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RESEARCH ARTICLE

EVALUATING THE SPECIFIC RESISTANCE OF CONDITIONED SLUDGE FILTRATION ON NATURAL DRYING BED

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ABSTRACT

A sludge drying bed of 1.2m by 0.75m was designed and used in dewatering sewage sludge collected from the University of Nigeria, Nsukka waste water treatment plant. This was used in determining parameters necessary in the formulation of an equation for sludge filtration based on the concept of specific resistance using LMT dimensional analysis. The equation was used in determining the performance of sludge drying bed which is a natural means of sludge dewatering. This shows that the resistance to filtration for conditioned sludge decreases as the conditioner concentration increases showing that the derived equation is in consonance with Carman's equation and it can be used in evaluating sludge dewatering parameters. The modified equation based on the concept of specific resistance can be adopted in sludge dewatering investigations as it seems to agree with already existing Carman's filtration equation that the resistance to filtration for conditioned sludge decreases as the conditioner concentration increases. The results of the experiment showed that the sludge was filterable due to the calculated values of specific resistance.

INTRODUCTION

The presence of contaminants in sewage sludge arising from municipal discharges is the most challenging problem and may be the deciding factor in determining the choice of a utilization dewatering option. The contaminants accumulated in the sludge can render the material unfit for any beneficial use. The most common option used for sludge dewatering is the natural sand drying beds. The decision to select an environmentally sustainable approach to sludge dewatering can be used very effectively to review and correct point source polluting practices up-stream that should not be taking place. There are techniques used in dewatering devices in removing moisture from waste water sludge which include mechanical and non mechanical methods. In mechanical methods, mechanically assisted physical means are used to dewater the sludge more quickly. The physical means are centrifugation, belt-filter press, filter presses and vacuum filtration. The non mechanical methods rely on natural evaporation and percolation to dewater the solids. These are drying beds and sludge lagoons. The mechanical methods have the advantage of high capacity per unit of space and are often used in large wastewater treatment plant Drying beds are usually used for small industrial or community waste treatment plants to dewater sludge which rely on drainage and evaporation to effect moisture reduction. The liquid from the under drains is returned to the sewage treatment process for further treatment. One of the problems of drying beds in sewage treatment plant is the large area requirement. Sludge drying beds are open; and, as such, are very susceptible to climatic conditions such as precipitation, sunshine, air temperature, relative humidity, and wind velocity. LMT (length, mass and time) dimensional analysis is a mathematical technique used to check derived equations and computations (Rajput, 1998). The seeming problem in evaluating a suitable equation for filtration process depends on the sludge filtration resistance which is a parameter used in quantifying the filterability of sludge. This parameter cannot be easily measured directly like other variables normally incorporated into filtration expressions. Wastewater treatment processes result in the production of large quantities of sludge. The sludge generated is difficult to handle and dispose of because of its high water content of about 97.5 percent (Ademiluyi *et al*, 1983). Dewatering is a physical unit operation used to reduce the moisture content of sewage sludge so that it can be handled and/or processed as a semi-solid instead of liquid (Metcalf &Eddy, 2004). Dewatering process increases solid content or sludge between 20 to 35% (Agunwamba, 2001). The handling of sewage sludge is one of the most significant challenges in wastewater management. In many countries, sewage sludge is a serious problem due to its high treatment costs and the risks to environment and human health (Ghazy *et al*, 2009). Dewatering of sewage sludge is not only found in removal of the excess moisture but to render the sludge odourless and nonputrescible (Garg, 2008). Dewatering is only one component of the wastewater solids treatment process and must be integrated into the overall wastewater system so that performance of both the liquid and solids treatment is optimized. This is a major economical factor in the operation of wastewater treatment plants (Mehrdadi *et al.*, 2006). Dewatering of sewage sludge prior to drying or disposal is an important step because the lower the water content of the

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sludge, the less costly it will be the transport, the less liable to degradation and odour production, and the easier it will be to dry. Typical approaches involve addition of conditioning chemicals to increase the dewatering rate and improve filtrate quality, and then processing the sludge in centrifuges, belt presses or other dewatering unit (Octavio, 2007). Texier (2008) reported that sludge disposal is a growing problem for all wastewater leads to increased sludge production. The amount of produced sludge being very high, it is economically important to reduce its volume by removing as much water as possible in order to reduce the transport, handling, and disposal costs. Sludge filtration theories and derived equations have been based on experimental assumptions and conditions, each researcher making effort to modify already existing theory in order to introduce a completely new concept for evaluating sludge filtration equation. Carman (1934, 1938) proposed a sludge filtration equation for dewatering of sludge at constant pressure. Carman's work was based on the concept of specific resistance and the time velocity plot of sludge filtration at constant pressure. He postulated that specific resistance is independent of suspended solid concentration and assumed that the total loss of filtration pressure arises from pressure drop across filter cake, pressure drop across initial resistance and loss incurred in recovering filtrate. Ademiluyi *et al* (1987), proposed a concept of sludge filterability referred to as sludge dewaterability number (SDN) that was found to be dependent on not only the equipment design but also on the sludge treatment prior to dewatering. They stated that filter medium has significant effects on SDN and it has been experimentally demonstrated that sludge shearing affects SDN. Ruth (1935) established experimentally that the plot of filtrate volume (V) versus time (t) followed a parabolic relation in line with theoretical predictions based on Carman's equations. Anazodo (1975) stated that, the dimensions of length are spatially discriminated into L_x, L_y, and L_z (x, y, z being three mutually perpendicular axes in space), and as well as making distinction between inertial mass,M_μ, and, the amount of matter, M_i: so increasing the multiplicity of the basis of six, viz: $TM_\mu M_i L_x L_y L_z$.

MATERIALS AND METHOD

Experimental setup

Sewage sludge was collected from the Imhoff tank situated at the University of Nigeria, Nsukka, with a bucket into the drying bed located at the station. The detailed description of the designed drying bed is as follows: The length of the drying bed is estimated as 1.2m. The depth is 0.80m, while the width is 0.75m. The lower course of gravel around the under drains is 0.20m extending above the top of the under drains. The top course consists of 0.20m of clean coarse sand. The finished sand surface was leveled. The sludge depth is 0. 30m.The drying bed was designed with a metal wall with under drains pipe laid with open joints. The drainage from bed of filtrate is returned to the sewage treatment plant, where the treatment process is repeated. Sludge that remains on top of the sand bed is solidified by the percolation of water downward into the sand and also from the evaporation from the surface of the sludge. Therefore, the area of the drying bed is estimated to be 0.9m^2. The schematic layout of a sand drying bed is shown in figure 1.

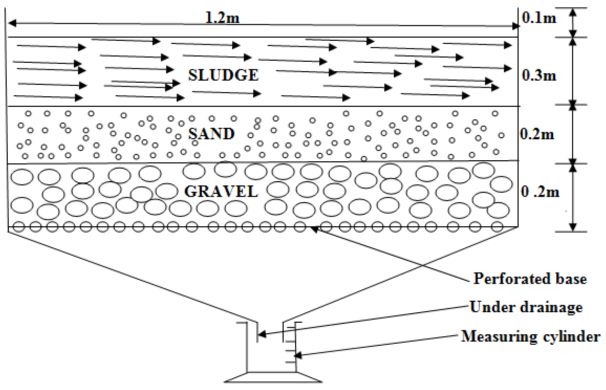

Figure 1: Schematic Diagram of Sand Drying Bed

Filtration parameters determined are as follows Volume of filtrate, time of filtrate, height of sludge on sand bed, sludge temperature, pressure of filtration, Area of filtration, dynamic viscosity, and solid content.

DERIVATION OF SLUDGE FILTRATION EQUATION USING ANAZODO'S METHOD

The dimensions of the variables are summarized in the table below:

Table 1: LMT Dimensions

Variables	LMT Dimensions
Volume (V)	$L_x L_y L_z$
Pressure (P)	$M_i L_z L_x^{-1} L_y^{-1} T^{-2}$
Area (A)	$L_x L_y$
Solid Content (C) mass/volume	$M_\mu L_x^{-1} L_y^{-1} L_z^{-1}$
Dynamic Viscosity(**μ**)	$M_i L_z^{-1} T^{-1}$
Specific Resistance (R)	$L_z M_\mu^{-1}$
Time (t)	T

$V = P^a\, A^b\, C^c\, \mu^d\, R^e\, t^f$ (2.1)

Using $M_\mu M_i L_x L_y L_z T$ for LMT

$L_x L_y L_z = (M_i L_z L_x^{-1} L_y^{-1} T^{-2})^a\, (L_x L_y)^b\, (M_\mu L_x^{-1} L_y^{-1} L_z^{-1})^c\, (M_i L_z^{-1} T^{-1})^d$
$(L_z M_\mu^{-1})^e\, (T)^f$ (2.2)

For $L_x L_y$: $1 = -a + b - c$ (2.2a)

For L_z : $1 = a - c - d + e$ (2.2b)

For M_i : $0 = a + d$ (2.2c)

For M_μ : $0 = c - e$ (2.2d)

For T: $0 = -2a - d + f$ (2.2e)

Five equations in six unknowns may be solved in terms of one unknown, say 2.2c.

From equation (2.2c)

$a = -d$

From equation (2.2d)

$c = e$

Substituting c in equation (2.2b)

$1 = a - c - d + e$

$1 = a - e - d + e$

$1 =$
$a - d$ (2.2f)

From equation (2.2f)

$1 = a - d$

$1 = a - (-a)$

$1 = 2a$

$a = ½$

If $a = ½$

Hence, $d = -½$

From equation (2.2a)

$1 = -a + b - c$

$1 = -½ + b - c$

$b - c = 1 + ½ = 3/2$

$b - c = 3/2$

$b = (3/2 + c)$

From equation (2.2e)

$0 = -2a - d + f$

$0 = -2(½) - (-½) + f$

$0 = -1 + ½ + f$

$f = ½$

$\therefore a = ½, b = 3/2 + c, c = e, d = -½, f = ½$

Hence,

$$V = P^{1/2} A^{(3/2 + c)} C^c \mu^{-1/2} R^c t^{1/2} \quad (2.3)$$

$$V = \left(\frac{Pt}{\mu}\right)^{1/2} A^{3/2} A^c C^c R^c \quad (2.4)$$

$$V == \left(\frac{Pt}{\mu}\right)^{1/2} A^{3/2} (ACR)^c \quad (2.5)$$

$$V = \left(\frac{PtA^3}{\mu}\right)^{1/2} (ACR)^c \quad (2.6)$$

Since pressure (P) is hydrostatic, that is ρgh. Then, the equation becomes

$$V = \left(\frac{(\rho gh)tA^3}{\mu}\right)^{1/2} (ACR)^c \quad (2.7)$$

$$V = \left(\frac{\rho ghtA^3}{\mu}\right)^{1/2} (ACR)^c \quad (2.8)$$

$$V = t^{1/2} \left(\frac{\rho ghA^3}{\mu}\right)^{1/2} (ACR)^c \quad (2.9)$$

$$\frac{V}{t^{1/2}} = \left(\frac{\rho ghA^3}{\mu}\right)^{1/2} (ACR)^c \quad (2.10)$$

$$\frac{t^{1/2}}{V} = \left(\frac{\rho ghA^3}{\mu}\right)^{-1/2} (ACR)^{-c} \quad (2.11)$$

$$\frac{t}{V^2} = \left(\frac{\rho ghA^3}{\mu}\right)^{-1} (ACR)^{-2c} \quad (2.12)$$

$$\frac{t}{V} = V\left(\frac{\mu}{\rho ghA^3}\right) (ACR)^{-2c} \quad (2.13)$$

A plot of t/v against solid content(C) gave a linear relationship

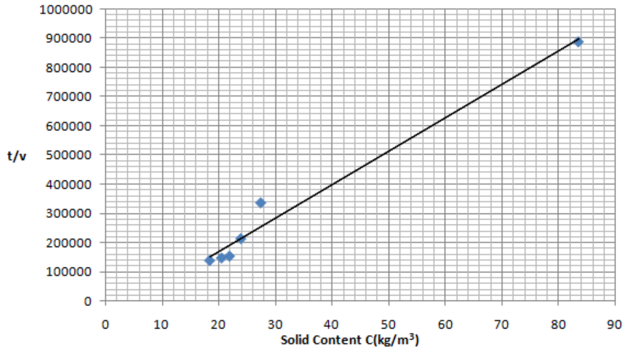

Figure 2. Graph of t/v against Solid Content

Hence, volume of filtrate (V) is proportional to solid content(C)

Therefore, $-2c = 1$

$\therefore c = -\frac{1}{2}$

$$\frac{t}{V} = V\left(\frac{\mu}{\rho ghA^3}\right)(ACR)^{-2\times-1/2} \quad (2.14)$$

$$\frac{t}{V} = V\left(\frac{\mu}{\rho ghA^3}\right)(ACR) \quad (2.15)$$

Hence,

$$\frac{t}{V} = V\left(\frac{\mu CR}{\rho ghA^2}\right) \quad (2.16)$$

Taking the slope of the line as (b) and equating the coefficient of (V), (R) was calculated from the formula:

$$\therefore R = \left(\frac{\rho ghA^2}{\mu C}\right) b \quad (2.17)$$

where,

A = Area of Filtration (m^2) C = Solid Content (kg/m^3)

ρgh = Hydrostatic Pressure (N/m^2)

R = Specific Resistance (m/kg) V = Volume of Filtrate (m^3) μ = Dynamic Viscosity ($N.s/m^2$)

b = Slope (s/m^6)

RESULTS AND DISCUSSION

The Effect of Ferric Chloride on Specific Resistance using One bucket of Sludge with 10g of Ferric Chloride, 20g, 30g, 40g and 50g are shown below

Table 2: The Effect of Ferric Chloride on Specific Resistance using One bucket of Sludge with 10g of Ferric Chloride

Time t (s)	Volume of filtrate (V) m^3	t/v	V^2	V*t/v
1200	0.00135	888888.889	0.000001823	1200
2400	0.002595	924855.491	0.000006734	2400
3600	0.003735	963855.422	0.00001395	3600
4800	0.004755	1009463.72	0.00002261	4800
6000	0.005335	1124648.55	0.000028462	6000
	0.01777	4911712.07	0.000073579	18000

Height (h) m =0.02, Temp. (^{o}C)= 28, Density of water (kg/m^3) = 996.23, Area (A) m^2= 0.9, Hydrostatic Pressure P =ρgh (N/m^2) = 195.46, Dynamic Viscosity μ ($N.s/m^2$) = 0.8917, Solid Content (C) mass/vol. kg/m^3 = 83.5, ∴ R = 11.0920×10^7 m/kg

Table 3: The Effect of Ferric Chloride on Specific Resistance using One bucket of Sludge with 20g of Ferric Chloride

Time t (s)	Volume of filtrate (V) m^3	t/v	V^2	V*t/v
1200	0.00165	727272.727	0.000002723	1200
2400	0.003175	755905.512	0.00001008	2400
3600	0.004515	797342.193	0.00002039	3600
4800	0.005571	861604.739	0.00003104	4800
6000	0.006221	964475.165	0.00003870	6000
	0.021132	4106600.34	0.000102925	18000

Height (h) m =0.016, Temp. (^{o}C)= 29, Density of water (kg/m^3) = 995.94, Area (A) m^2= 0.9, Hydrostatic Pressure P =ρgh (N/m^2) = 156.32, Dynamic Viscosity μ ($N.s/m^2$) = 0.8917, Solid Content (C) mass/vol. kg/m^3 = 83.5, b = $4.7299\times 10^7 s/m^6$, ∴ R = 8.2996×10^7 m/kg

Table 4: The Effect of Ferric Chloride on Specific Resistance using One bucket of Sludge with 30g of Ferric Chloride

Time t (s)	Volume of filtrate (V) m^3	t/v	V^2	V*t/v
1200	0.006625	181132.075	0.00004389	1200
2400	0.009781	245373.684	0.00009567	2400
3600	0.011356	317013.033	0.000128959	3600
4800	0.012356	388475.235	0.000152671	4800
6000	0.013068	459136.823	0.000170773	6000
	0.053186	1591130.85	0.000591961	18000

Height (h) m =0.01, Temp. (^oC)= 30, Density of water (kg/m^3) = 995.65, Area (A) m^2= 0.9, Hydrostatic Pressure P =ρgh (N/m^2) = 97.6733, Dynamic Viscosity μ ($N.s/m^2$) = 0.8386, Solid Content (C) mass/vol. kg/m^3 = 83.5, b = $4.1007\times 10^7 s/m^6$, ∴ R = 4.6330×10^7m/kg

Table 5: The Effect of Ferric Chloride on Specific Resistance using One bucket of Sludge with 40g of Ferric Chloride

Time(s)	Volume of filtrate (V) m^3	t/v	V^2	V*t/v
1200	0.007565	158625.2	0.00005723	1200
2400	0.011421	210139.2	0.000130439	2400
3600	0.013076	275313.6	0.000170982	3600
4800	0.014126	339799	0.000199544	4800
6000	0.014936	401714	0.000223084	6000
	0.061124	1385591	0.000781278	18000

Height (h) m =0.008, Temp. (^oC)= 30, Density of water (kg/m^3) = 995.65, Area (A) m^2= 0.9, Hydrostatic Pressure P =ρgh (N/m^2) = 78.1386, Dynamic Viscosity μ ($N.s/m^2$) = 0.8386, Solid Content (C) mass/vol. kg/m^3 = 83.5, b = $3.1173\times 10^7 s/m^6$, ∴ R = 2.8177×10^7m/kg

Table 6: The Effect of Ferric Chloride on Specific Resistance using One bucket of Sludge with 50g of Ferric Chloride

Time(s)	Volume of filtrate (V) m^3	t/v	V^2	V*t/v
1200	0.009625	124675.3	0.00009264	1200
2400	0.014175	169312.2	0.000200931	2400
3600	0.016401	219498.8	0.000268993	3600
4800	0.017653	271908.5	0.000311628	4800
6000	0.018565	323188.8	0.000344659	6000
	0.076419	1108584	0.001218852	18000

Height (h) m =0.006, Temp. (^oC)= 30, Density of water (kg/m^3) = 995.65, Area (A) m^2= 0.9, Hydrostatic Pressure P =ρgh (N/m^2) = 58.6040, Dynamic Viscosity μ ($N.s/m^2$) = 0.8386, Solid Content (C) mass/vol. kg/m^3 = 83.5, b = $2.0767\times 10^7 s/m^6$, ∴ R = 1.4078×10^7m/kg

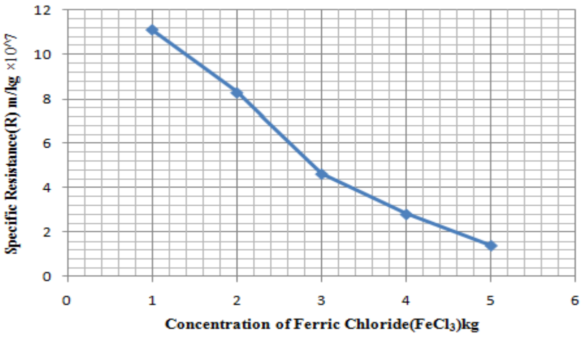

Figure 3. Graph of Specific Resistance (R) against Concentration of Ferric Chloride

From the tables and graph presented it shows that the increase in the amount of ferric chloride makes the filtration to be faster in breaking down the resistance of sludge. The results gave specific resistance of 11.0920×10^7m/kg, 8.2996×10^7m/kg, 4.6330×10^7m/kg, 2.8177×10^7m/kg, and 1.4070×10^7m/kg for a conditioner concentration of 10g, 20g, 30g, 40g, and 50g respectively. This shows that the resistance to filtration decreases with increase in the concentration of ferric chloride showing that the modified equation is valid.

CONCLUSION

Ferric chloride was used to check the effect of conditioner on specific resistance. The results gave specific resistance of 11.0920×10^7m/kg, 8.2996×10^7m/kg, 4.6330×10^7m/kg, 2.8177×10^7m/kg, and 1.4070×10^7m/kg for a conditioner concentration of 10g, 20g, 30g, 40g, and 50g respectively. This shows that the resistance to filtration decreases with increase in the concentration of ferric chloride showing that the modified equation is in consonance with Carman's equation and it can be used for both sludge drying bed and vacuum filtration but for vacuum filtration it will be multiplied by 2 since Carman's equation is based on vacuum filtration. Since residues from each wastewater plant are unique, no specific treatment process for dewatering will yield the same results. The modified equation for specific resistance based on the concept of dimensional analysis can therefore be adopted in sludge dewatering investigations.

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