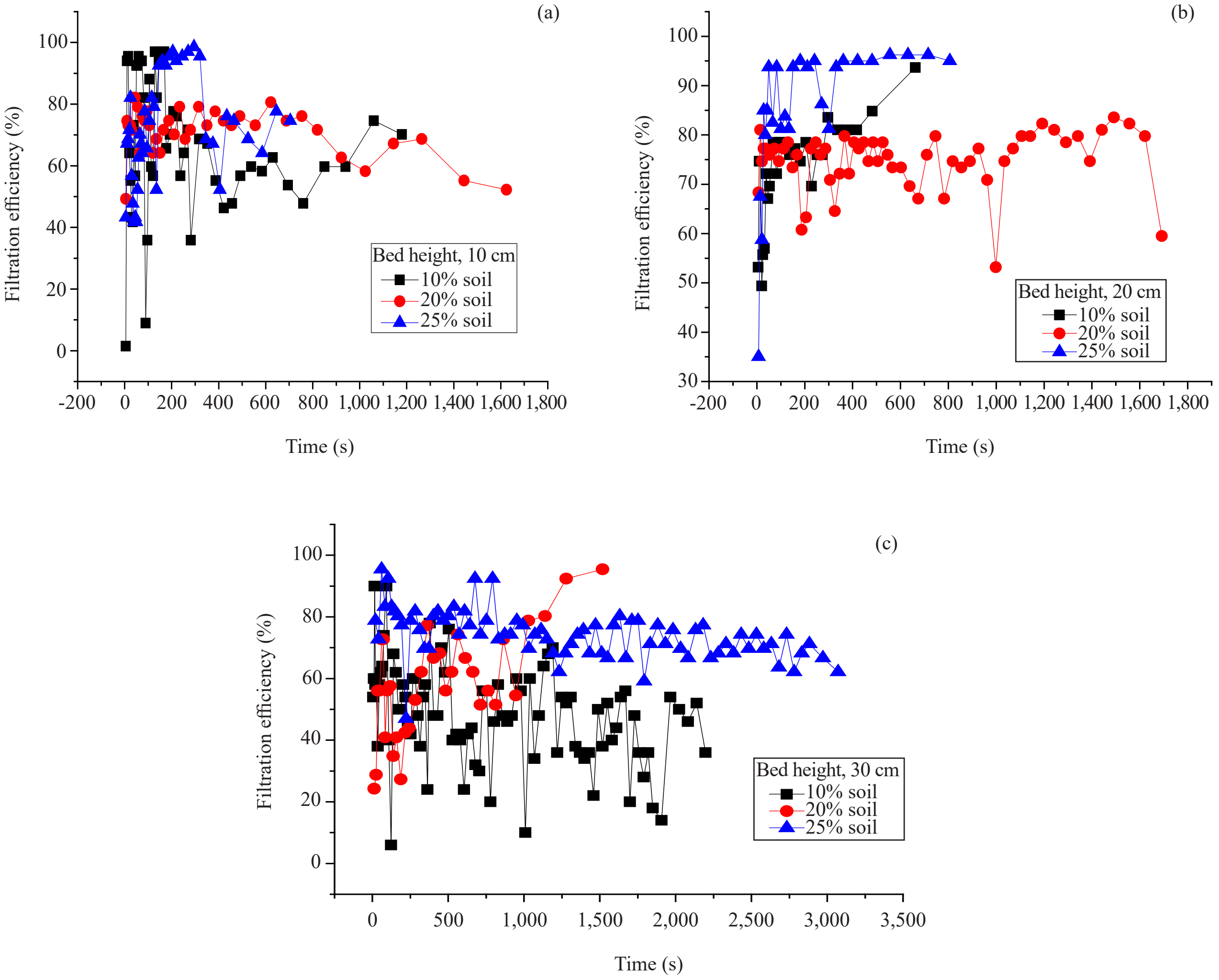

Figure 6. Effect of soil % on filtration efficiency a) 10 cm b) 20 cm c) 30 cm bed heights

3.2.3 *Effect of wastewater pH on filtration efficiency*

The effect of pH on filtration efficiency was conducted at pH 4 and 9, and the results are presented in Figure 7. pH 9 showed the longest filtration time and had a maximum efficiency value of 98.04% and a minimum of 62.75%, while pH 4 had a maximum value of 97.60% and a minimum value 47.36%. However, pH 9 recorded mean and SD efficiencies of 90.85 ± 8.25, while pH 4 recorded 86.86 ± 13.69. The pH of SS3 was 6.73,[14] so it was acidic; hence, the fact that SWW with pH 9 had better results at longer filtration times suggests there was an attraction between the positively charged soil and negatively charged SWW, hence giving a more favourable removal efficiency. Meanwhile, an ANOVA statistical test was carried out to identify the significant difference between the three mean groups. It was found that $P < 0.05$ (P value was very small), which implies strong evidence of difference in means of filtration efficiency across various pH. To identify which pairs of means were not equal, a post hoc test was carried out which illustrated insignificant differences in mean filtration efficiency between samples at pH 4.0 and pH 9.0. These results are contrary other results reported in literature, though with different pollutants and materials. For example, Boughou et al.[30] studied the effects of pH on the removal of conductivity and COD from Rabat slaughterhouse wastewater by coagulation-flocculation using ferric chloride. They reported that lowest conductivity reduction occurs at pH between 5.83 and 6.28, and a highest reduction at pH 9.28. The decrease can be interpreted by the formation of a complex of Fe(OH) from Fe(III) and also by the destabilization of the colloidal particles, while the increase at pH 9.28 is due the simultaneous presence of several hydrolyzed $Fe(OH)_3$ and $Fe(OH)_2$ (soluble and insoluble). However, this trend was reversed for COD removal where best removal occurred at pH 5.83, and this reduction can be interpreted by the removal of the organic matter under the effect of ferric chloride. The lowest COD removal occurred at pH 9.28 and can be interpreted by the presence of the fulvic acids (FA) which are derived from the decomposition of the organic plant matter. Al-Said et al.[31] treated slaughterhouse wastewater (SWW) using the sequential three-step electro-coagulation (EC)-electro-oxidation (EO)-adsorption column (AC) processes, and the highest conductivity removal efficiency occurred at a pH 4. These results shows that the material used in the treatment strongly determines the efficiency of the process.

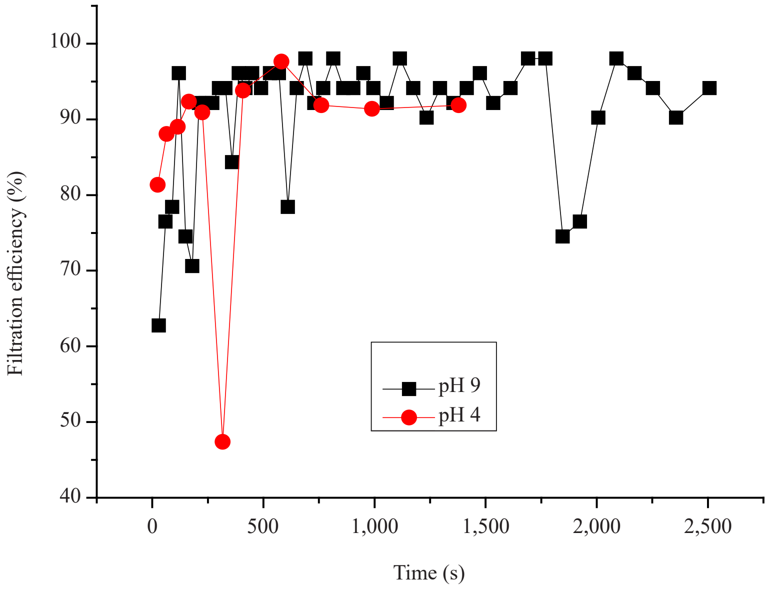

Figure 7. Effect wastewater pH on filtration efficiency

3.2.4 *Effect of concentration on filtration efficiency*

Four concentrations (absorbances) 0.022, 0.030, 0.038, and 0.042 were studied and the results are given in Figure 8. It can be observed from Figure 8 that there is an increase in removal efficiency with an increase in concentration as 0.042, 0.038, and 0.030 all had over 97% removal in the first 200 s compared to about 80% removal for 0.022 concentration. The increase in discoloration of SWW with an increase in SWW initial concentration results from an important driving force provided at a higher initial concentration necessary to overcome all mass transfer resistance.[4] These findings are opposite to those of Thuong et al.,[32] who investigated the elimination of methylene blue and crystal violet from wastewater using a fixed-bed column of pre-treated durian peel and witnessed a sharp reduction in the removal efficiency when dye concentration increased from 200 to 600 ppm. This was the same trend with Jedidi et al.,[33] who reported a reduction in the efficiency of methylene blue elimination from water using homogenous and layered soils in fixed bed column when dye concentration increased from 100 to 800 mg/L. These differences are probably due to the composition of the materials used in the column as well as the nature of the adsorbate. Comparing the mean and SD efficiency values for the different concentrations: 0.022 (55.18 ± 22.25%), 0.03 (59.27 ± 19.56%), 0.038 (86.07 ± 13.78%), and 0.042 (84.94 ± 15.82%) using ANOVA resulted to $p < 0.05$, indicating there is evidence that the sample filtration efficiencies differ across the various concentration. This implies strong evidence of differences in means of filtration efficiencies across various concentration levels. A post hoc analysis shows insignificant mean differences when comparing filtration efficiency between 0.038 and 0.042 and 0.03-0.022.

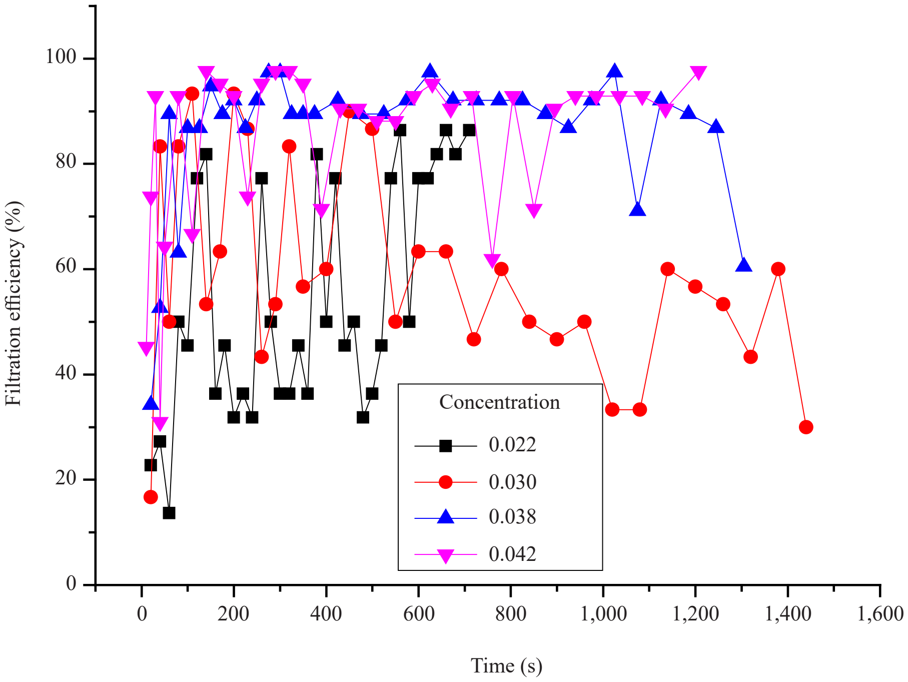

Figure 8. Filtration efficiency of various concentrations over time

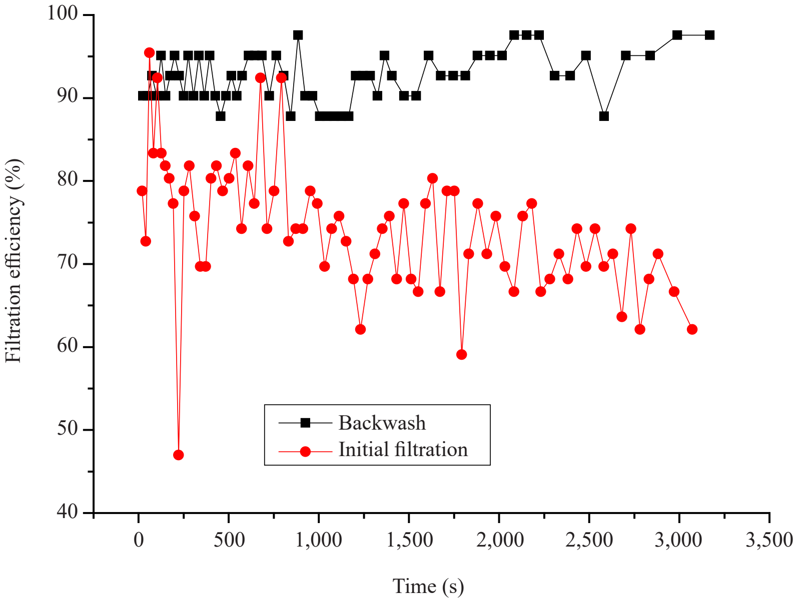

Figure 9. Filtration efficiency of filtration column before and after backwashing

3.2.5 *Effects of filtration after backwashing*

From Figure 9, it can be seen that the filtration efficiency of the back washed column was significantly higher than that of initial filtration. Equally, while the efficiency of the backwashed keeps increasing over time, that of the initial filtration shows a decreasing trend over time. The mean and SD efficiencies were 92.56 ± 2.94 and 74.22 ± 7.78 for backwash and initial filtration respectively. During backwashing, trapped particles are flushed out thereby liberating the surface of the materials for more fixation of pollutants. In addition, some dissolution of the column material may occur, creating more sites and increasing the porosity of the filter media for treatment. Ahmed et al.[34] reported a similar trend to this study as they reported that treatment efficiency increased from 92% up to 97% by backwashing a sand filter. Wang et al.[35] used a series of manganese and quartz sand filters under empty bed contact times (EBCTs) of 2 h and 4 h to explore variations in micropollutant degradation and temporal dynamics of the microbial community after backwashing. After backwashing with filtered water, the removal efficiency of atenolol in the manganese sand filter increased rapidly but remained at a high level (almost 100%) in the quartz sand filter for both EBCTs.

Table 1. Physico-chemical analysis of raw and treated slaughterhouse wastewater

Parameters	Symbols	Unit	Specification (Standards)	SWW	TWW	Removal efficiency (%)
pH	pH	UPH	5.5-7.5	5.84	4.032	30.96
Temperature	T0	°C	< 25	29.6	28.42	3.99
Turbidity	NTU	NTU	< 4.0	9.12	5.47	40.02
Conductivity	Cond/TDS	Us/cm/mg/L	< 100	1,948	845	56.62
Phosphates	PO_4	mg/L	< 20	11.7	7.2	38.46
Sulfate	SO_4	mg/L	< 20	22	17	22.73
Hardness	TH	^{0}F	< 5	ND	3.8	43.13
Allkalinity	TA	^{0}F	< 1	1.4	0.69	50.71
Bicarbonate ions	TAC	^{0}F	< 5	5.6	5.4	3.57
Nitrate	NO_3	mg/L	< 0.1	2.1	1.2	42.86
Nitrite	NO_2	mg/L	< 0.1	1.6	0.91	43.13
Nitrogen	N	mg/L	< 40	124	59	52.42
COD	COD	mg/L	< 50	> 3,950	44	98.89
BOD_5	BOD_5	mg/L	< 50	549	9.54	98.26
Aluminium	Al	mg/L	< 0.2	0.56	0.18	67.86
Iron	Fe	mg/L	< 0.2	0.56	0.12	78.57
Chlorine	Cl-	mg/L	< 50	98	35	64.29
Colour				Red	Colorless	

4. Comparing physico-chemical properties of slaughterhouses before and after coagulation and filtration

A physico-chemical analysis was carried out on raw SWW and treated slaughterhouse wastewater (TWW) and the results are presented in Table 1. The treated water chosen for physico-chemical analysis was water coagulated with 0.2 g of local alum and filtered through a bed height of 30 cm with a soil sand mixture of 25/75%. Though color was the only parameter monitored during treatment, these results show that the tested system is very efficient in eliminating other pollutants in slaughterhouse wastewater. Bustillo-Lecompte et al. confirmed that combined processes are cost-effective with high removal efficiencies that can lead to a reduction in operation & management costs compared to individual processes.[36,37] The Organic matter (COD and BOD_5) which is the main constituent of SWW was almost completely removed.

5. Conclusion

The treatment of SWW by coagulation using chemical alum on the one hand and the treatment by filtration using three different soil samples mixed with sand on the other hand were investigated in this work. Equally, the physico-chemical analysis was investigated on water treated by combined coagulation and filtration as a case study. The effects of coagulant dose, initial SWW concentration, and reactor volume were used to study the efficiency of coagulation. Meanwhile, soil type, soil percentage and bed height, pH, concentration, and backwashing were used to evaluate the filtration process. The parameter used to evaluate the efficiency of the treatment in both coagulation and filtration was color removal. Results obtained show that coagulation efficiency generally increases with increasing concentration and volume of slaughterhouse wastewater, with a maximum coagulant dosage of 0.2 g for 100 mL SWW. The SS3 soil sample had the highest filtration efficiency with maximum value 97.22%, followed by SS1 due to the fact that these soil samples have high porosity because of high content of sand and gravel. The 25/75% soil/sand mixture and 30 cm bed height gave the best filtration results in terms of treatment and flow time of the column for most parameters. The pH 9 showed the longest filtration time and had a maximum efficiency value of 98.04% compared to 97.60% at pH 4, indicating electrostatic attractions governed removal in the column. There is an increase in removal efficiency with an increase in SWW's initial concentration. Furthermore, a test was carried out on backwashing, and it was found that backwashing has a positive effect on filtration media, as the media becomes more effective after backwashing. SWW treated by combined coagulation and filtration was safe for discharge as pollutant levels found in the raw wastewater were significantly reduced. The tested local soil and sand used in filtration gave satisfactory results and can replace or complement chemical alum (which can cause secondary contamination) for cheaper, easier, and safer process of SWW treatment. However, for a more efficient and cost effective treatment process, the combined chemical coagulation with small amounts of coagulant in large volumes of SWW and soil/sand (25/75%) filtration media at high fixed bed heights will enhance the quality of SWW effluent.

Conflict of interest

The authors declare no competing financial interest.

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