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Buckingham PI Dimensional Analysis of Cake Yield from Sludge Filtration Process

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ABSTRACT: *Buckingham Pi dimensional analysis was used to derive an equation expressing filterability in terms of Filter cake yield. The model shows that the cake yield from a pressure filter is directly proportional to the filter area of the vessel, applied pressure and initial solids content of the sludge while being inversely proportional to specific resistance, viscosity of filtrate, compressibility coefficient of the slurry and pressing time. The new model which incorporated the compressibility attribute of the slurry hitherto unaccounted for in previous models enables performance of a pressure filter (Filter Press) to be predicted from a simple laboratory determination of cake yields. It was observed that increasing ferric chloride dosage from 11.87% to 22.61% increased filter cake yield from 3.785 x 10-4g/cm^{2}s to 4.4118 x 10-4g/cm^{2}s while reducing specific resistance from 1.7372 x 1010cm/g to 1.5940 x 1010cm/g. Moreover, the optimum dosage from the graph to attain acceptable filtrate quality was 19.63% for an operating pressure of 6628.18g/cm^2. It was also observed that increasing compressibility from 0.7076 cm s^2/g to 0.7314 cm s^2/g led to decreased solids capture from 3.7682 g/cm^{2}s to 3.5763 g/cm^{2}s for the tested 0.0194 g/cm^3 sludge sample. Considering the differences in the parameters tested, the comparative analytical results showed that there was closer agreement between the actual cake yield and predicted values while values predicted from other models were out of range. Experimental verification of the new model showed that the predicted performance agrees with the actual experimental values with a correlation coefficient of 0.993.*

Keywords: *Cake yield, Sludge, Compressibility, Pressure filtration, Buckingham method, Dimensional analysis, Filter press*

I. INTRODUCTION

Sludge is semi-solid slurry that can be produced from a range of industrial processes, from water treatment or on-site sanitation systems. There is increasing concern over hazards posed by indiscriminate discharge of untreated sludge into the environment. The need to develop scientific models to tackle the problems in an environmentally sound manner cannot be over-emphasized. Sludge dewatering which is an integral part of sludge treatment involves removal of the water content of the sludge so that the formed residue on the filter medium effectively behaves as a solid for handling purposes [1]. Sludge dewatering models have over the years been expressed in terms of specific resistance to filtration. Most of the models formulated in this regard including Carman's modified equation were based on Darcy's law for incompressible sludge filtration.

These have been found to be in error, as they cannot validly predict compressible sludge filterability. The basis upon which they were formulated has also been found to be inconsistent [2]. Moreover, the mere absence of the compressibility attribute of the sludge which has been found to determine the effectiveness of a filtration process in these models necessitated the study. This study adopted entirely a different approach by accounting for the compressibility attribute of the sludge under constant pressure filtration process. The specific objectives were to formulate a new cake yield model with cake compressibility as a measure of sludge filterability using the Buckingham pi dimensional analysis and compare the developed model with modified cake yield model developed by [3] and the actual experimental values.

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II. REVIEW OF MODELS ON CAKE FILTRATION

It has been observed from previous researches that one of the most important sludge parameters, the compressibility coefficient was obviously unaccounted for in the formulation of cake filtration equations. Amongst such models are the traditional filtration equations suggested by [3] & [4]; [5], [6] and [7]) where the sludge compressibility effects on filterability were obviously unaccounted for. It has been discovered in literature that the traditional equations were embedded with uncertainties in the areas of formulating them. [8] stressed that since the literature is replete of dewatering operations which have unsatisfactory performance predictions and formulations and considering the controversies among prominent researcher to the present knowledge of filtration equations, it is justified that an acceptable equation which characterize the filtration process has to be derived. The equation to be derived must contain the compressibility coefficient 'S' as an attribute. The incorporation of 'S' will make such equation acceptable to the previous researchers. In this study, a valid equation based on Buckingham pi method of Dimensional Analyses was used in evaluation of the compressibility attribute of sludge and it's effect on filter cake yield equally investigated.

Carman derived his equation based on non-compressible sludge cakes. In his equation, which was modification of Darcy's equation, he stressed that the specific resistance is constant throughout the filtration process. Hence, [3] proposed the equation,

$$Y = (\frac{2PC}{\mu R\theta})^{\frac{1}{2}} \qquad 1$$

where Y is the cake yield (kg/m^2s)
V = volume of filtrate. m^3
P = pressure drop, kg/m^2
C = concentration of solids in the feed, kg/m3
R = specific cake resistance, kg/m
µ = liquid viscosity, poiseType equation here.
θ = filtration time, s

While modifying the previous work of [9] for sludge undergoing rotary filtration process, [7] assumed that for a yield equation to be fully described as parabolic, the initial specific resistance must be assumed as zero. His model which failed to account for the compressibility attributes of the slurry is given as.

$$L = \frac{4.6(100 - C_i)}{100(C_i - C_f)}.[PC_i\frac{100 - C_i}{TR\eta}]^{\frac{1}{2}} \qquad 2$$

where L = cake yield as dry solids, kg/m.s
ɲ = viscosity of filtrate, $N.sec/m^2$
Ci = initial moisture content of sludge, kg/m^3
Cf = final moisture content of cake, kg/m^3
P = filtration pressure, kg/m^2
T = filtration time, S
R= specific resistance, kg/m

[6] in their model maintained that Carman's modified cake yield equation can only be applied to determine a sludge filtration process if sludge conditioning does not appreciably alter the solids content of the original slurry, as is usually with chemical coagulants. He stated that if the main objective of sludge conditioning is to improve filter yield, it is better to express filterability as yield. He thereafter modified [10] equation to account for both the original sludge

solids and conditioner solids as follows:

$$Y_N = \frac{FPW}{\mu Rt} \qquad 3$$

where YN = net cake yield, kg/m^3.s
P = pressure, N/m^2
W = dry solids mass per unit volume, kg/cm^3
μ = filtrate viscosity, N.sec/m^2
t = filtration time, S
R = specific resistance, kg/m
F = original sludge solids/ (original sludge solids + conditioner solids)

However, It is important to note that the traditional Carman's equations, Rebhun, Jones, Gale and co-workers did not account for the compressibility coefficient in the formulation of their equations as highlighted earlier. While Carman or Darcy equations may hold true for sand bed filtration under laminar flow, it cannot hold true for compressible cake under pressure filtration process. This is due to the fact that the equation was formulated based on the incompressibility of the Newtonian fluid.

III. METHODOLOGY

The study adopted modeling and experimental approaches based on Buckingham pi dimensional analysis. Constant pressure filtration experiments with the aid of a filter press assembly were carried out respectively on five sludge samples with initial solid content of 0.0128 g/cm^3, 0.0194 g/cm^3, 0.0220 g/cm^3, 0.02465 g/cm^3 and 0.0393 g/cm^3 using varying dosage of ferric chloride suspension. The pressure range for the filtration experiments was between 2039.43 g/cm^2 to 6628.155 g/cm^2. For each of the filtration cycle, 60 ml of the formed sludge slurry was introduced into the Filter press assembly via the feed inlet container. Compressed air was admitted into the press by gradually opening the pressure cylinder outlet valve until the desired pressure was indicated on the vessel pressure gauge. Filtration was initiated by gradually opening the filtrate outlet valve. The durations for the slurry to filter were noted using a stop clock, while the volumes of filtrate collected at every 10 seconds intervals were read from the measuring cylinder. The actual filter cake yield per each cycle was thereafter calculated after oven drying the deposited solid residue at 105oC for 24 hours. Statistical analysis was carried out on the data generated following the Buckingham pi method. The compressibility of the sludge was calculated from the slope of the plot of Log R against Log P using Armanante equation.

3.1 Developing the new filtration equation

In order to derive the new Filter cake yield equation, the Buckingham's pi method of dimensional analysis was employed. The sludge cake yield (Y) is a function of volume of the sludge (V), filter paper area (A), time of filtration (t), mass of solids per unit volume of filtrate (C), net filtration pressure (P), viscosity of filtrate (μ), the average specific resistance of filter cake (R) and Sludge compressibility (S). This is mathematically expressed as equation (3.4). Table 3.1 is a summary of the relevant variables and their dimensions as applied in this derivation.
Assigning any arbitrary value to the exponent of the variables of interest and expressing the variable as a product of others became expedient hence,

$$Y = f(P, A, C, V, \mu, t, Y, R, S) \qquad 4$$

Or

$$f(P, A, C, V, \mu, t, Y, R, S) = 0 \qquad 5$$

The theorem propounded by [11] states that if there is physically meaningful equation involving a certain number of n variables, then the original equation can be rewritten in terms of a set of p = n-k dimensionless parameters π1, π2,…πp constructed from the original variables where k is the number of physical dimensions involved.

From the Buckingham's pi method theorem, the total number of variables (n) is nine while the number of fundamental dimensions (m) is three,

Hence, the number of π- terms is n – m, 9 – 3 = 6. Therefore, number of π-terms in the equation can be written as:

$$f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6) = 0 \quad 6$$

π_1 = $Pa\, A^b\, \mu^c\, y$ 7
π_2 = $Pa\, A^b\, \mu^c\, R$ 8
π_3 = $Pa\, A^b\, \mu^c\, C$ 9
π_4 = $Pa\, A^b\, \mu^c\, t$ 10
π_5 = $Pa\, A^b\, \mu^c\, V$ 11
π_6 = $Pa\, A^b\, \mu^c\, S$ 12

Where π_1 to π6 are dimensionless terms while a, b, and c are exponents to be determined by dimensional Analysis.

Table 1: Summary of LMT Dimensional formula

Physical Variables	Symbols	Dimensions
Yield	Y	$ML^{-2}T^{-1}$
Volume	V	L^3
Filtration Area	A	L^2
Time for Filtration	t	T
Mass of cake dry solids per unit volume of filtrate	C	ML^{-3}
Net filtration Pressure	P	$ML^{-1}T\text{-}2$
Viscosity of filtrate	μ	$ML^{-1}T\text{-}1$
Average specific resistance of filter cake	R	LM^{-1}
Compressibility coefficient	S	$M^{-1}LT^2$

Considering π1– Term

By replacing the right hand side of Equation (7) with the corresponding dimensions of the variables and the dimensionless term on the left hand side with $M^0 L^0 T^0$, equation obtained is given as:

$$M^0 L^0 T^0 \;=\; (ML^{-1}T^{-2})^a\, (L^2)^b\, (ML^{-1}T^{-1})^c\, (ML^{-2}T^{-1}) \quad 13$$

Where a, b, c, are unknowns to be determined using dimensional homogeneity between variables.

Equating the exponents of M, L and T on the left hand side to the corresponding exponents on the right hand side, we get,

M :0 = a + c + 1 .(i)

L : 0 = -a + 2b –c -2 (ii)

T : 0 = -2a –c -1 .(iii)

From equation (iii), c = -2a-1 (iv),

Combining equation (i) and (iii), => a-2a-1 +1 =0

= a = 0, c= -1

Solving equation (ii) for the values of a=0 and c=-1 yields, b= ½

Substituting the values of a, b and c in Equation (7), we obtain:

$$\pi_1 = \frac{A^{1/2}Y}{\mu} \quad 14$$

Analyzing π_2 term in equation (8) dimensionally,

$\pi_2 = P^a A^b \mu^c R$

$$M^0L^0T^0 = [ML^{-1}T^{-2}]^a [L^2]^b [ML^{-1}T^{-1}]^c [M^{-1}L] \quad 15$$

M:0 = a + c -1 (i)

L:0 = -a+ 2b-c+1 (ii)

T:0 = -2a-c (iii)

From equation (i), a = 1-c (iv)

Solving equations (iv) and (iii) simultaneously, -2(1-c)-c

=>-2+2c-c =0 c =2, a =-1,

Substituting values of a and c in equation (ii) yields b = 0

Hence, equation (8) becomes,

$$\pi_2 = \frac{R\mu^2}{P} \quad 16$$

Analyzing π_3 term in equation (9) dimensionally,

$\pi_3 = P^a A^b \mu^c C$,

$$M^0L^0T^0 = [ML^{-1}T^{-2}]^a [L^2]^b [ML^{-1}T^{-1}]^c [ML^{-3}] \quad 17$$

M:0 = a+c+1 (i)

L:0 = -a+2b-c-3 (ii)

T:0 = -2a-c (iii)

From equation (i), a = -1-c (iv)

Combining equations (i) and (iii), 0 = -2(-1-c)-c

=>2+2c-c =0, c= -2, a = 1

By substituting a=1 and c=-2 in equation (ii) above, we get b= 1

Hence,

$$\pi_3 = \frac{PAC}{\mu^2} \quad 18$$

Analyzing π_4 term in equation (10) dimensionally,

$\pi_4 = P^a A^b \mu^c t$,

$$M^0L^0T^0 = [ML^{-1}T^{-2}]^a[L^2]^b[ML^{-1}T^{-1}]^c\,[T] \quad 19$$

M:0 = a+c (i)

L:0 = -a+b-c (ii)

T:0 = -2a-c+1 (iii)

From equation (i), a= -c (iv)

Substituting Equation. (iv) in (iii) gives -2(-c)-c+1 =0

=>2c-c+1=0, c=-1, hence, a=1

Solving for b in equation.(ii) with the values of a and c given;

-1+b-(-1) =0 b=0

Hence,

$$\pi_4 = \frac{Pt}{\mu} \quad 20$$

Also analyzing π_5 term in Equation (11) dimensionally,

$\pi_5 = P^a A^b \mu^c V$,

$$M^0L^0T^0 = [ML^{-1}T^{-2}]^a[L^2]^b[ML^{-1}T^{-1}]^c\,[L^3] \quad 21$$

M:0 = a+c (i)

L:0 = -a+2b-c+3 (ii)

T:0 = -2a-c .(iii)

From Equation (i), a=-c (iv)

Combining Equations (iv) and (iii), -2(-c)-c=0, => 2c-c =0, hence, c=0,a=0

Solving for b in equation (ii), 0+ 2b-0 +3 = 0,

2b=-3, hence, b=-3/2

Hence,

$$\pi_5 = \frac{V}{A^{3/2}} \quad 22$$

Moreover, analyzing π_6 term in equation (12) dimensionally,

$\pi_6 = P^a A^b \mu^c S$,

$$M^0L^0T^0 = [ML^{-1}T^{-2}]^a[L^2]^b[ML^{-1}T^{-1}]^c\,[M^{-1}LT^2] \quad 23$$

M:0 = a+c-1 (i)

L:0 = -a+2b-c+1 (ii)

T:0 = -2a-c+2 (iii)

Substitute a=1-c from equation (i) in (ii), -2(1-c)-c+2=0

-2+2c-c+2=0, => c=0, hence, a=1

Solving for b in equation (ii) by substituting values of a and c yields,

-1+2b-0+1=0, => b=0

Hence, Equation (12) transforms to:

$$\pi_6 = PS \quad 24$$

Substituting the specific expressions for the dimensionless terms

π_1, π_2, π_3, π_4, π_5 and π_6 into Equation (6), Equation (25) is obtained:

$$f\left(\frac{A^{1/2}Y}{\mu}.\ \frac{\mu^2 R}{P}\cdot\frac{PAC}{\mu^2}\cdot\frac{Pt}{\mu}\cdot\frac{V}{A^{3/2}}.PS\right) = 0 \quad 25$$

Since Equation (25) does not give the exact relationship between the parameters being investigated; there is need to generate experimental data. Following Buckingham's π-method, any of the dimensionless terms of Equation (25) can be written as a function of the others hence, it transforms to:

$$\frac{A^{1/2}Y}{\mu} = K\left(\frac{\mu^2 R}{P}\right)^a\left(\frac{PAC}{\mu^2}\right)^b\left(\frac{Pt}{\mu}\right)^c\left(\frac{V}{A^{3/2}}\right)^d (PS)^e \quad 26$$

The exponents in Equation (26) can be obtained by regression analysis using experimental data.

For easy determination of the exponents, the above equation can be transformed as;

$$\text{Ln}\,\frac{A^{1/2}Y}{\mu} = \text{Ln}\,K + a\,\text{Ln}\,\frac{\mu^2 R}{P} + b\,\text{Ln}\,\frac{PAC}{\mu^2} + c\,\text{Ln}\,\frac{Pt}{\mu} + d\,\text{Ln}\,\frac{V}{A^{3/2}}\ e\,\text{Ln}\,PS \quad 27$$

ASSUMPTIONS

Let $M = Ln\,\frac{A^{1/2}Y}{\mu}$, $X_1 = Ln\,\frac{\mu^2 R}{P}$, $X_2 = Ln\frac{PAC}{\mu^2}$, $X_3 = Ln\,\frac{Pt}{\mu}$, $X_4 = Ln\frac{V}{A^{3/2}}$, and X_5 = PS

Hence, Equation (27) becomes,

$$M = \text{Ln}\,K + aX_1 + bX_2 + cX_3 + dX_4 + eX_5 \quad 28$$

From the experimental data obtained (Data too large to reproduce), values of the constants a, b c, d and e were evaluated by Regression using SPSS (Table 2).

Table 2: Model Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.1571	1.0451	-0.1503	0.8811	-2.2516	1.9374
2.1147	-0.8266	0.0787	-10.5044	0.0000	-0.9843	-0.6689
21.0151	0.1485	0.0620	2.3958	0.0200	0.0243	0.2728
19.0380	-0.1565	0.0441	-3.5456	0.0008	-0.2450	-0.0681
-1.8157	-1.1885	0.4252	-2.7951	0.0071	-2.0407	-0.3364
7.0733	-0.0494	0.0301	-1.6424	0.1062	-0.1096	0.0109

From Table 2 above, LnK = -0.1571, K = 0.8546

a = -0.8270, b = 0.1485, c = -0.1565, d = -1.1885, e = -0.0494

But $\frac{A^{1/2}Y}{\mu} = K\left(\frac{\mu^2 R}{P}\right)^a \left(\frac{PAC}{\mu^2}\right)^b \left(\frac{Pt}{\mu}\right)^c \left(\frac{V}{A^{3/2}}\right)^d (PS)^e$,

Hence, substituting the values of K, a, b, c, d and e in Equation (26) yields,

$$\frac{A^{1/2}Y}{\mu} = K\left(\frac{\mu^2 R}{P}\right)^{-0.827} \left(\frac{PAC}{\mu^2}\right)^{0.1485} \left(\frac{Pt}{\mu}\right)^{-0.1565} \left(\frac{V}{A^{\frac{3}{2}}}\right)^{-1.1885} (PS)^{-0.0494} \qquad 29$$

$$Y = 0.8546\, x \,\frac{P^{0.7696}\, C^{0.1485} A^{1.4313}}{R^{0.827}\, \mu^{0.7945}\, t^{0.1565} V^{1.1885} S^{0.0494}} \qquad 30$$

Equation (30) can be transformed as follows:

By multiplying both sides of Equation (30) by V^8 and rearranging,

$$V^{9.189} = \frac{K\, x\, P^{0.7696}\, C^{0.1485} A^{1.4313}}{Y\, R^{0.827}\, \mu^{0.7945}\, t^{0.1495}\, S^{0.0494}}\, x\, \frac{V^8}{t^{0.007}} \qquad 31$$

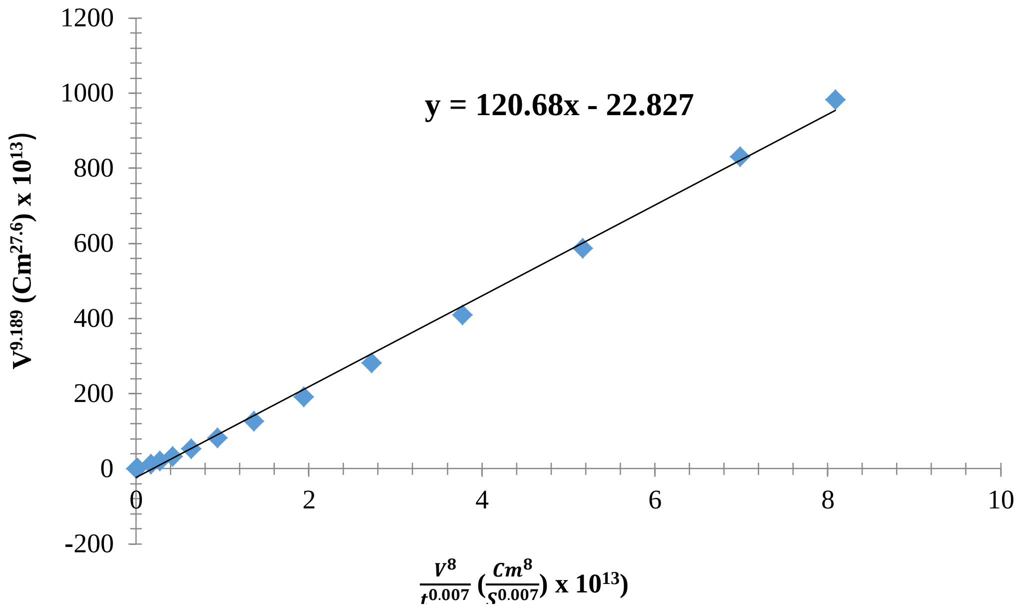

Figure 1: A plot of $\mathbf{V^{9.189}}$ and $\frac{\mathbf{V^8}}{\mathbf{t^{0.007}}}$ for the determination of slope, b_2

A plot of $\mathbf{V^{9.189}}$ and $\frac{\mathbf{V^8}}{\mathbf{t^{0.007}}}$ gives a straight line with slope, b_2 = 120.68

Hence, Equation (31) becomes,

$$Y = \frac{0.8546\, P^{0.7696}\, C^{0.1485} A^{1.4313}}{R^{0.827}\, \mu^{0.7945}\, t^{0.1495}\, S^{0.0494}\, x\, b_2} \qquad 32$$

Equation (32) is the desired Cake yield equation.

Let the predicted cake yield be designated with $Y_{P,}$

Substituting the values of b_2 and K in Equation (32) above yields,

$$\boldsymbol{Y_P} = 0\,.\mathbf{007082}\frac{\boldsymbol{P^{0.770}}\ \boldsymbol{C^{0.149}}\boldsymbol{A^{1.431}}}{\boldsymbol{R^{0.827}}\ \mu^{\mathbf{0.795}}\ \boldsymbol{t^{0.1495}}\ \boldsymbol{S^{0.049}}} \qquad \mathbf{33}$$

IV. RESULTS AND DISCUSSION

The developed model shows that the predicted cake yield from a filter press (Yp) is directly proportional to the filter area of the pressure vessel (A), applied pressure (P) and initial solids content of the sludge(C) while being inversely proportional to specific resistance of cake (R), viscosity (μ), compressibility coefficient of the sludge (S) and pressing time (t). It enables performance of a pressure filter to be predicted from a simple laboratory determination of cake yields.

$$Y_P = 0.007082\frac{P^{0.770} C^{0.149} A^{1.431}}{R^{0.827} \mu^{0.795} t^{0.1495} S^{0.049}}$$

4.1 Variation of Cake Yield with Pressing Time

From the model, cake yield is inversely proportional with the pressing time. Hence, from Equation (33),

$$Y_P \propto \frac{1}{\theta^{0.1495}}.$$

Hence, $Y_P = \frac{K}{\theta^{0.1495}}$

Where K is proportionality constant given as $[0\,.007082\frac{P^{0.770}\ C^{0.149} A^{1.431}}{R^{0.827}\ \mu^{0.795}\ S^{0.049}}]^{0.69}$

The variation of cake yield with time is however affected by chemical dosages which tend to decrease the amount of period needed for the filtration process to complete. It is important to note that in pressure filters, time of filtration varies as cake thickness increases according to [7]. However, the dependence of pressing time on cake yield is shown on Figure 2.

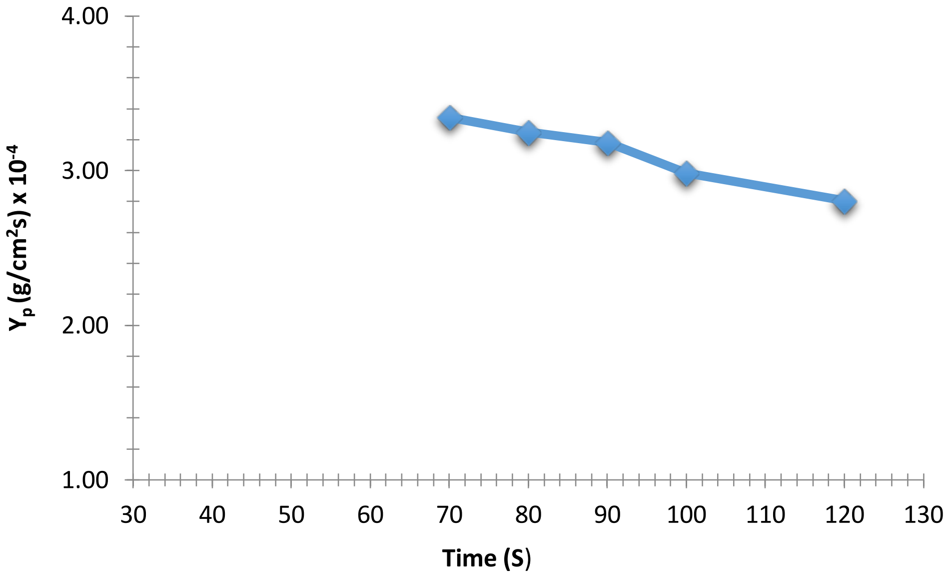

Figure 2: Variation of Yield with Pressing time at various dosages.

4.2 Effects of Pressures on Filter Cake Yield

According to the relationship derived from Darcy's law which relates pressure drop to dry solids yield, an increase in pressure drop should result in an increase in dry cake production. This is the case if the filter cake is not highly compressible such that the specific cake resistance increases with pressure drop [12]. It is also beneficial to gradually increase the pressure until a constant pressure is reached. This is because the solids are non-homogeneous and a high initial pressure drop can result in particles plugging the interstices of the cloth.

The graph in Figure 3 shows the effects of pressures on filter cake yields, the model cake yield increased as the operating pressure increased, which was in agreement with both Carman and Jones's findings earlier cited above. As filtration continued, more and more solid settled reducing the porosity of particles so that the pressure of water increased and also the cake yield.

It is important to note that [7] had found out that the proportional increase in cake yield with pressure was also a function of sludge compressibility. The effects of operating pressures on the cake yield as developed were in agreement with the findings of the other researchers earlier cited.

Mathematically from the model,

$$Y_P \propto P^{0.77}$$

Furthermore, the deterioration of filtrate quality as the pressures were increased cannot be ignored as was the case with previous Researchers. However, physically, it is quite easy to explain. As the operating pressures were increased, sludge flocs were ruptured accounting for the poor filtrate quality.

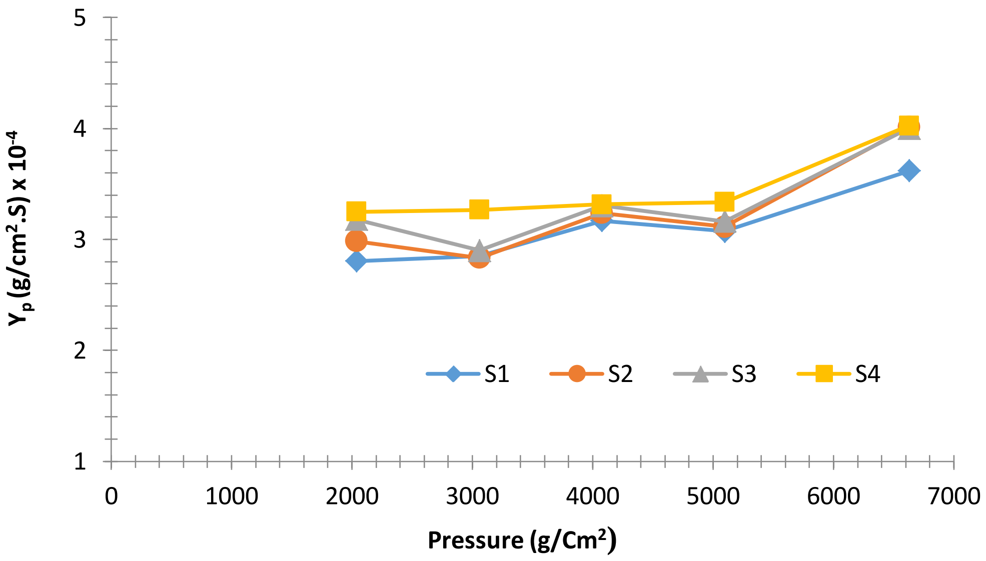

Figure 3: Effects of Operating Pressures on Filter Yield

4.3. Effects of Conditioner dosages on Cake Yield

From Figures 4, cake yield increases with increased conditioner dosage until an optimum dosage was reached, all other conditions being equal. For instance, increasing Ferric Chloride dosage from 11.87% to 22.61% increased filter cake yield from 3.785 x 10^{-4} g/cm^{2}s to 4.4118 x 10^{-4} g/cm^{2}s while reducing specific resistance from 1.7372 x 10^{10} cm/g to 1.5940 x 10^{10}cm/g. The optimum dosage from the graph to attain acceptable filtrate quality was 19.63% for P_5 = 6628.18g/cm^2. Considering the differences in the concentrations of the five sludge samples tested, it is significant that they all responded similarly. Also, the increase in the cake yield may be attributable to the reduction in sludge compressibility due to the increased conditioner doses. In summary, the new model conforms favourably with previous works of [5], [7] and [13] where the cake yield increased as the rate of conditioning increased while the specific resistance of the sludge decreased.

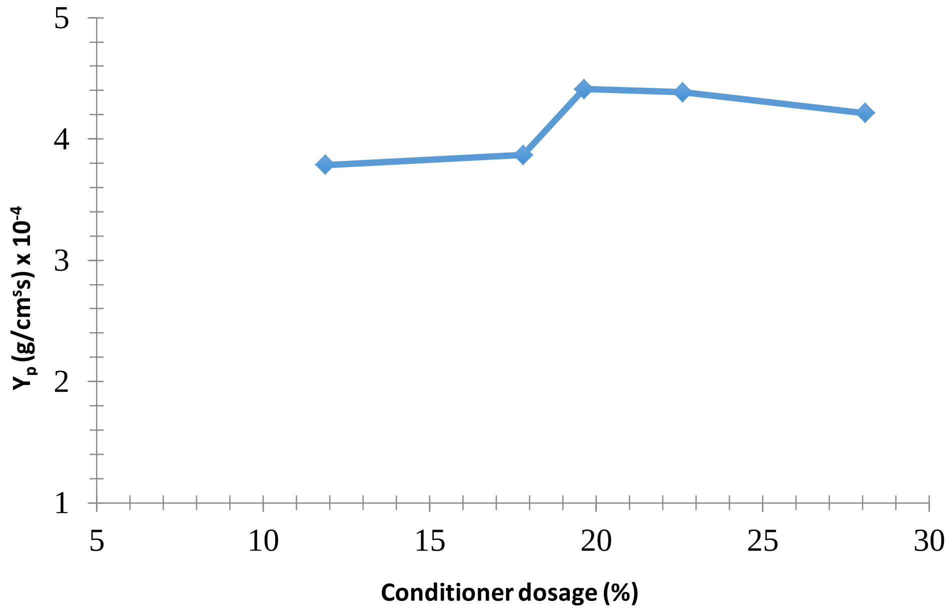

Figure 4: Effects of Conditioner dosages on Cake yield at a Pressure of 5098.58 g/cm^2

4.4 Variation of Cake Yield with Initial Solids Content at Various Pressures

Many Researchers including [5], [6], [14] and [15] have indicated this filterability dependence on initial solids content especially when considering the effects on specific resistance on filtration and filterability number, but the effect was never reported to be as great as observed in this study.

The variation of cake yields for different values of initial solids content at different operating pressures is shown in Figure 4.4. It is important to note here that the effect of initial solids moisture on performance is much more pronounced in Filter Presses than in Vacuum filtration, [7]. Cake yield increases with initial solids content at higher pressures. From the developed model, cake yield is mathematically related to operating initial solids content, C as shown below;

$$Y_P = KC^{0.149}$$

where K is proportionality constant.

Similarly, results show that an increase in the concentration of solids in the feed results in an increase in dry cake production and that an increase in the specific cake resistance can result in a decrease in the dry cake production.

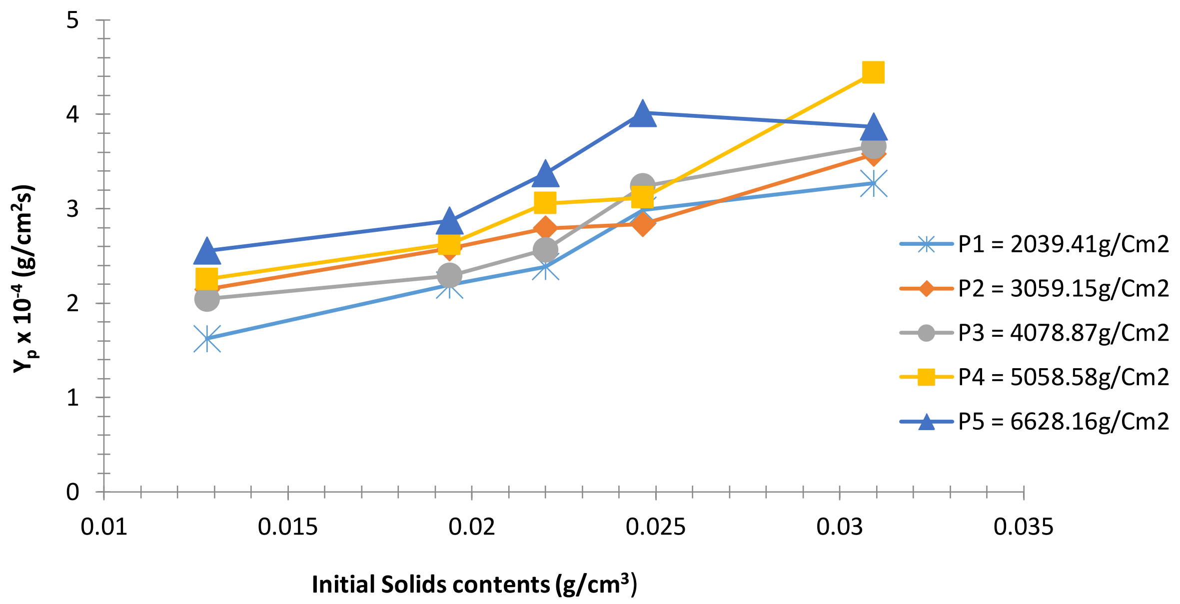

Figure 5: Variation of Yield (Y_p) with Initial Solids content for 17.81% Conditioned sludge at various Pressures.

The relationship between the total dry cake produced and the solids concentration is very nearly accurate to the relationship described above. Deviation from linearity can be due to the effect of the filter medium resistance, which was neglected in the derivation of the relationship. The benefit of a higher feed solids concentration can be seen in the resultant reduction in specific cake resistance.

4.5 Variation of Cake Yields with Specific Resistance

The developed cake yield model predicts that more solids are captured on the filter as specific resistance decreases. The effect of specific resistance on yield is shown on Figure 6. Increasing ferric chloride dosage from 11.87% to 22.61% increased filter cake yield from 3.785 x 10^{-4} g/cm^{2}s to 4.4118 x 10^{-4}g/cm^{2}s while reducing specific resistance from 1.7372 x 10^{10} cm/g to 1.5940 x 10^{10} cm/g. However, the reason for this is that more cake are deposited when there is less restriction to filtration, taking into account other conditions such filtration pressures, time and conditioner dosages. This can be mathematically represented as follows;

$Y_P = k/R^{0.827}$, where k is proportionality constant given as $0.007082 \, x \, \frac{P^{0.770} C^{0.149} A^{1.431}}{\mu^{0.795} S^{0.049} \theta^{0.1495}}$

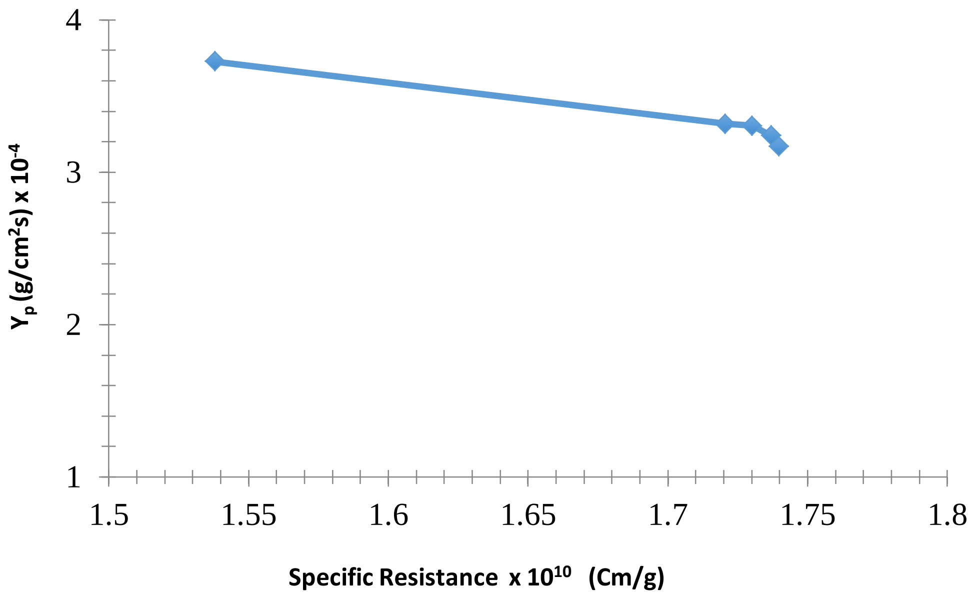

Figure 6: Effects of Specific resistance on Cake yield at a pressure of 4078.87 g/cm^2.

4.6 Variation of Cake Yield with Sludge Compressibility

From the developed yield equation, cake yield increases and decreased correspondingly with compressibility for 0.0194g/cm^3 tested sludge sample. For instance, Figure 7 shows that cake yield increased at lower compressibility values. It was also observed that increasing compressibility from 0.7076 cm s/g to 0.7314 cm s/g led to decreased solids capture from 3.7682 g/cm^{2}s to 3.5763 g/cm^{2}s for the tested sludge sample In summary, the graph agrees with the model theoretical prediction given as;

$Y_P = k/S^{0.049}$, where: k is proportionality constant.

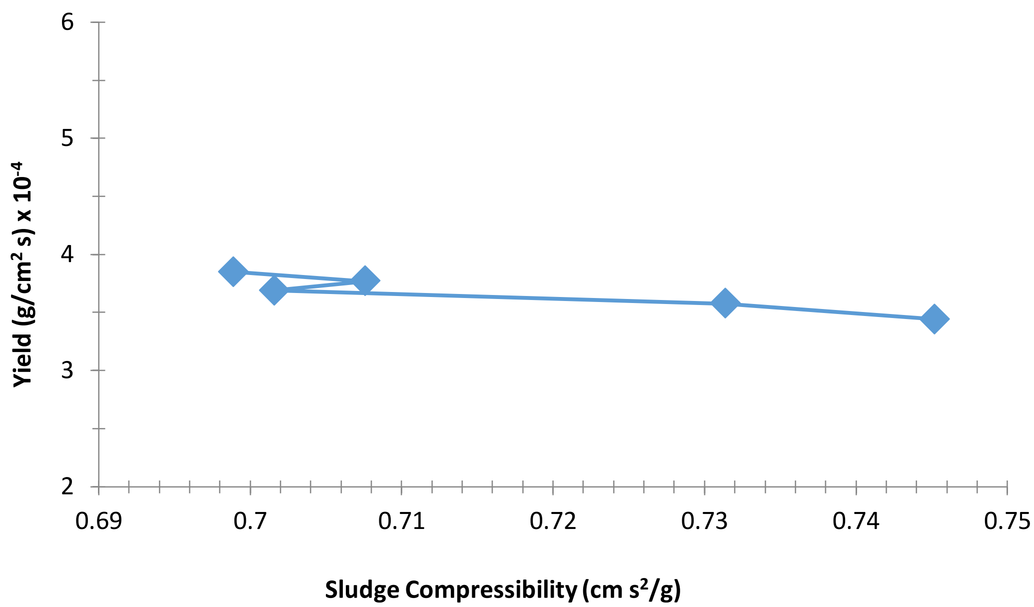

Figure 7: Variation of cake yield with sludge compressibility

4.7 Correlation between experimental and predicted yields

The correlation between the actual and predicted yield from Figure 8 was found to be 0.9933 showing the validity of the developed model.

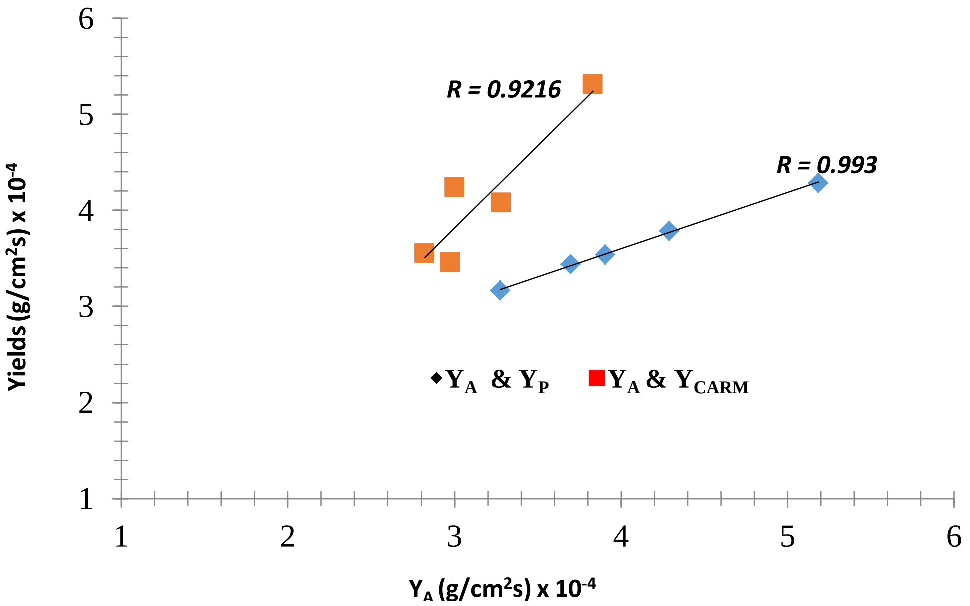

Figure 8: Correlation between Actual yield (Y_A) Carman's model yield (Y_{CARM}) and Predicted yield, Y_p

V. CONCLUSION

Curves derived from the model show how cake yield depends on a number of these parameters. Considering the differences in the parameters tested, the comparative analytical results showed that there was closer agreement between the actual cake yield and predicted values while values predicted from Carman's model were out of range. Filter pressing at 5098.38 g/cm^2 gave cake yield values of 3.0004 g/cm^{2}s, 3.1069 g/cm^{2}s and 4.0247 g/cm^{2}s for actual, developed model and Carman's model respectively. Experimental verification of the new model shows that the predicted performance agrees with the actual experimental values with a correlation coefficient of 0.993.

The study shows that cake yield increases as sludge compressibility is lowered using appropriate ferric conditioners dosages. Moreover, the rate of solids capture on sludge compressibility is independent on the applied pressures. While other operating parameters such as pressures, initial solids content, pressing time and specific resistance to filtration may directly affect filter cake formation, only conditioner type and dosages were found to significantly affect sludge compressibility.

VI. REFERENCES

1. Brix, H., 2017. Sludge Dewatering and Mineralization in Sludge Treatment Reed Beds. MDPI Water, Vol. 9(160), doi:10.3390/w9030160.
2. Ademiluyi, J. O., 1987. Development in constant vacuum cake filtration Theory. Proceedings of the Engineering section of the science Association of Nigeria Journal. Vol. 6 and 7.
3. Carman, P. C., 1934. A study of Mechanism of filtration Part 11. Journal of the society of Chemical Industry, Transactions communication. Vol. 53, No 6.1591-1651.
4. Carman, P. C., 1938. Fundamental Principles of Industrial Filtration. Transaction- Institution of Chemical Engineers Vol 16, pp 168-188.
5. Gale, R. S, Baskerville, R. C., 1970. Studies on the Vacuum Filtration of Sewage Sludges. Water Pollution Control. 514-536.
6. Rebhun, M, Zall, N., Galil, N., 1989. Net Sludge Solids Yield as an Expression of Filterability for Conditioner Optimization. Journal of Water Pollution Control Fed, Vol.61, No.1, pp52-54

7. Jones, B. R., 1956. Vacuum sludge filtration II: Prediction of Filter Performance. Sewage Industrial Wastes Journal, Vol. 28, pp 1103-1115.
8. Peter K, Donald (1975). Transport Phenomena applied to sludge dewatering. Journal of the A.S.C.E, Environmental Eng. Div. Vol. 10, pp.927-985.
9. Coackley, P. C and Jones, B. R., 1956. Vacuum sludge filtration I: Interpretation of Result by Concept of Specific Resistance. Saw. Ind.Water.
10. Dick, R.I., 1972. Sludge Treatment in Physiochemical Process for Water Quality Control. W. J Weber, Jr., (Ed.), Wiley Inter-science, New York.
11. Buckingham, E., 1914. On Physically Similar Systems: Illustrations of the use of Dimensional Equations. Physical Review, 4(4), pp345-476.
12. Svarovsky, L., 2000. Solid-Liquid Separation. Oxford: Butterworth-Heinemann.
13. Zall, J, Rebhun, M., 1987. Skeleton Builders for Conditioning Oily Sludge. Journal of Water Pollution Control Fed. 99, pp 699-740.
14. Ademiluyi, J.O, Onwe, J.I., 2018. Use of the Concept of Ive's Filterability Number to Determine the Effects of Vacuum Filtration Process. Nigerian Journal of Technology. 37(2), pp.548-555. dx.doi.org/10.4314/njt.v37i2.35
15. Onosakponeme, O.R, Onyejekwe, S. C., 2014. Systematic Modelling of Sludge Filtration Process using Dimensional Analyses Technique. International Journal of Engineering Research and Applications, Vol.4, Issue 6(3), pp43-53.