EFFECT OF SLUDGE COMPRESSIBILITY COEFFICIENT ON SLUDGE FILTRATION RESISTANCE

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ABSTRACT

This study investigates the effect of sludge compressibility coefficient on sludge filtration resistance (R_e). The compressibility of sludge was calculated from the slope of the line plotted for Log (R_e) against Log (P), using Carman's definition through the relation with the experimental data for the effect of conditioner on synthetic sludge filtration at variable pressure using the developed model for sludge filtration resistance (R_e) of electrical resistance analogy. It was observed that there is an initial decrease in compressibility coefficient between 10g, 12g and 14g of Calcium Chloride ($CaCl_2$). After the initial decrease, compressibility coefficient increases with increasing amount of dissolved salt between 16g and 18g of $CaCl_2$. The increase in compressibility coefficient with increasing dilution of dissolved salt may be as a result that sludge attains higher degree of fluidity at higher dilution than at lower dilution. The decrease noted in compressibility with increasing Calcium Chloride content may be due to the effect of coagulation of the conditioner which provides more rigid cake structure thereby making the cake less compressible with increasing Calcium Chloride content which agrees with available literature.

KEYWORDS: Sludge Filtration Resistance, Compressibility Coefficient, Dewatering, Conditioning Characteristics, Wastewater Treatment.

1. Introduction

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 [1], [2]. 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. 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.

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 [3] .In many countries, sewage sludge is a serious problem due to its high treatment costs and the risks to environment and human health based on the factor in the operation of wastewater treatment plants [4], [5], [6]. Rao and Rao [7] stated that, sewage sludge can be dewatered for efficient handling and disposal which is accomplished by both mechanical and natural methods.

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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 [8], [9], [10], [11], [12]. A new drying unit has been designed for disposing waste activated sludge consisting of a screw conveyor with double shell, all in stainless steel used for drying by both direct– in the conveyor – and indirect heating – through the mantle-, using flue gases from diesel [13]. Sewage sludge quantities and characteristics depend not only on types and levels of wastewater treatments but also on the quality of the influent and effluent [14], [15]. Sludge Stabilization is used for reducing undesirable effects of sludge on environment, including the removal of pathogens and the reduction of volatile solids and offensive odours [16]. Sanin and Vesilind [17] developed a novel chemical surrogate for activated sludge, which they named synthetic sludge, to study sludge dewatering, settling and conditioning characteristics. Synthetic sludge is made up of non-living particles that resemble activated sludge components. A model of filtration dewatering is presented. The model is based on the d'Arcy flow equation in which the resistance to filtration is described by the Corzeny–Carman equation and the driving force is the difference between the external pressure and the osmotic pressure of the filter cake. It has been found that this model reproduces all known features of filtration dewatering and is found to be consistent with experimental data [18]. Bürger et al., [19] defined filtration as a mechanical method which is commonly applied for solid–liquid separation while Mowla et al., [20] proposed that improving sludge cake filterability is one of several ways to enhance biosludge dewaterability. 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. Wett et al., [12] developed a mathematical description of dewatering process based on the superposition of two models, the Conventional Filtration Theory for the filtration phase and the BT-model for the drying phase. The compressibility of sludge is another parameter which affects sludge filtration and is defined as the decrease in unit volume per unit increase in pressure. It's a measure of the ease with which the solid particles collected on the filter medium are deformed. The greater its value, the more compressible is the sludge cake and the more the resistant is the cake to passage of filtrate. When a compressive load is applied to sludge, a decrease in its volume takes place, the decrease in volume under pressure is known as compression and the property of the sludge mass pertaining to its tendency to decrease in volume under pressure is known as compressibility. Ruth [21] suggested that his equation does not enable low compressibility to be evaluated with any degree of accuracy (for a rigid cake $^{S}{}_{C} = 0$) and states that $^{S}{}_{C}$ should equal unity for low compressibility. He proposed that the compressibility coefficient $^{S}{}_{C}$ is a measure of the compressibility of cake and gave the equation as:

$$r = r_1 (1+ r_2 P^{S_C}) \quad (1)$$

where, r = Specific Resistance r_1, r_2 = Constants

The above procedure is noted to be tedious and consumes time, requiring the generation of various laboratory data [22]. Therefore, Carman's theory on which the evaluation of r is based has been described to be an error in recent years [23]. The continual controversy in sludge filtration equation is as a result of not applying Darcy's law (applicable to rigid cake) to compressible or non- rigid materials. Ademiluyi et al. [1], [22] investigated the effect of dilution and chemical conditioning on compressibility coefficient '$^{S}{}_{C}$'using Carman's equation. They concluded that the decrease in compressibility with increasing dilution as noted within the range of some concentrations indicates that with certain systems and concentration, Carman's empirical relationship may not be admitted. The equation is thus:

$$r = KP^{S_C} \quad (2)$$

where, r = Specific Resistance, K = Proportionality Constant, P = Filtration Pressure $^{S}{}_{C}$ = Compressibility Coefficient

An equation for sludge dewatering using FMTLxLyLz dimensional analysis based on specific resistance and compressibility [24], [25], [26]. The analysis of experimental data was in accordance with theoretical predictions. Thus,

$$R = b\left(\frac{\rho g h A^2 V_s}{\mu W_d}\right) \quad (3)$$

New equation to sludge filtration processes has been proposed for use in routine laboratory. The equation has been suggested to replace Ademiluyi's cake filtration equation in view of the limitations of the latter. The new equation can be used for sludges whose compressibility factor is more than one but Ademiluyi's cake filtration equation can only be used for sludges whose compressibility coefficient is less than one. The new sludge filtration equation was derived using $\tan^n\theta$ reduction method. The generalized equation thus obtained resembles Ademiluyi's equation in the mode of parameter combination except the presence of summation notation in the new equation [27].

The purpose of this work was to investigate the effect of sludge compressibility on sludge filtration resistance (SFR).

2. Materials and Methods

2.1 Investigating the effect of sludge compressibility on SFR

The compressibility of sludge was calculated from the slope of the line plotted for Log (R_e) against Log (P), using Carman's definition (Equ.2) through the relation with the experimental data generated for the effect of conditioner on synthetic sludge filtration at variable pressure by Arimieari and Ademiluyi [28].

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$$\therefore R_e = \frac{P}{b} \quad (4)$$

where,

$R_e = \text{Sludge Filtration Resistance } (N.s/m^5)$

P = Pressure (N/m^2)

b = Slope (m^3/s)

3. Results and Discussion

The compressibility of sludge was calculated from the slope of the line plotted for Log (R_e) against Log (P), using Carman's definition (Equ.2) through the relation with the experimental data generated for the effect of conditioner on synthetic sludge filtration at variable pressure. The results are shown in Figs. 1-5.

Table 1: Effect of conditioner on synthetic sludge filtration using 10 g of $CaCl_2$

P*10^5	R_e*10^8	Log (P)	Log (R_e)
6.895	3.63	5.838534271	8.559906625
7.584	4.21	5.879898324	8.624282096
8.274	5.91	5.917715517	8.771587481
8.963	6.90	5.952453396	8.838849091
9.653	8.04	5.984662306	8.905256049
10.342	9.04	6.014604533	8.95616843

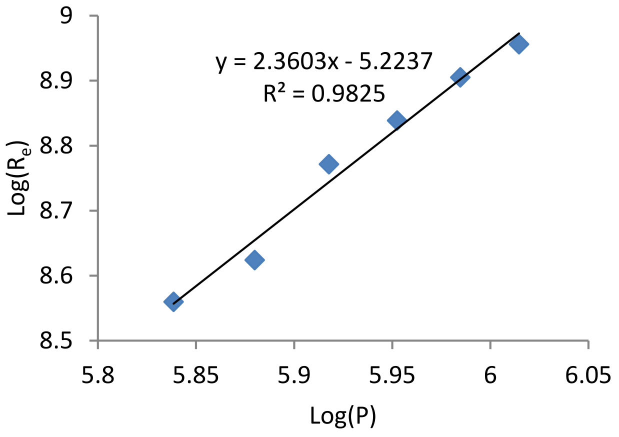

Fig. 1: Plot of Log (R_e) against Log (P) for 10g of $CaCl_2$

Table 2: Effect of conditioner on synthetic sludge filtration using 12 g of $CaCl_2$

P*10^5	R_e*10^8	Log (P)	Log (R_e)
6.895	3.28	5.838534271	8.515873844
7.584	3.79	5.879898324	8.57863921
8.274	4.6	5.917715517	8.662757832
8.963	5.27	5.952453396	8.721810615
9.653	6.03	5.984662306	8.780317312
10.342	7.39	6.014604533	8.868644438

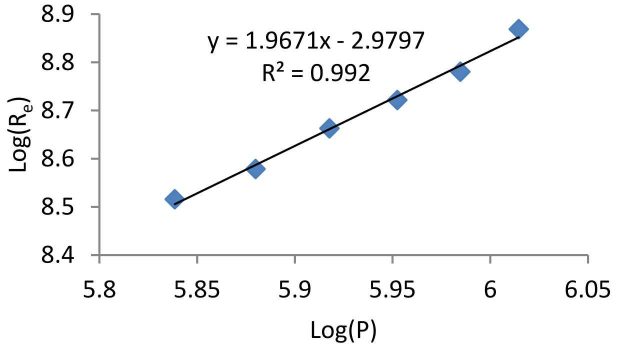

Fig. 2: Plot of Log (R_e) against Log (P) for 12g of $CaCl_2$

Table 3: Effect of conditioner on synthetic sludge filtration using 14 g of $CaCl_2$

P*10^5	R_e*10^8	Log (P)	Log (R_e)
6.895	3.13	5.838534271	8.495544338
7.584	3.61	5.879898324	8.557507202
8.274	4.36	5.917715517	8.639486489
8.963	4.98	5.952453396	8.697229343
9.653	5.68	5.984662306	8.754348336
10.342	6.9	6.014604533	8.838849091

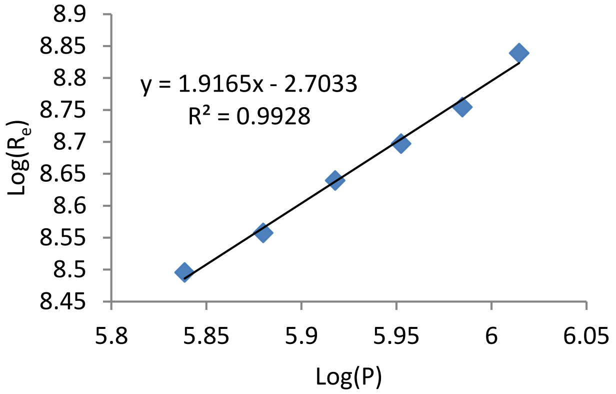

Fig. 3: Plot of Log (R_e) against Log (P) for 14g of $CaCl_2$

Table 4: Effect of conditioner on synthetic sludge filtration using 16 g of $CaCl_2$

P*10^5	**R_e*10^8**	**Log (P)**	**Log (R_e)**
6.895	2.87	5.838534271	8.457881897
7.584	3.45	5.879898324	8.537819095
8.274	4.14	5.917715517	8.617000341
8.963	4.72	5.952453396	8.673941999
9.653	5.36	5.984662306	8.72916479
10.342	6.46	6.014604533	8.810232518

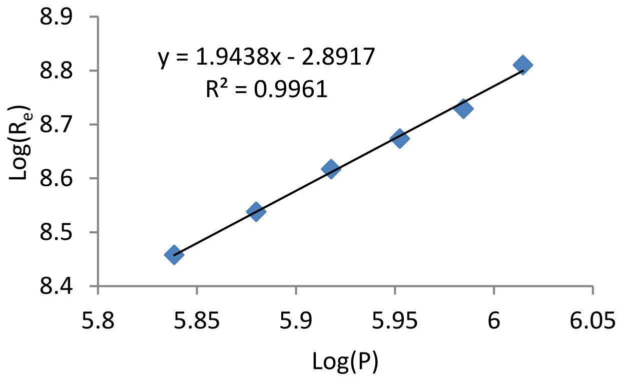

Fig. 4: Plot of Log (R_e) against Log (P) for 16g of $CaCl_2$

Table 5: Effect of conditioner on synthetic sludge filtration using 18 g of $CaCl_2$

P*10^5	**R_e*10^8**	**Log (P)**	**Log (R_e)**
6.895	2.65	5.838534271	8.423245874
7.584	3.16	5.879898324	8.499687083
8.274	3.76	5.917715517	8.575187845
8.963	4.48	5.952453396	8.651278014
9.653	5.08	5.984662306	8.705863712
10.342	6.08	6.014604533	8.783903579

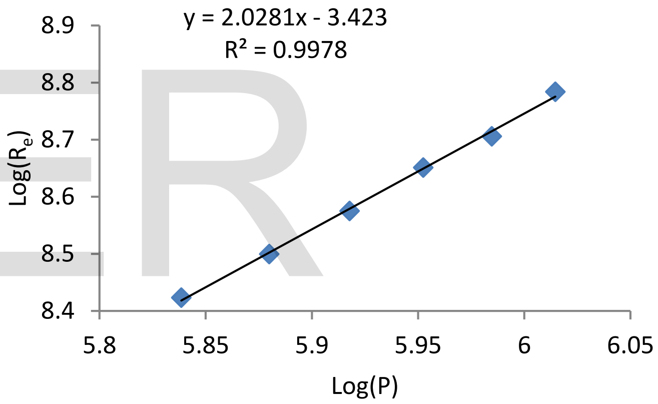

Fig. 5: Plot of Log (R_e) against Log (P) for 18g of $CaCl_2$.

In Figs. 1-5, it was observed that there is an initial decrease in compressibility coefficient between 10g, 12g and 14g of ($CaCl_2$). After the initial decrease, compressibility coefficient increases with increasing amount of dissolved salt between 16g and 18g of $CaCl_2$. The increase in compressibility coefficient with increasing dilution of dissolved salt may be as a result that sludge attains higher degree of fluidity at higher dilution than at lower dilution. No reason can be given to the increase in compressibility with increasing

Calcium Chloride content. The decrease noted in compressibility with increasing Calcium Chloride content may be due to the effect of coagulation of the conditioner which provides more rigid cake structure thereby making the cake less compressible with increasing Calcium Chloride content.

4. Conclusion

In order to investigate the effect of sludge compressibility on R_e, it was observed that there is a decrease in compressibility coefficient with increasing concentration of dissolved salt ($CaCl_2$) as the applied pressure increases. Figures 1-5 show the plots of log (R_e) versus log (P). The plots are linear; it was observed that there is an initial decrease in compressibility coefficient between 10g, 12g and 14g of ($CaCl_2$). After the initial decrease, compressibility coefficient increases with increasing amount of dissolved salt between 16g and 18g of $CaCl_2$. The slopes of the graphs give the compressibility coefficients of synthetic sludge. The increase in compressibility coefficient with increasing dilution of dissolved salt may be as a result that sludge attains higher degree of fluidity at higher dilution than at lower dilution. The decrease noted in compressibility with increasing Calcium Chloride content may be due to the effect of coagulation of the conditioner which provides more rigid cake structure thereby making the cake less compressible with increasing Calcium Chloride content. The general increase in R_e with increasing pressure is due to a compressible cake which contains particles soft enough to undergo deformation; so that as the filtration pressure is increased; the porosity of the cake becomes smaller and hence the overall flow channel of filtrate is decreased.

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