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

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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 upstream 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 plants 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 (Metcalfe & Eddy, 2004). Dewatering process increases solid content or sludge between 20 to 35% (Agnwamba, 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...
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 Lₓ, Lᵧ, and Lz (x, y, z being three
mutually perpendicular axes in space), and as well as making
distinction between inertial mass, Mₓ, and, the amount of
matter, Mᵧ; so increasing the multiplicity of the basis of six,
viz: TMₓMᵧLₓLᵧLz.

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
0.9m². The schematic layout of a sand drying bed is shown in
figure 1.

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>
<thead>
<tr>
<th>Variables</th>
<th>LMT Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (V)</td>
<td>LₓLᵧLz</td>
</tr>
<tr>
<td>Pressure (P)</td>
<td>MᵧLₓLᵧLz⁻¹T⁻²</td>
</tr>
<tr>
<td>Area (A)</td>
<td>LₓLᵧ</td>
</tr>
<tr>
<td>Solid Content (C)</td>
<td>MᵧLₓLᵧLz⁻¹</td>
</tr>
<tr>
<td>mass/volume</td>
<td></td>
</tr>
<tr>
<td>Dynamic Viscosity(µ)</td>
<td>MᵧLₓ⁻¹T⁻¹</td>
</tr>
<tr>
<td>Specific Resistance (R)</td>
<td>L₂Mᵧ⁻¹</td>
</tr>
<tr>
<td>Time (t)</td>
<td>T</td>
</tr>
</tbody>
</table>

\[
V = P^a A^b C^c \mu^d R^e T^f 
\]

Using \(MᵣMᵧLₓLᵧLzT\) for LMT

\[
LₓLᵧLz = (MᵧLₓLᵧLz⁻¹T⁻²)^b (LₓLᵧ)^c (MᵧLₓLᵧLz⁻¹LₓLᵧ⁻¹)^d (MᵧLₓLᵧLz⁻¹T⁻¹)^e (L₂Mᵧ⁻¹)^f (T)^g
\]

For \(LₓLᵧ \): \(1 = -a + b - c - d + e \) (2.2a)

For \(Lₓ \): \(1 = a - c - d + e \) (2.2b)

For \(Mᵧ \): \(0 = a + d \) (2.2c)

For \(Mᵣ \): \(0 = c - e \) (2.2d)

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

Five equations in six unknowns may be solved in terms of one
unknown, say \(a \).

From equation

\(a = -d \) (2.2c)

From equation

\(c = e \) (2.2d)

Substituting \(c \) in equation

\(1 = a - d + e \) (2.2b)

\(1 = a - e - d + e \) (2.2b)
Therefore, content(C)

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

Then, the equation becomes

Since pressure (P) is hydrostatic, that is

Hence,

From equation (2.2f)

From equation (2.2a)

Hence, d = a

If a = ½
Hence, d = - ½

From equation (2.2e)

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

where,

A = Area of Filtration (m²)  \( C \) = Solid Content (kg/m³)  \( \rho gh \) = Hydrostatic Pressure (N/m²)  \( R \) = Specific Resistance (m/kg)  \( V \) = Volume of Filtrate (m³)  \( \mu \) = Dynamic Viscosity (N.s/m²)

b = Slope (s/m⁴)

RESULTS AND DISCUSSION

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

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Volume of filtrate (V) (m³)</th>
<th>t/v</th>
<th>V²</th>
<th>V*t/v</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>0.00135</td>
<td>888888.889</td>
<td>0.000001823</td>
<td>1200</td>
</tr>
<tr>
<td>2400</td>
<td>0.002595</td>
<td>924855.491</td>
<td>0.000006734</td>
<td>2400</td>
</tr>
<tr>
<td>3600</td>
<td>0.003735</td>
<td>968355.422</td>
<td>0.00001395</td>
<td>3600</td>
</tr>
<tr>
<td>4800</td>
<td>0.004755</td>
<td>1009436.72</td>
<td>0.00002261</td>
<td>4800</td>
</tr>
<tr>
<td>6000</td>
<td>0.005335</td>
<td>1124648.55</td>
<td>0.000028462</td>
<td>6000</td>
</tr>
<tr>
<td>7200</td>
<td>0.006635</td>
<td>1200000.80</td>
<td>0.00003759</td>
<td>8000</td>
</tr>
</tbody>
</table>

Height (h) m = 0.02, Temp. (°C) = 28, Density of water (kg/m³) = 996.23, Area (A) m² = 0.9, Hydrostatic Pressure P = \( \rho gh \) (N/m²) = 195.46, Dynamic Viscosity \( \mu \) (N.s/m²) = 0.8917, Solid Content (C) mass/vol. kg/m³ = 83.5, \( R \) = 11.0920 × 10⁷ m/kg

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Volume of filtrate (V) (m³)</th>
<th>t/v</th>
<th>V²</th>
<th>V*t/v</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>0.00165</td>
<td>727272.727</td>
<td>0.000002723</td>
<td>1200</td>
</tr>
<tr>
<td>2400</td>
<td>0.003175</td>
<td>755905.512</td>
<td>0.00001008</td>
<td>2400</td>
</tr>
<tr>
<td>3600</td>
<td>0.004515</td>
<td>797342.193</td>
<td>0.00002039</td>
<td>3600</td>
</tr>
<tr>
<td>4800</td>
<td>0.005571</td>
<td>861604.739</td>
<td>0.00003104</td>
<td>4800</td>
</tr>
<tr>
<td>6000</td>
<td>0.006221</td>
<td>964475.165</td>
<td>0.00003870</td>
<td>6000</td>
</tr>
<tr>
<td>7200</td>
<td>0.021132</td>
<td>410660.34</td>
<td>0.000102925</td>
<td>18000</td>
</tr>
</tbody>
</table>

Height (h) m = 0.016, Temp. (°C) = 29, Density of water (kg/m³) = 995.94, Area (A) m² = 0.9, Hydrostatic Pressure P = \( \rho gh \) (N/m²) = 156.32, Dynamic Viscosity \( \mu \) (N.s/m²) = 0.8917, Solid Content (C) mass/vol. kg/m³ = 83.5, \( R \) = 8.2996 × 10⁷ m/kg

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

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

Therefore, -2c = 1
\[ c = \frac{-1}{2} \]
Table 4: The Effect of Ferric Chloride on Specific Resistance using One bucket of Sludge with 30g of Ferric Chloride

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Volume of filtrate (V) m³</th>
<th>V/t</th>
<th>V²/²</th>
<th>V³/²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>0.006625</td>
<td>181132.075</td>
<td>0.00004389</td>
<td>1200</td>
</tr>
<tr>
<td>2400</td>
<td>0.009781</td>
<td>245373.684</td>
<td>0.00009567</td>
<td>2400</td>
</tr>
<tr>
<td>3600</td>
<td>0.011356</td>
<td>317013.033</td>
<td>0.000128959</td>
<td>3600</td>
</tr>
<tr>
<td>4800</td>
<td>0.012356</td>
<td>388475.235</td>
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<td>4800</td>
</tr>
<tr>
<td>6000</td>
<td>0.013068</td>
<td>459136.823</td>
<td>0.000170773</td>
<td>6000</td>
</tr>
<tr>
<td>7200</td>
<td>0.014386</td>
<td>530074.659</td>
<td>0.000190241</td>
<td>7200</td>
</tr>
</tbody>
</table>

Height (h) m = 0.01, Temp. (°C) = 30, Density of water (kg/m³) = 995.65, Area (A) m² = 0.9, Hydrostatic Pressure P = gh (N/m²) = 97.6733, Dynamic Viscosity µ (N.s/m²) = 0.8386, Solid Content (C) mass/vol, kg/m³ = 83.5, b = 4.1007 × 10⁶/s/m⁶, ∴ R = 4.6330 × 10⁷/m/kg

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

<table>
<thead>
<tr>
<th>Time(s)</th>
<th>Volume of filtrate (V) m³</th>
<th>V/t</th>
<th>V²/²</th>
<th>V³/²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>0.007556</td>
<td>158625.2</td>
<td>0.00005723</td>
<td>1200</td>
</tr>
<tr>
<td>2400</td>
<td>0.011421</td>
<td>210139.2</td>
<td>0.00010439</td>
<td>2400</td>
</tr>
<tr>
<td>3600</td>
<td>0.013076</td>
<td>275313.6</td>
<td>0.000109492</td>
<td>3600</td>
</tr>
<tr>
<td>4800</td>
<td>0.014126</td>
<td>339799</td>
<td>0.000119544</td>
<td>4800</td>
</tr>
<tr>
<td>6000</td>
<td>0.014936</td>
<td>401714</td>
<td>0.000223084</td>
<td>6000</td>
</tr>
<tr>
<td>7200</td>
<td>0.016124</td>
<td>463496</td>
<td>0.000255876</td>
<td>7200</td>
</tr>
</tbody>
</table>

Height (h) m = 0.008, Temp. (°C) = 30, Density of water (kg/m³) = 995.65, Area (A) m² = 0.9, Hydrostatic Pressure P = gh (N/m²) = 78.1386, Dynamic Viscosity µ (N.s/m²) = 0.8386, Solid Content (C) mass/vol, kg/m³ = 83.5, b = 3.1173 × 10⁶/s/m⁶, ∴ R = 2.8177 × 10⁷/m/kg

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

<table>
<thead>
<tr>
<th>Time(s)</th>
<th>Volume of filtrate (V) m³</th>
<th>V/t</th>
<th>V²/²</th>
<th>V³/²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>0.009625</td>
<td>124675.3</td>
<td>0.00009264</td>
<td>1200</td>
</tr>
<tr>
<td>2400</td>
<td>0.014175</td>
<td>169312.2</td>
<td>0.000208931</td>
<td>2400</td>
</tr>
<tr>
<td>3600</td>
<td>0.016401</td>
<td>219498.8</td>
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<td>4800</td>
<td>0.017653</td>
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<td>0.018565</td>
<td>323188.8</td>
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<tr>
<td>7200</td>
<td>0.020769</td>
<td>385222.3</td>
<td>0.000391284</td>
<td>7200</td>
</tr>
</tbody>
</table>

Height (h) m = 0.006, Temp. (°C) = 30, Density of water (kg/m³) = 995.65, Area (A) m² = 0.9, Hydrostatic Pressure P = gh (N/m²) = 58.6040, Dynamic Viscosity µ (N.s/m²) = 0.8386, Solid Content (C) mass/vol, kg/m³ = 83.5, b = 2.0767 × 10⁷/s/m⁶, ∴ R = 1.4078 × 10⁷/m/kg

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 × 10⁷/m/kg, 8.2996 × 10⁷/m/kg, 4.6330 × 10⁷/m/kg, 2.8177 × 10⁷/m/kg, and 1.4070 × 10⁷/m/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 × 10⁷/m/kg, 8.2996 × 10⁷/m/kg, 4.6330 × 10⁷/m/kg, 2.8177 × 10⁷/m/kg, and 1.4070 × 10⁷/m/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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**REFERENCES**


