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Settlement and compressive properties of suspended solids in a domestic-institutional wastewater

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Abstract

It is well known that most of the projected global population increases will take place in third world countries that already suffer from land, water, food and health problems. Increasingly, the various water uses must be coordinated with and integrated into the overall water and land management of the region. Sustainability, public health, environmental protection and economics are key factors. More storage of water in artificial lakes and artificial recharge of underground water is necessary to save water during water surplus for use during water shortage. Domestic-institutional (DI) and municipal wastewaters can be an important water resource but its use must be carefully planned, treated and regulated to prevent adverse health effects due to contamination of groundwater. In this paper settlement and compressive properties of suspended solids in DI wastewater is presented. Column tests were carried out on a DI wastewater in a bench scale. Wastewater samples were collected from influent into Obafemi Awolowo University, Ile-Ife, waste stabilization pond and subjected to laboratory studies. Laboratory analysis of suspended solids in the samples was carried out using a standard method. Solids removed were analysed using isoconcentration curves and compressive times graph. The study revealed that 57% of suspended solids in the wastewater were removed at a depth of 1.20 m and at a retention time of 60 minutes. An analysis of isoconcentration curves shows that overall solids removal is 71 percent. Compression settling constant of the settled solids was found to be 5.50 x 10^{-3} m per m x minute. Information on relationship between porosity, stress and the depth of landfill for development was provided to aid final disposal of the waste removed and to provide information for agricultural use of the landfill area.

Key words: Suspended solid, isoconcentration curves, domestic-institutional wastewater, compression settling constant, total stress, porosity, landfill.

Introduction

Nowadays biological treatments of domestic and industrial wastewaters have increased tremendously, because they have been found to be appropriate technologies for most developing nations, where land and labour are still relatively cheap and the climate favour natural degradation of organic matters. The treatment process is known for effective removal of nitrogenous compounds, heavy metals, BOD and COD [1-3] just to mention a few. Solids in wastewater must be significantly reduced before it could be discharged into the environment, otherwise the solids will increase biochemical oxygen demand (BOD) and chemical oxygen demand (COD) levels when discharged into receiving waters. Solids in wastewaters can be in the form of settle-able, suspended as well as dissolved solids, organic, inorganic, non-volatile or volatile materials. The presence of solids in wastewater is due to human waste, industrial processing of food and chemical substances. Effect of settled suspended solids on biological treatment plants are well known as follows: reduction in the hydraulic retention time supports anaerobic reaction which yields gases such as methane and hydrogen sulphide that inhibit microorganisms and reduction of the efficiency of biological treatment plants [4-6]. Methods for removing solids from wastewaters include coagulation, flocculation, biological removal, filtration and sedimentation. Out of these methods sedimentation and biological removal are cheapest because of low initial and operational costs. Removal of suspended solids from domestic-institutional wastewater has rarely been mathematically described nor its column test and isoconcentration curves had been presented [3, 5]. Attempts must be made toward the study of suspended solids and settled suspended solid removal from domestic-institutional wastewaters in an effort to provide pre-treatment to improve efficacy of biological treatment and to aid final disposal of the solid in landfill which is normally used for agricultural and recreational purposes. This study was geared toward settlement properties of suspended solids in a domestic-institutional wastewater and its isoconcentration curves presentation to improve efficacy of biological treatment and to aid final disposal of the solid in landfill. It also intends to provide guidance on the possible use of landfill for future development and recreation purposes.

Materials and Methods

Wastewater samples were collected weekly (randomly at selected hours of the day and selected days of the week) from influent into waste stabilization ponds of Obafemi Awolowo University, Ile-Ife, for six months. Wastewater samples collected were fed into a column (1500 mm long, 70 mm diameter) through which column tests were carried out as specified in literature [1, 4]. Laboratory analysis of the solids (suspended solids) concentration in the influent and effluent from the column was carried out as outlined in standard methods [7]. Specifically, Gooch crucible and Whatman filter paper number 40 were dried in the oven at 105°C for an hour, cooled in a desiccator and weighed (W_1). The wastewater sample of 200 ml was filtered through the filter paper. The filter paper was removed from the funnel and placed in the crucible. The crucible, filter and solid were dried in the oven at 105°C for an hour, cooled in a desiccator and reweighed (W_2). Triplicate determinations of each of the samples were carried out and suspended solid in mg/l were computed using Equation 1.

$$TSS(mg/l) = \frac{1000(W_2 - W_1)}{volume \ of \ sample \ used(ml)} \qquad (1)$$

Overall averages were analysed using isoconcentration curves and statistical method (specifically ANOVA). Averages and deviations of suspended solids removed at different depths and at different times were used for isoconcentration curves from which overall percentages of solid removed at different depths and at different retention periods were computed. Simulation of landfill property was carried out using the results.

Results and Discussion

The efficiencies of the column test equipment were determined regularly (after 10, 20, 30, 40, 50 and 60 minutes) at different depths from the inlets based on the ability to reduce suspended solid concentrations. The summary of the efficiencies at each depth and at a different retention time during the study is presented in Table 1. A statistical analysis (ANOVA) of the results shows that there is a significant difference between the suspended solids removed along the depth at 90% confidence level ($F_{8,2}$ = 30.17) and between solids removed at different time at 90% confidence level ($F_{8,4}$ = 3.25). These results and the statistical analysis show that removal of suspended solids from domestic-institutional wastewater is a function of both time and depth.

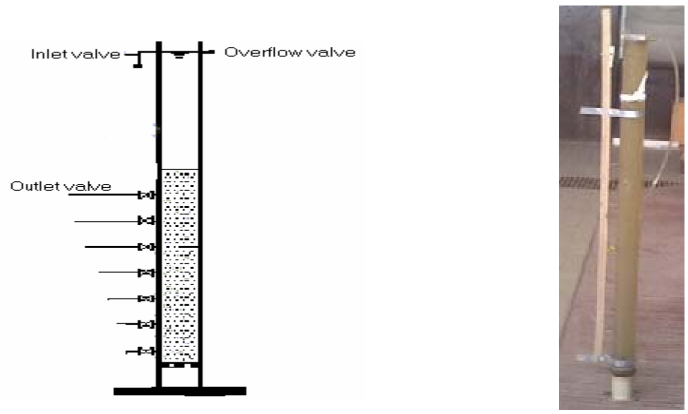
In order to establish relationships between the depth, time and suspended solids removed smooth isoconcentration curves (the maximum trajection of settling path for specific concentrations in a flocculent suspension) for the suspended solids removed at various depths and at various times were plotted. Attempts were made to fit the suspended solids removed from domestic-institutional wastewater into isoconcentration curves of the best fit forced through intercept of zero. The isoconcentration curves describing the best fit for the suspended solids in domestic-institutional wastewater are as presented in Fig. 2. The isoconcentration curves (Fig. 2a-e) have common characteristics, namely: i) between the depth of 0.0 and 0.4 metres the curves have the greatest slope, ii) followed by the slope between 0.4 and 0.8 metres, iii) with the slope between 1.0 and 1.2 metres having the least slope.

Each of these slopes indicates that suspended solids of higher particle sizes were being formed between the depth 0.0 and 0.4 metres (the effect of flocculation on the particles was much because of the greater slope curves obtained) after which maximum sizes were reached at the depth of 0.8 metres followed by settlement thereafter between 0.8 and 1.2 metres, which led to removal of these solids from the effluent. Similarly, the description of the curves indicates that possible flocculation of suspended solids in domestic-institutional wastewater occurs between the influent stage and the depth less than 0.8 metres after which the influence of flocculation on the suspended solids decreases with the depth of the column. In addition these isoconcentration curves show that for an effective settlement (removal) of suspended solids in domestic-institutional wastewater minimum depth of 0.8 metres is required.

In establishing relationships between the suspended solids removed and time, various combinations (linear, polynomial, power, logarithmic and exponential) were tried. Correlation between suspended solids and time using linear, polynomial, power and exponential relationships was found to have very low correlation coefficient of less than 0.75 which indicates that there is no significant relationship between these two parameters using these mathematical functions. The results of the combination show that fractions of suspended solids removed from domestic-institutional wastewater are related to the retention time in a logarithmic relation (Fig. 3). All relationships were found to be statistically significant at the 95% confidence level and there was a slight improvement in the correlation coefficients as the depth increases (0.9222, 0.9669 and 0.9683 for the depth of 0.8, 1.0 and 1.2 metres respectively), although these increments in correlation coefficients were statistically insignificant. These results show that suspended solids removal from domestic-institutional wastewaters can be established from isoconcentration curves and that removal efficiency is a function of time logarithmically. This result indicates that increase in time brings about higher change in the portion of suspended solids removed. From Fig. 3 the minimum and maximum theoretical hydraulic retention time for different depths were found to be 11 (minimum) and 203, 163 and 129 (maximum) minutes for a column depth of 0.8, 1.0 and 1.2 metres, respectively. These maximum retention times correspond to the recommended values between 60 and 180 minutes [1] and between 60 and 120 minutes [4]. The results indicate that suspended solids removable are inversely proportional to maximum time required and partly fixed with the minimum time required. From Fig. 4 the economic retention periods of 80, 75 and 70 minutes for effective depths (0.8, 1.0 and 1.2

Table 1. Averages and deviations of suspended solid removed from domestic–institutional wastewater and standard deviation.

Time (minutes)	10	20	30	40	50	60
Depth of the column from the inlet (m)	Suspended solid removed (mean ±standard deviation, %)					
0.10	36±10.83	43±10.19	49±11.79	57±7.83	62±8.01	70±5.50
0.25	31±8.73	38±9.99	44±11.08	51±12.10	58±8.45	66 ±6.41
0.50	25±7.87	33±9.62	38±11.08	45±10.09	53±8.41	63±7.31
1.00	20±6.62	26±8.71	32±10.31	40±9.91	48±9.05	61±8.31
1.20	16±6.68	23±7.61	28±9.31	37±9.72	46±9.58	57±8.98



a

b

Figure 1. Front view of the column a) schematic diagram, b) pictorial view.

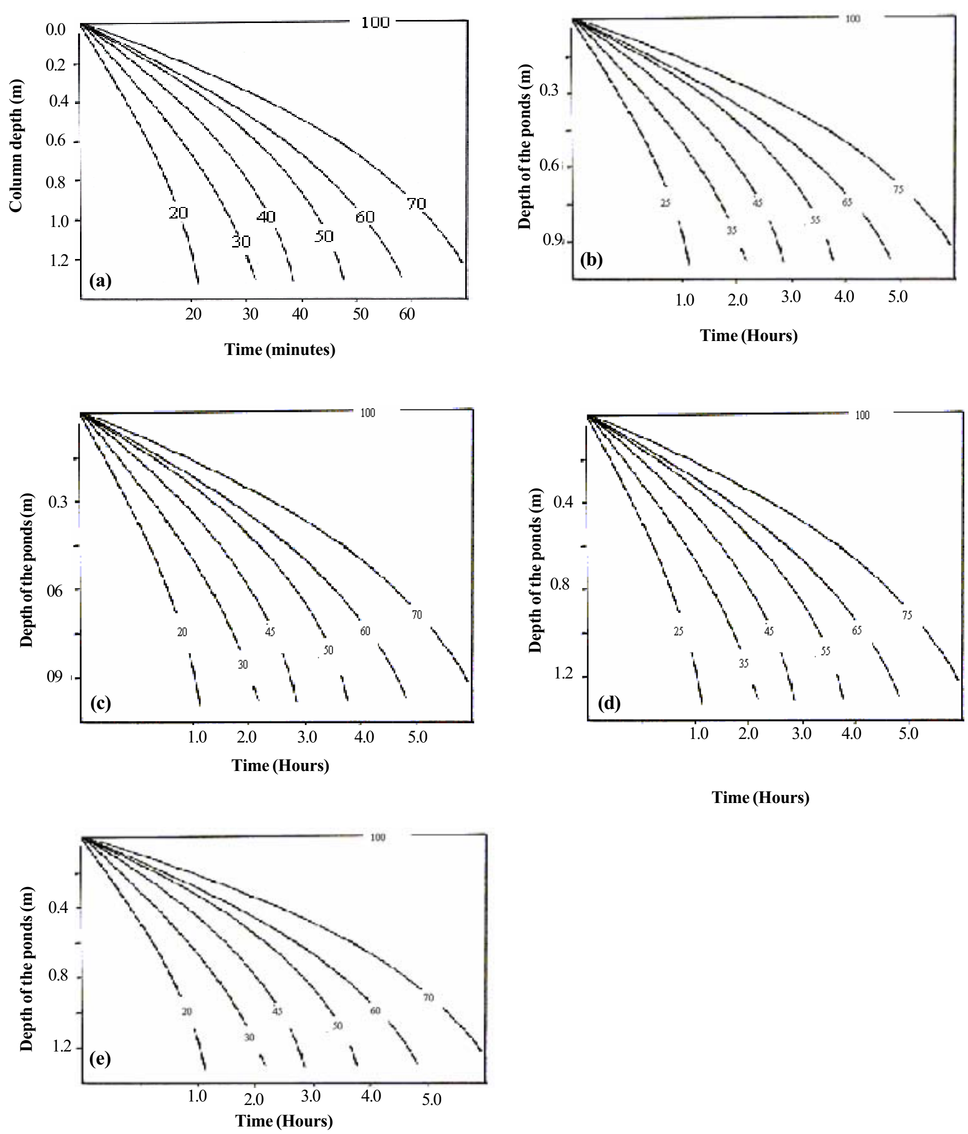


Figure 2. Isoconcentration curves of the suspended solids removed from a domestic-institutional wastewater; (a) Sample 1; (b) Sample 2; (c) Sample 3; (d) Sample 4 and (e) Sample 5.

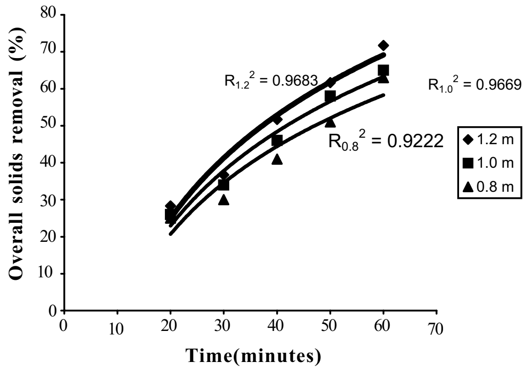


Figure 3. Relationship between overall suspended solids removed from the wastewater and time.

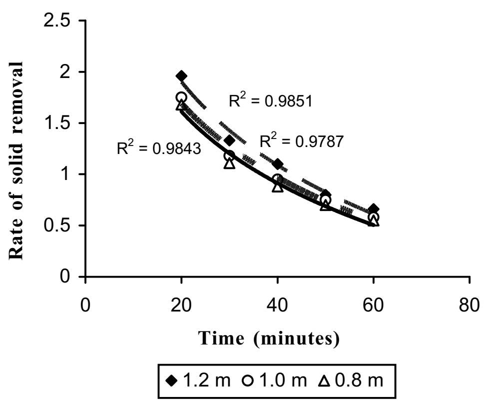


Figure 4. Rate of solids removal versus retention time.

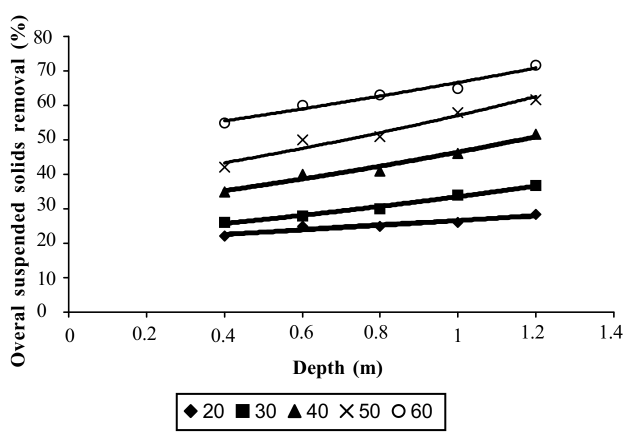


Figure 5. Exponential relationship between overall suspended solids removed from the wastewater and depth of the column.

metres) were obtained by drawing tangential line at the turning points.

The fractions of suspended solids removed from domestic-institutional wastewater were found to be related to the depth logarithmically with correlation coefficients of 0.901, 0.957, 0.910, 0.923 and 0.901 for the retention time of 60, 50, 40, 30 and 20 minutes respectively and related exponentially with correlation coefficients of 0.970, 0.949, 0.970, 0.989 and 0.893 for the retention times (Fig. 5). The results show that exponential relationships predict better than logarithms due to increment in the correlation coefficients insignificance. From these relationships the maximum theoretical hydraulic depth for different retention times to remove 75% influent suspended solids were found to be 1.79 and 2.75 metres respectively. The maximum theoretical hydraulic depth of 1.79 metres is lower than 2.1 metres recommended [4]; this shows that a factor is needed to convert theoretical depths to practical depths. Statistical analysis of the results shows that there is a significant difference between the suspended solids removed along the depth and the time at 95% level.

Fig. 6 shows relationship between compression ratio and retention time of the settled solids using Equation 2. Correlation coefficient of the relationship (R^2) is 0.987 indicating that there is a good fit between these two parameters and the compressing constant is 5.5 x 10^{-3} m per m x unit time. This result indicates that settled solid could be compressed easily under natural condition.

$$H_t - H_\alpha = (H_2 - H_\alpha)\exp^{-i(t-t_2)} \quad (2)$$

Rearranging Equation 2 gives:

$$\frac{H_t - H_\alpha}{(H_2 - H_\alpha)} = \exp^{-i(t-t_2)} \quad (3)$$

Plotting the right hand side against the values of ($t-t_2$) the value of compressive constant will be obtained (as shown in Fig. 6). This value of compressive constant can be related to earth settlement since final solid (sludge which is the settled solids) will be disposed either into landfill or any other means. It is well known that when a saturated, fine grained soil such as settled solids are subjected to an increase in a compressive stress from axial loadings, the soil skeleton undergoes deformation or strain (which is a cumulative effect of grain distortion and particle rolling and slipping). The strain in the soil, which resulted in a reduction in void ratio or void volume can be expressed by a consolidation equation (4).

$$e_i = e_o - (1 + e_0)\frac{s_i}{h} \quad (4)$$

Voids ratio (which is a ratio of the volumes of the void spaces and the mineral grains) is important in this study because many important properties of soil depend on the closeness of the packing of the mineral grains. Landfill is potentially a swampy area of weak soil which is usually converted to recreation centre where building structures are put in place. If adequate measures are not taken to estimate bearing capacity and settlement characteristic of the soil differential settlement may occur which may eventually lead to failure and collapse of such buildings.

Substituting for the value of compressive constant equation (5) becomes Equation 6 as shown below:

$$e_i = e_o - (1+e_0)\frac{5.5x10^{-3}}{h} \quad (5)$$

$$e_i = e_o - C_c \log_{10}\frac{\partial_i}{\partial_0} \quad (6)$$

Using Equation 5, relationship between final void ratio and the depth of the solid in the landfill can be represented as shown in Fig 7. Similarly, Equation 4 was modified to give Equation 6 which relates void ratio and stress together. Fig. 8 shows relationship

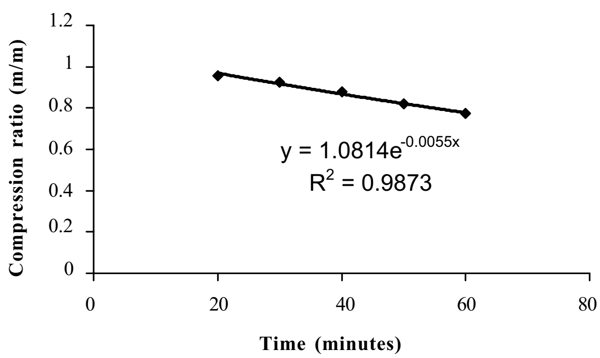


Figure 6. Relationship between compression and retention time.

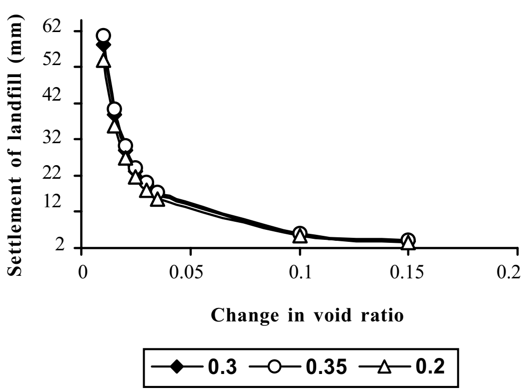


Figure 7. Relationship between overburden and void ratio.

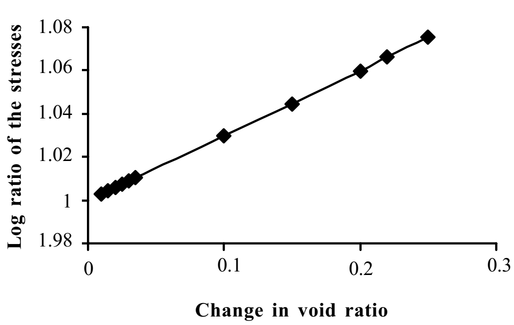


Figure 8. Relationship between overburden stress and void ratio.

between void ratio and ratio of the stresses. It should be noted that the principle of effective stress determines the effect of a pore pressure on the behaviour of a soil with a given total stress[9]. Therefore, when vertical stress (such as building) is applied on such soil, the soil compresses due to dissipation of pore pressure (i.e. reduction in water content), which also results in reduction of void. The effective stress (σ') in granular soil is determined from Equation 7.

$$\sigma' = \sigma - u \quad (7)$$

Based on Equation 7, it can be observed that if the effective stress is reduced, then, the soil will swell (i.e. increase in volume) and its strength will reduce. Conversely, if the effective stress is increased, the soil will compress (i.e. reduction in volume) and its strength will increase. Therefore, building to be constructed on landfill should be supported by the appropriate foundation based on the allowable bearing capacity of the soil.

Conclusions

Based on the findings of the study conducted the following conclusions can be drawn about settling property of domestic-institutional wastewater: i) Settling property of domestic-institutional wastewater is similar to those obtained in domestic wastewaters, but different from those obtained in industrial wastewaters such as textile and tannery. ii) Desludging of settled solids would not be difficult and deep pond ahead of biological treatment plant would help in removing solids and thus influence efficacy of the plant positively. iii) It is important to estimate the void ratio, settlement characteristics and the allowable bearing capacity of the landfill before structures are erected on it in order to prevent differential settlement which can result in collapse.

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