Development of a Sludge Dewatering Filter and Utilization of Dried Sludge in Brick Making

*Oluseyi E. Ewemoje and Tinuadeji T. Bademosi

Department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria
{seyiajayi2 | tinuadebademosi}@yahoo.com

Abstract— These A dewatering filter was designed and constructed to dewater sludge collected from Eleyele waterworks using slow sand filtration. Washed sand passing through sieve mesh size of 1.18 mm was used as the filter media. The flow rate of the filtrate was monitored for six (6) days and readings were taken at 30-minute intervals for 6 hours after each sludge loading of 15 L. The dewatered and dried sludge was investigated for use as brick material. The sludge and laterite samples were characterized using Atomic Absorption Spectroscopy. The major chemical components of the sludge and laterite samples were silicon, aluminium and iron oxides. The laterite soil sample consisted of 60.47% SiO_2, 17.77% Al_2O_3 and 8.18% Fe_2O_3 while the sludge sample consisted of 52.98% SiO_2, 29.46% Al_2O_3 and 3.63% Fe_2O_3. Batching method by weight was used in mixing the materials in the ratios of sludge at 0%, 15% and 30% to produce laboratory scale bricks with dimensions of 70 mm by 70 mm by 70 mm and the properties of the bricks were investigated. The average compressive strength of the laterite bricks with dried sludge content of 0%, 15% and 30% were 3.15 N/mm^2, 3.08 N/mm^2 and 2.64 N/mm^2, respectively. The results of this research demonstrated that a locally constructed sludge dewatering filter can be used to thicken waterworks sludge and laterite-sludge can be made from dewatered water works sludge.

Keywords—Compressive strength, bricks, filter, media slow sand filtration, waterworks sludge

1 INTRODUCTION

Sludge from water treatment plants remains an unavoidable by-product of water and wastewater treatment processes which creates problems of disposal and environmental pollution. Water treatment sludge (WTS) is the waste produced during water treatment which may be harmful to public health and environment if not properly disposed in an environmentally friendly manner. Sludge from some water treatment plants in Nigeria is usually discharged into nearest watercourse without any further treatment (Anyakora, 2012; Sabo *et al*, 2014). Channeling untreated WTS into open water courses leads to the accumulation of aluminum in water bodies and human bodies thereby increasing the chances of occurrence of Alzheimer's disease (Hegazy *et al*, 2012). It also causes the production of malodorous gases as a result of the decomposition of the organic materials contained in WTS, thereby constituting an unsightly situation in the areas nearest to the WTS conveying drains (Sabo *et al*, 2014).

Siltation of water courses is another possible effect of the careless disposal of WTS which may lead to dam failure and flooding. Also, since the coagulants are basic in nature, hydrophytes growth in receiving water bodies might be greatly enhanced. At Eleyele waterworks, Ibadan, sludge effluent is disposed into Eleyele river. This is a big river that flows through many communities where the water is put into use. The flow channels are open drains constructed in a manner that enhances flow by gravity till sludge reaches the river course. From observation, the conveyance of sludge through these open drains is unsightly and creates an unpleasant odour. There are other disadvantages of discharging WTS into the dam from which part of the raw water treated for the community is drawn. Siltation of water channel, which could lead to flooding, and disruption of sun rays to the bottom of water course are effects of careless and inappropriate disposal of sludge. Therefore, sludge disposal in an environmentally friendly manner is not only agreeable but essential.

* Corresponding Author

Globally, studies have been conducted on the reuse of WTS while some others have simply improved its physical and handling characteristics in order to safely dump into a landfill, instead of water bodies. WTS has been found to be a potential recyclable produce, offering one of the greatest profitable potentials for reuse. It is useful as source of soil nutrients in the reclamation of degraded land, admixture in the production of bricks, application on pastures and croplands, eutrophic lake recovery and mobilization of soil microorganisms (Verlicci and Masotti, 2000; Sabo *et al*, 2014). Solidification for landfill or other uses of WTS has been achieved by the utilization of calcium carbonate powder, slag and dehydrate gypsum, quarry fines, silica fumes, fly ash and rice husk (Nurliyana, 2015). Also, the effect of slag-based solidification material on the solidification and stabilization of sludge has been investigated (Miroslav, 2008; Hegazy *et al*, 2012; Wei, 2013).

According to Babatunde and Zhao (2007), the incorporation of WTS in construction materials has been studied and practiced. Records of achievements and advancement of positive utilization of WTS in some countries are available and the research on application of WTS is still on-going. However, the hesitation of the building and construction industry for full acceptance of WTS materials is based on the variability observed in the final products due to varying chemical composition, water and organic content. In order words, WTS construction materials must be seen to be compositionally stable and reliable to make them cost effective and justify their use. The increased demand for construction materials over the years has resulted in a search for alternatives. Waste reuse and recycling into sustainable construction materials is a good alternative for waste disposal. In the construction industries, an important key to a full-scale use of the various waterworks sludge reuse options remains a steady and reliable source of the sludge, with minimal compositional variety. The use of sludge in the construction industry contributes to the sustainability of limited natural resources. It is also environmentally friendly. From reviewed literature, it was obvious that the main application of waste sludge in the construction industry is in brick production (Hegazy et al, 2012; Rocarro *et al.*, 2015; Anyakora, 2012). In Portugal, the inclusion of sludge from a water treatment plant in cement mortars was studied by Arlindo *et al.* (2004). The sludge from a Portuguese water treatment plant was characterized and it was found that the dewatered sludge contained basically water, calcium, aluminum and silica with an organic content of 6%. The mineralogical constituents were mainly calcite and clay materials which enabled it for use in cement mortars. Johnson *et al* (2014) also reported that the use of different types of sludge as a raw material in the construction industry is practicable without compromising the material requirements according to available standard.

The aim of this research is to design and construct a slow sand filter for dewatering WTS and also evaluate the performance of the constructed filter in a slow sand filtration experiment. The dewatering of sludge effluent with the aid of a locally designed and manufactured sand filter will reduce the time required for sludge thickening and enhance further use. Fabricating a locally designed filter may also be a means to decrease the cost of sludge dewatering by the absence of imported sand filters. Also, the properties and performance of a mixture of sludge effluent from an urban waterworks and laterite as brick for construction will also be looked at.

2 METHODOLOGY

2.1 LOCATION OF THE STUDY

The sludge used in this study was that collected from sedimentation tanks from Eleyele waterworks, Ibadan Nigeria (Geographical Coordinates: 7 45'N, 3 51' E). Eleyele water works is an urban waterworks and one of the nine water supply scheme stations of the Water Corporation of Oyo state government.

2.1.1 Design and Construction of a Sludge Dewatering Filter

The factors that were put into consideration in the design of the sludge dewatering filter are Availability of materials, Strength and durability, Ease of operation, Portability, Ease of maintenance and Cost.

Design Specifications- The specifications for the slow sand filter were:

Depth (D) = 0.12 m

Width (R) = 0.2 m

Assumed length (L) = $4D = 4(0.12) = 0.48\,m$.

Average flow rate of 0.56L/sec

Surface Area- In order to design an efficient slow sand filter, the surface area was based on overflow rate of 0.833 L/sec-m².

The surface area was calculated using Equation (1)

$$A = \frac{Q_c}{Q_R} \quad (1)$$

Where A is surface area (m²)

Q_C is flowrate L/sec

Q_R is overflow rate L/sec-m²

$$\therefore A = \frac{0.56}{0.83} = 0.672m^2$$

The volume was calculated using Equation (2)

$$V = Q_c T \quad (2)$$

Where V is the Volume (m³)

Q_C is flowrate L/sec

T is Detention Time (hrs)

V = 0.56×6=3.36m³

Flow through velocity- First the cross-sectional area of the filter was calculated as follows:

$$A = \pi r^2 \quad (3)$$

Where A is cross-sectional area (m²)

Radius = 0.06m

∴ A=0.011m²

The flow velocity through the filter was determined using Equation (4)

$$V_L = \frac{Q_c}{A} \quad (4)$$

Where V_L is flow through velocity (m/sec)

Q_C is flow rate (L/sec)

$$V_L = {}^{0.56}/_{0.024} = 2.33m/sec$$

2.1.2 Description of Functional Parts of the Sludge Dewatering Filter

i. *The cover/inlet:* The dewatering filter has a cover which serves a double purpose, to serve as inlet for sludge during loading of sludge and to prevent rainwater from getting into the filter media. The filter being a cylindrical component has a cylindrical cover to fit firmly on to the top of the filter. The inlet is designed to be wide enough only to allow a funnel to ensure that sludge enters the filter without spillage.
ii. *The Filter Chamber:* The filter chamber, which can also be called the sludge collection zone, is about the most important aspect of the filter as without it, the set-up is just a cylindrical drum. The filter is designed in a cylindrical manner so as to disallow sludge pockets that normally form in rectangular containers. Since waterworks sludge contains water, Galvanized steel was chosen in order to prevent corrosion of the filter to a large extent. Also, galvanized steel satisfies the strength and durability criteria. The filter chamber consists of the sieves and the filter media. There are two screens of varying mesh sizes, one at the base (1mm mesh size) and the other just below the inlet (2mm mesh size). The top screen was used to increase the surface area of the part of sieve unto which sludge drops. The sieve breaks the water or sludge into droplets of spray forms and reduces velocity of sludge on the sand media. The base sieve first of all serves as a support for the filter media and the sludge to be dewatered. The media used in the filter to dewater sludge are sand and gravel. The gravel served as a strong support to the filtering system which prevents clogging, with sizes ranging from 5 to 30mm. The sand particles, the main filtering agent, are those passing between sieve mesh size 1.18mm.
iii. *Clear water collection chamber/outlet:* This is a small space included in the design of the filter to enable easy passage of filtrate out of the system. So, the chamber is also a cylindrical one (as is the shape of

the whole dewatering filter) and a small cylindrical pipe outlet is attached for water removal. The filter is supported by a frame.

To design for height of the supernatant chamber for dewatering of about 50 L of sludge, using the volume of a cylinder,

$$\text{Volume} = \pi r^2 h \quad (5)$$

$50\ L = 0.05m^3$

Assumed radius = 0.2m

$0.05 = \pi \times (0.2)^2 \times h$

h = 0.14m

Therefore, the required height to dewater 15L of sludge should not be less than 0.12m (12cm), excluding the height of the gravel and sand media. However, because of the fact that the filter may be used to dewater greater amounts of sludge, the filter chamber was constructed with a higher value of 0.5 m. The dimensions of the dewatering filter are 1000mm by400mm. The filter chamber is 500mm high.

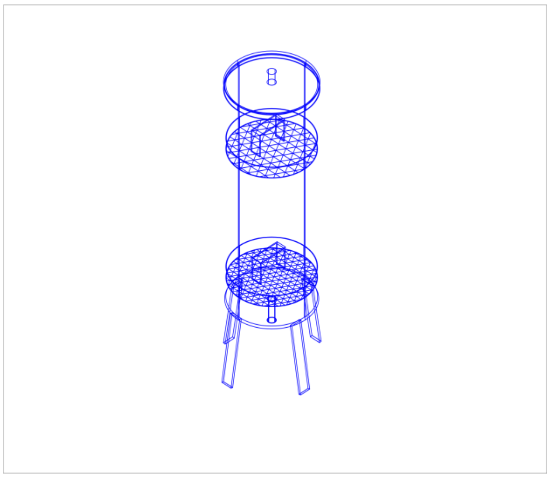

Fig. 1: Isometric view of the sludge dewatering filter

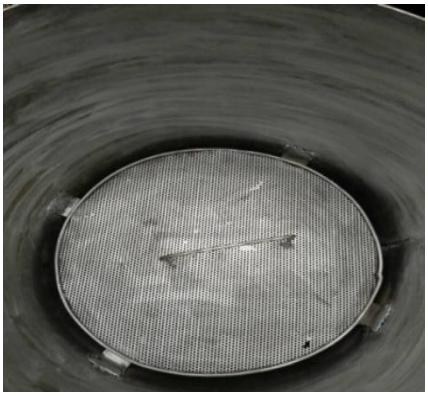

Plate 1: The 2mm mesh size top screen

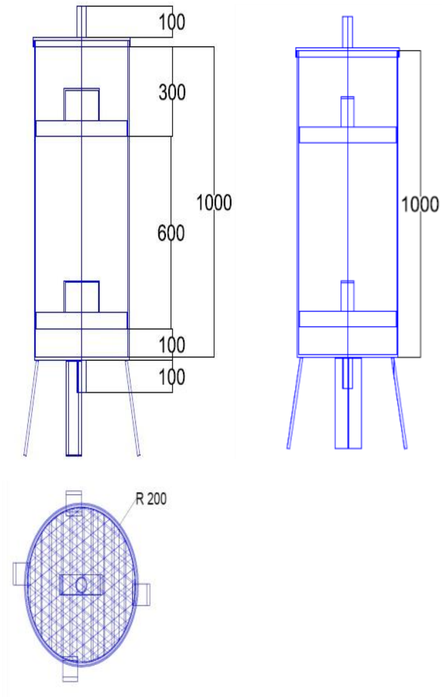

Fig. 2: Orthographic diagram of the sludge dewatering filter(dimensions are in mm)

Plate 2: The 1mm mesh size base screen

Plate 3: The sludge dewatering filter

2.1.3 Evaluation of Sludge Dewatering Filter

15L of sludge was manually poured into the filter with average flow rate of 0.56L/sec. For subsequent loadings after the first, the caked semi-solid sludge was carefully scraped off and dried before the input of sludge. For 6 hours, the rate of flow of filtrate out of the filter was observed at 30 minute-intervals to monitor the filtration rate and efficiency of the filter. This was measured by noting the volume of water filtered (dewatered) with a graduated measuring cylinder. The formula for measuring the filtration rate is given below:

$$\text{Filtration rate } (L/m^2/hr) = \frac{flowrate(\frac{L}{hr})}{surface\ area(m^2)} \quad (6)$$

The proportion of water drained over a period of time was obtained by the following equation:

$$\%\ \text{water drained} = \frac{amount\ of\ water\ filtered}{total\ amount\ of\ sludge\ loaded} \quad (7)$$

2.2 Investigation of Brick Properties

Sludge was collected from sedimentation tanks and the suspended solids content of sludge was determined by weighing the dry residue obtained when sludge sample is filtered through a weighed standard glass fibre. The sludge was then dewatered by slow sand filtration method in the pre-fabricated filter (plate 3) and subsequently air-dried (plates 4 and 5). The dried sludge was incorporated in brick making without further treatment. Laterite was locally obtained and air dried. Thereafter, grinding was carried out to break the lumps present in the materials. Also, sieving of both samples was done using a wire mesh screen of 0.85 mm diameter and only materials passing through the sieve were used.

The oxide contents of the sludge and laterite samples were determined using atomic absorption spectroscopy. Particle size distribution and Atterberg limits were also determined. Subsequently, various proportions of sludge and laterite were prepared in batches.

Plate 4: The fresh dewatered sludge

Plate 5: The air-dried sludge

2.2.1 Preparation of Brick Samples

Batching method by mass was employed in mixing the brick component to produce laboratory-scale bricks with nominal dimensions of 70 mm x 70 mm x 70 mm. Three groups of bricks were prepared with percentages of sludge as supplement for laterite as 0%, 15% and 30%, with the one of 0% as the control. Five (5) bricks each were produced from each group, giving a total of 15 experimental bricks.

Mixing was done on an impermeable surface made free from all harmful materials by sweeping. Mixing of raw materials was in two steps, dry mixing and blending with water. The optimum moisture content of a mixture was based on the moisture requirement in which maximum bonding among the mixture particles is retained. The optimum moisture content of the mixtures for the control bricks and 15% dried sludge bricks were 25% of laterite amount. For the 30% sludge-laterite mixture, 30% moisture content was observed to be optimum for mixture. Thorough mixture was done to eliminate lumps and to ensure homogenous mixture before moulding.

Hand moulding method was used in making the bricks. The bricks were produced using a wooden mould. The interiors of the mould were lubricated with oil to enhance easy removal of bricks and also to give the brick a smooth surface. The mixtures were put into the mould and manual compaction method was employed, ensuring uniform compaction of brick samples. Excess mixture was scraped off and the surface was leveled to produce straight edges. The Laterite-sludge bricks were carefully extruded in fine shape and placed on a clean and hard flat surface after one day of forming. The wet brick samples were subjected to drying under normal atmospheric temperature and pressure. They were dried for 3 weeks.

3 Results and Discussion

3.1 Particle Size Distribution of the Laterite and Sludge

Fig. 3 shows the outcome of the particle size distribution of the laterite and sludge samples. The samples both contain a wide variety of grain constituents, mostly passing between sieve number 8 (2.36mm) and sieve number 72 (0.212mm). It can be seen that a higher percentage of sludge aggregates passed through sieve number 8 when compared with laterite aggregates with percentage passing 93.08% and 64.84% respectively. It can also be observed that a higher percentage of sludge aggregates also passed through sieve number 72 (the smallest sieve mesh size for the study) when compared to laterite aggregates. This implies that the dried sludge sample contained relatively finer particles than the laterite sample.

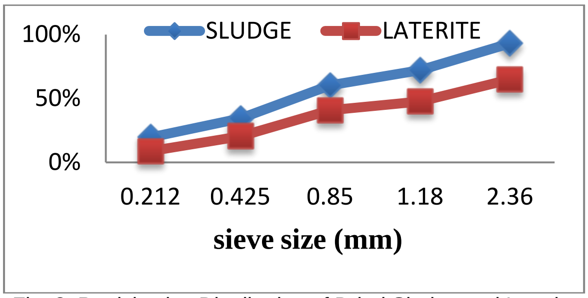

Fig. 3: Particle size Distribution of Dried Sludge and Laterite

3.2 Chemical Composition of the Sludge

As shown in Table 1, the major chemical components of the sludge sample were silicon, aluminium and iron oxides, which are similar to major chemical compositions of laterite soil but with higher alumina content. Silica content (SiO_2), an oxide of Silicon that is mostly found in quartz and is the major component of sand, was the highest in Laterite soil sample with a percentage by weight of 60.47%. Similarly, the Silica content of dried sludge sample was highest, attaining up to 52.98% by weight. The difference can however be attributed to the nature of solids present in raw water before treatment. Alumina (Al_2O_3), an oxide of Aluminium, was the second highest constituent of the sludge, having a proportion by weight of 29.46%. The Alumina content of the sludge was higher than that in laterite which was 17.77%, though it was also the second highest in the laterite soil sample. Iron (III) Oxide (Fe_2O_3) was the third highest component in both samples, with laterite having a proportion of 8.18% by weight while sludge had a proportion of 3.63%. The presence of a relatively high proportion of ferric oxide in the sludge effluent from Eleyele waterworks implies presence of a lot of iron in the raw water treated. The Loss on Ignition value, a crude measure of organic content of the sludge sediment, was found to be 10.65%. It can therefore be said that the components of sludge are similar to those of Laterite, and also similar to those of waterworks sludges that have been reported in literature (Anyakora, 2012; Hegazy *et al.*, 2012; Njau and Park, 2003).

Table 1. Characteristics of Sludge and Clay

Property	Sludge	Laterite
Condition of sample	Air dry	Air dry
Colour	Brown	Brownish Red
Liquid limit (%)	-	61.22
Plastic limit (%)	-	33.77
Plasticity index (%)	-	27.45
Suspended solids content (mg/l)	542	-
Specific gravity	2.869	2.766
pH	6.34	6.62
Bulk density (g/cm³)	1.02	0.76
SiO_2 (%)	52.98	60.47
Al_2O_3 (%)	29.46	17.77
K_2O (%)	0.99	1.17
CaO (%)	1.91	0.47
TiO_2 (%)	1.16	ND
MnO (%)	0.01	0.03
Fe_2O_3 (%)	3.63	8.18
P_2O_5 (%)	0.01	ND
Na_2O (%)	0.58	0.44
LOI (%)	10.65	ND

3.3 Bulk Density of the Bricks

The bulk density of the brick samples ranged from 1.38g/cm³ to 1.80g/cm³. The laterite (control) bricks have an average bulk density of 1.77g/cm³ which was the highest of the three samples. The bulk densities were observed to reduce as the proportion of sludge in the brick increased, which means that the density of the bricks is inversely proportional to the quantity of sludge added to the mixture. A decrease in bulk density was also reported by Anyakora (2012) and Jock *et al.* (2013) with an increase in addition of sludge and rice husk respectively.

Table 2. Data of the Density of the Brick Composites

Sample composition	Mean Density (g/m³)
100% Laterite 0% Sludge	**1.77**
85% Laterite 15% Sludge	**1.66**
70% Laterite 30% Sludge	**1.39**

It was observed from the result of the ANOVA that there was significance difference between the density values of control laterite bricks and the laterite sludge bricks with Fcal>Fcrit. Since the P-value is less than 0.05, it means that there was significant difference in the density values obtained for the three samples.

3.4 Compressive Strength of the Bricks

The results of the compressive strength test showed that the strength is dependent on the amount of sludge in the brick. The values ranged between 2.49N/mm² to 3.33N/mm². Compared with the control laterite bricks, the two laterite-sludge brick types exhibited lower strength. With the addition of 15% and 30% sludge to laterite, the average compressive strength achieved were 3.08N/mm² and 2.64N/mm² respectively. Though the compressive strengths are lower compared with the control bricks, the sludge laterite bricks strength dried for at least two weeks met the minimum 2.5N/mm² strength standard as building bricks according to Nigerian Industrial Standard (1976).

Table 3: Data of the Compressive strength test

Sample composition	Mean Compressive strength (N/mm²)
100% Laterite 0% Sludge	**3.15**
85% Laterite 15% Sludge	**3.08**
70% Laterite 30% Sludge	**2.64**

It was also observed that there is significance difference between the compressive strength values of control laterite bricks and the laterite sludge bricks with Fcal>Fcrit. Since the P-value is less than 0.05, it means that there is significant difference in the density values obtained for the three samples.

The volume of water drained for consecutive three (3) days were 5.45L, 5.235L and 3.5L respectively for each day, after a period of 6 hours, as shown in Table 6. Similarly, the percentage of water drained for three (3) days were 36.3%, 34.9% and 23.3% for each day, with maximum and minimum filtration rates of 0.25 L/m²/min and 0.06 L/m²/min. It was observed that the volume of water drained per day reduced as fresh sludge samples were poured daily. However, after initial observation of 6 hours reported above, the volume of water drained after 18 hours was recorded to be approximately 6L. The implication of this is that the filtration rate reduces over time as sludge is poured into the dewatering filter in consecutive days. The volume of water drained for three (3) non-consecutive days 1, 2 and 3 were 5.95L, 6.09L and 6.62L respectively for each day, after a period of 6 hours, as shown in table 2. Similarly, the percentage of water drained for three (3) days were 39.7%, 40.6% and 44.1%, with maximum and minimum filtration rates of 0.34 L/m²/min and 0.06 L/m²/min. It was observed that the volume of water drained per day increased as fresh sludge samples were poured every other day.

On two instances, samples were taken before the raw sludge was poured into the filter and from the resulting filtrate. After careful collection, storage and analysis, there was a significant decrease in the TSS (Total Suspended Solids) value compared before and after, showing the ability of the dewatering filter to trap suspended solid particles of the sludge. On an occasion, the TSS value of the raw sludge was 564mg/L and the TSS value of the filtrate was 200mg/L, showing a percentage decrease of about 62%. For the other sample, TSS value of the raw sludge effluent was 520mg/L and the TSS value of the filtrate was 202mg/L, showing a percentage decrease of about 61%. The concentration of sludge in the constructed sludge filter follows after that of Hegazy *et al.* (2012).

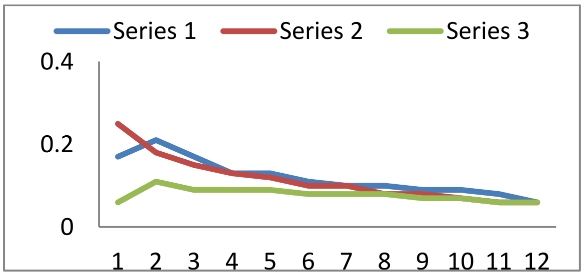

Fig.4: Pattern of filtration rate in 3consecutive days

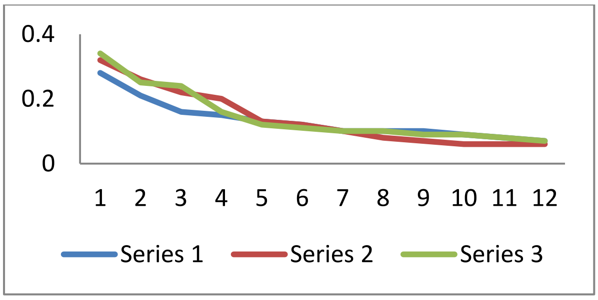

Fig. 5: Graph showing the pattern of filtration rate in 3 non-consecutive days

4 CONCLUSION

A sludge dewatering filter was designed and fabricated with locally available materials i.e. laterite and sludge. The use of the filter demonstrated that water works sludge can be effectively thickened by slow sand filtration. The results of this work demonstrated that a locally constructed sludge dewatering filter can be used to thicken waterworks sludge. The results obtained from this study have shown that laterite-sludge bricks can be produced using water treatment sludge as supplement for laterite. The proportion of sludge was the key factor affecting the quality of the bricks. The resulting sludge cake residue was found suitable for laterite bricks at different sludge ratios of 0%, 15% and 30% with average compressive strengths of 3.15 N/mm², 3.08 N/mm² and 2.64 N/mm². Such bricks, when produced in the required dimensions, have been found to be cost effective and energy efficient. (Kasthurba *et al.*, 2014). The laterite-sludge bricks can be used as building blocks for various constructions.

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