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POSSIBILITIES FOR THE USE OF SLUDGE FROM A DRINKING WATER TREATMENT PLANT AT GGABA III IN KAMPALA, UGANDA

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ABSTRACT

Sludge from the drinking water treatment plant at Ggaba III, located in Kampala (Uganda), was tested to evaluate the feasibility of two valorization routes, for building material and Solid Recovered Fuel (SRF) production. The aim of the research was to divert the huge amount of sludge produced every year, approximately equal to 2,140 metric tons of TSS/year, from landfilling. The average high heating value of the sludge was 8.44 MJ/kg TS, corresponding to the lower value of the interval of variation typically reported for other biosolids (8.0-23 MJ/kg). Different bricks were prepared at sludge to clay ratios of 0, 0.05, 0.1, 0.3 and 0.5 by weight. For each mixture composition, bricks of nominal size 215 x 102.5x 65mm were prepared by hand and fired for 6hrs in a Hoffman kiln at temperatures: 850°C, 900°C, 950°C, 1000°C and 1050°C. The bricks produced with a sludge to clay ratio of 0.1 fired at temperatures of ≥980°C met the compressive strength of 3N/mm^2 for common bricks according to Ugandan Standard (US) 102:1995. These results suggest that water treatment sludge at Ggaba is more suitable for the production of common bricks than using it as an energy source. Given the encouraging results that make the studied valorization route applicable in an emerging economy country as Uganda, further investigations are required to assess the leaching behaviour and stability of the mechanical properties over time.

1. INTRODUCTION

The Ggaba III drinking water treatment plant is managed by the National Water and Sewerage Corporation (NWSC), a public utility company 100% owned by the Government of Uganda (NWSC, 2014). The plant provides part of the drinking water distributed to Kampala, the Capital city of Uganda. The water, collected from the Inner Murchison Bay of Lake Victoria, is treated by means of the following sequence of processes: screening, pre-chlorination, coagulation, flocculation, clarification, filtration, pH adjustment and post chlorination. During coagulation, aluminum sulphate (alum, $Al_2(SO4)_3.14H_2O$), is used and alum sludge is produced. In order to meet the increasing demand of high quality drinking water, the sludge production is expected to increase, in accordance with the rate of increase in water production at this plant.

As noted by Babatunde and Zhao (2006), the costs of handling the enormous quantities of water treatment sludge (WTS) can account for a significant part of the overall operating costs of drinking water production. The Authors also noted problems of limited land available for WTS disposal in sanitary landfill sites. As one of the ways of managing sludges, Diener et al. (2014) suggested to identify valorization routes, to minimize the overall amounts to be landifilled and to use the recovered cost in funding sludge management interventions.

In the literature, the following WTS valorization options have been proposed and studied: application in building and construction materials (Mohammed et al., 2008; Badr et al., 2011; Mageed et al., 2011), utilization to improve particulate pollutant removal from sewage (Lai and Liu, 2004; Guan et al., 2005), application for phosphorus adsorption (Huang and Chiswell, 2000; Zumpe et al., 2002; Yang et al., 2006; Babatunde and Zhao, 2007); soil remediation (Elliot and Dempsey, 1991; Roy and Coulliard, 1998); application in pavement construction and geotechnical works (Raghu et al., 1987; Carvalho and Antas, 2005). According to Hegazy et al. (2011), the use of sludge in construction industry is considered to be the most economic and environmentally sound option.

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WTS has also been used to make bricks with binders such as clay (Weng et al., 2003; Ramadan et al., 2008). The most relevant factors affecting the quality of bricks were found to be sludge dosage into the mixture and the firing temperature (Weng et al., 2003). In other studies, incinerated WTS was used in combination with rice husks (Chiang et al., 2009) and with shale (Mageed et al., 2010). Hegazy et al. (2011) used WTS in combination with silica fume as a complete replacement of clay in brick making. In the study by Hegazy et al. (2011), which was performed at the temperatures commonly practiced in the brick kiln (900-1200°C), the optimum sludge addition to produce brick from a mixture of sludge and silica fume was 50%. The produced bricks properties were found to be superior to the 100% clay control-brick and to those available in the Egyptian market (Hegazy et al., 2011).

It is important to identify valorization routes that are applicable under the conditions (availability of technologies, skills, funds for operation and maintenance) of an emerging economy country. Moreover, it is imperative that the proposed management of WTS is aimed at "closing the cycle" by reducing landfilling and promoting a local reuse of the material, otherwise considered to be waste. This research identifies valorization routes for the use of WTS in production of common bricks and as a raw material to provide energy for heating in industrial production of bricks.

2. METHODS AND MATERIALS

The liquid and dried WTS samples used in this study were obtained from Ggaba III water treatment plant while the clay samples were obtained from Lweza clays Ltd at Kajjansi.

2.1 Quantification of the WT sludge at Ggaba III

Liquid WTS at Ggaba III is discharged to the drying beds or wetlands through the nine groups of pipes from each of the four clarification tanks as illustrated in Figure 1. The sludge is discharged to the beds along with the cleaning water, from the cleaning operation of the clarifiers, which is done once a week according to the plant operators. In order to assess the sludge production rate, the time for the discharge of each clarifier was measured.

Up to 100 mL of liquid WTS samples was collected every 10 minutes for 60 minutes for the analysis of Total Suspended Solids (TSS) in triplicates using the procedures in Sandec Protocol Section D, SOP 014. Based on the discharge rate and TSS, the sludge production rate was computed as follows:

$$\text{Sludge production rate} = \text{Discharge}\left(\frac{m^3}{day}\right) * \frac{Average\ TSS\ (\frac{mg}{l})}{1{,}000{,}000} \quad (1)$$

2.2 Sampling

Composite samples were collected from sludge drying beds, illustrated in Figure 2. The top surface of a bed was cleared and a trowel inserted 2cm deep from the surface to obtain grab samples. The grab samples obtained were mixed in a plastic container to get composite samples, placed into a cool box and stored under controlled conditions for the subsequent characterization and experimental campaign.

2.3 Sample preparation

Clay samples, existing in the form of boulders were spread on a tarpaulin laid on a hard flat surface to dry in the sun for two days in order to attain moisture content of about 20%. The samples were then crushed using a tamping rod and sieved through a 425μm sieve in order to remove the coarse fraction. The WTS sample was air dried for 24 hours. The dried samples were pulverized using a ball mill crusher and sieved through a 425μm sieve.

2.4 Laboratory analysis on sludge and clay

Total Solids (TS), Total Volatile Solids (TVS) and ash content measurements were performed in triplicates according to the procedures in Sandec, Protocol Section D, SOP 013.

The higher heating value of air dried dewatered WTS samples was determined using a Bomb Calorimeter according to the procedure in Parr Manual (1948). The results were compared with those attained by using a Bomb Calorimeter IKA C1® according to DIN 51900, ISO 1928 standards without acid correction, using for calibration the pelletized benzoic acid as standard substance to determine the C-value of the calorimeter.

Dewatered WTS and clay samples were also tested for their moisture content, in triplicates according to British Standard (BS) 1377: Part 2: 1990 clause 3, elemental composition, by means of Xray fluorescence (Spectro Xepos), bulk density and particle size distribution (BS 1377: Part 2: 1990 Clause 9).

In order to determine the Plastic Limit of the different sludge and clay mixtures, the Atterberg method was applied in accordance to BS 1377: Part 2: 1990. Along with the plastic limit, liquid limit and linear shrinkage were measured.

2.5 Bricks production and characterization

Different mixtures containing sludge and clays were prepared in batch by varying the sludge dosage according to the following sequence: 0%, 5%, 10%, 15%, 20%, and 30% by weight. Thereafter, the mixture was spread on a tarpaulin laid on a hard flat surface, and mixed using spades until a uniform color was achieved. Water was added while mixing until the optimum moisture content of 13.2% was achieved and samples kept for at least three days to reduce air voids.

The commonly used hand moulding method (Nyakairu et al., 2002) for the preparation of local bricks was used. The raw material was placed into a water-lubricated wooden mould and then compacted by hands. The mixture in excess was scrapped off using a flat piece of wood to level the surface. Bricks, prepared from each of the above-described mixtures, were produced in accordance to BS 3921:1985 with a nominal size of 215 x 102.5x 65mm. A total of 200 bricks were produced and air dried for seven days prior to firing.

Firing of the bricks was done in two batches. The first

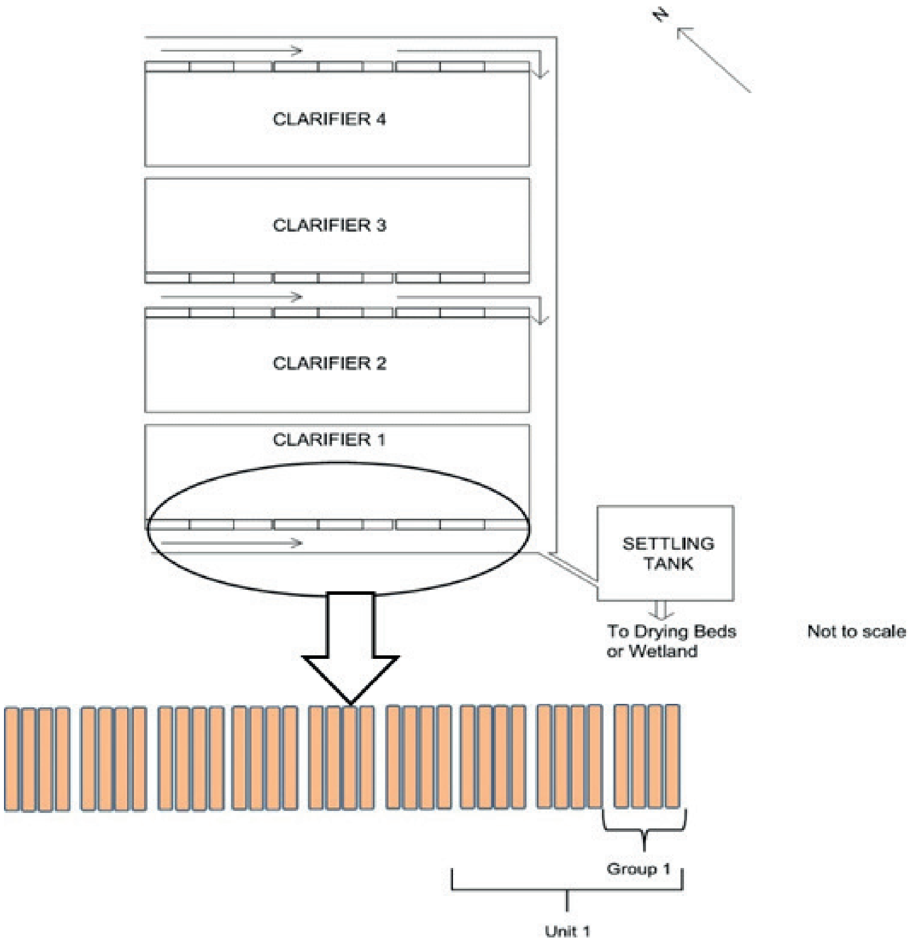

FIGURE 1: Illustration of discharge valves from one clarifier.

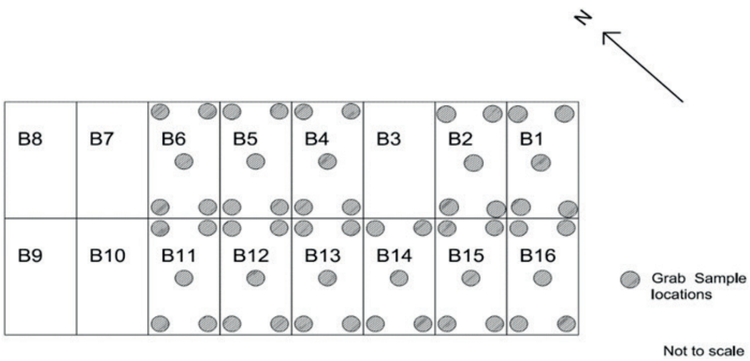

FIGURE 2: Schematic of sludge sampling points in the drying beds.

batch was fired in an electric furnace produced by Kilns and Furnaces Limited (Type: FL500, SN: FL 94 4417) at the Margret Trowell School of Industrial and Fine Arts Makerere University at temperatures equal to: 850, 900, 950, 1000 and 1050˚C for 6hrs. The second batch was fired in a furnace at Lweza Clays Ltd for 5 days. This was done in order to simulate the local conditions.

Tests were carried out on the fired bricks, as required by the Ugandan Standards (US), to establish their quality, including compressive strength measurement (BS 3921: 1985, BS EN 772-1:2011 and US 102: 1995), water absorption (BS 3921: 1985, BS EN 772-1:2011 and US 102: 1995), shrinkage, bulk density (BS 1881) and weight loss on ignition (BS 1377: Part 3: 1990).

3. RESULTS AND DISCUSSION

3.1 Sludge production rate at Ggaba III

For the four clarifiers, each discharge cycle was estimated to be equal to 9.9 minutes. The settled sludge discharged from the clarifiers at a rate of 0.56 m^3/min with an average TSS content of 737.817 mg/L, corresponded to approximately 2,140 metric tons TSS/year. This production rate cannot be handled by the capacity of the drying beds currently available at the plant, and as such some of it is being disposed in the wetland.

3.2 Physical properties of sludge and clay

Table 1 shows the average total solid, moisture and ash content of sludge and clay, along with the bulk density. The moisture content of dewatered sludge and clay was equal to 13.2%±1.2% and 16.7%±3.2%, respectively. The ash content of sludge was obtained as 79.7%. The bulk densities of WT sludge and clay were 1.2920 g/cm^3 and 1.9840 g/cm^3 respectively at the end.

3.3 Elemental composition

The elemental content of the sludge and clay are shown in Figure 3. From Figure 3, both the WTS and clay have similar composition in terms of macro-elements, including Al, Si, Fe, S, and P. WTS has higher aluminum and phosphorous content than clay, with an Al content of 119500 mg/kg for sludge and 95560 mg/kg for clay, and a phosphorous content of 5093 mg/kg for sludge and 509.3 mg/kg for clay. Conversely, clay showed much higher silicon content of 40460 mg/kg than WTS with a silicon content of 268400 mg/kg. Toxic metals, including Arsenic, Mercury, Cadmium

TABLE 1: Physical properties and element content of sludge and clay.

Property	Unit	WT sludge	Clay
Total solids	wt%	74.5	83.3
Moisture content	wt%	13.2±1.2	16.7±3.2
Average ash content	wt%	79.7	-
Bulk density	g/cm^3	1.2920	1.9840

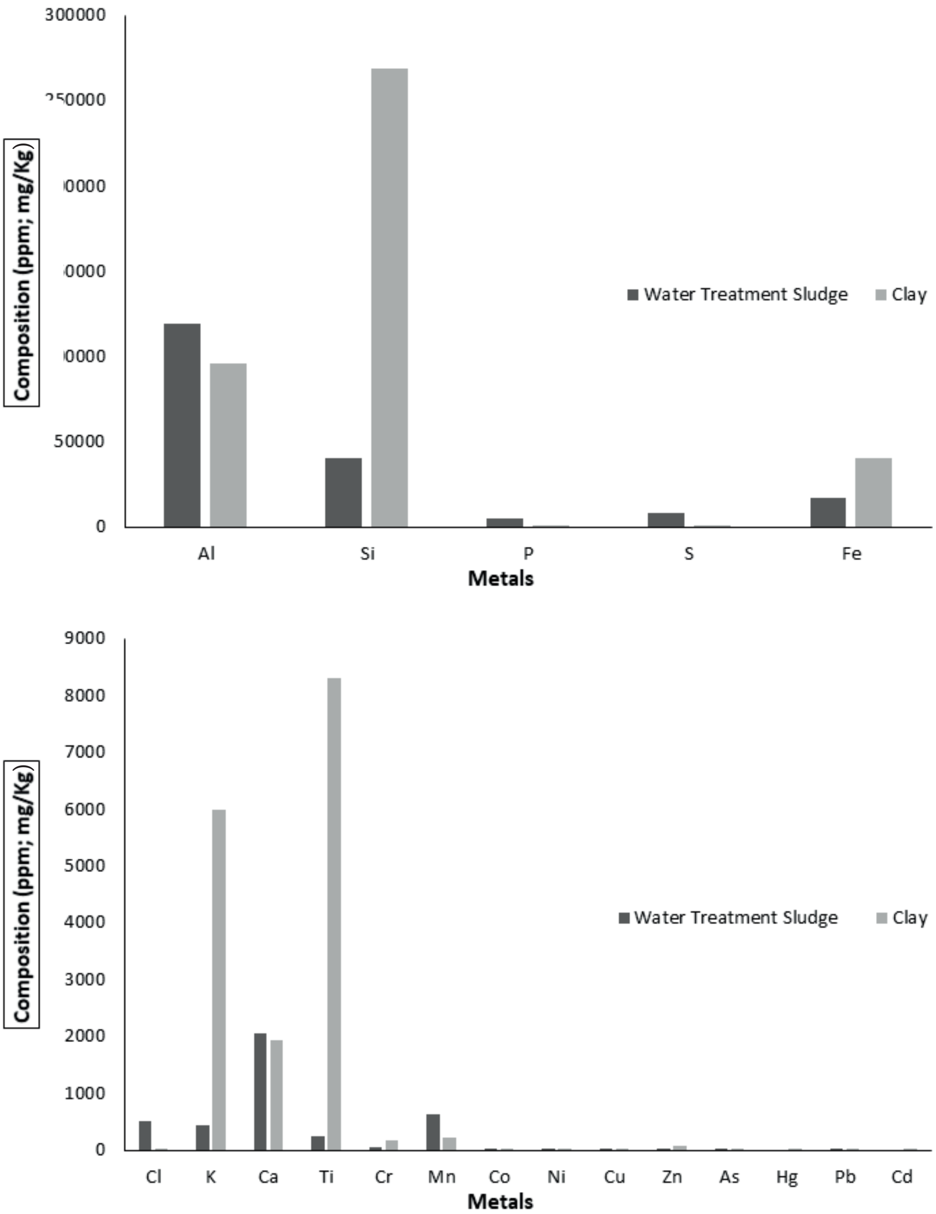

FIGURE 3: Elemental composition of sludge and clay.

and Lead were present in trace amounts.

3.4 Higher Heating Value

From the test carried out at Makerere University, the average higher heating value of the WTS obtained was 8.04 MJ/kg TS at an average moisture content of 13.2%. A higher heating value of 8.8415 MJ/kg TS was obtained from the test carried out at Paul Scherrer Institute (PSI) in Zurich Switzerland. The average higher heating value of 8.44 MJ/kg TS obtained in this study was compared with that of selected agricultural residues that are used as a source of renewal biomass energy as shown in the Figure 4.

The higher heating value of the WTS obtained in this study is lower compared to that of agricultural wastes usually used as biomass fuels. On the other hand, this value is comparable to the 8.0–23 MJ/kg observed from other biosolids (Spinosa and Vesilind, 2001; Mödinger and Mayr, 2006; Skjeggerud et al., 2009).

3.5 Particle size distributions

Figure 5 shows the particle size distributions of the WTS and clay respectively. Accordingly, the WTS and clay can be classified as fine sand, since maximum passing sieve No. 200 was 20%, which was less than 35% for silty soils, and clayey soil respectively basing on their plasticity and percentages of particles passing No. 200 sieve according to AASHTO classifications.

3.6 Atterberg limits

Atterberg Limits (BS 1377: Part 2, Clause 5:1990) testing was conducted to determine the Liquid and Plastic Limit (LL and PL, respectively) for each mixture. Atterberg limits are widely used in engineering to determine the plastic properties of clay materials (White, 1949). Plasticity enables the soil to undergo unrecoverable deformation without cracking or crumbling. It results from the presence of a significant content of clay mineral particles (or organic material) in the soil. The void space between such particles is generally very small in size with the result that water is held at negative pressure by capillary tension. This produces a degree of cohesion between the particles, allowing the soil to be deformed or moulded. The upper and lower limits of the range of water content over which the soil exhibits plastic behaviour are defined as the liquid limit and the plastic limit, respectively (Craig, 2004).

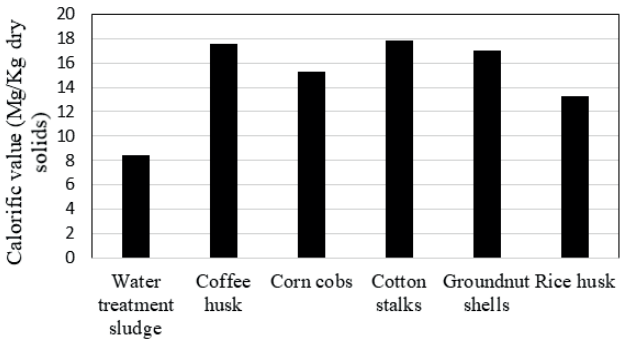

FIGURE 4: Calorific value of sludge and common wastes (Kumar et al, 2001).

The Liquid limit increased with increasing sludge addition to the mixture, as illustrated in Table 2. The plasticity index decreased with increase in sludge dosage implying a decrease in the water content range within which the mixtures exhibit plastic behavior. The Atterberg's tests showed that the plasticity index (PI) is inversely proportional to the sludge content of the brick.

3.7 Compressive Strength

The compressive strength test is the most important test for assuring the engineering quality of a building material (Weng et al, 2003). From the results shown in Figure 6, the compressive strength of the produced bricks is greatly dependent on the amount of sludge in the mixture and the firing temperature. The general decrease in strength with sludge addition was also noted with bricks fired at Lweza Clays Ltd. An increase in strength with firing temperature was observed for each mixture tested.

Bricks having sludge addition of 0% and 5% and for all the firing temperature had compressive strengths greater than 3 N/mm^2, the minimum compressive strength specified by

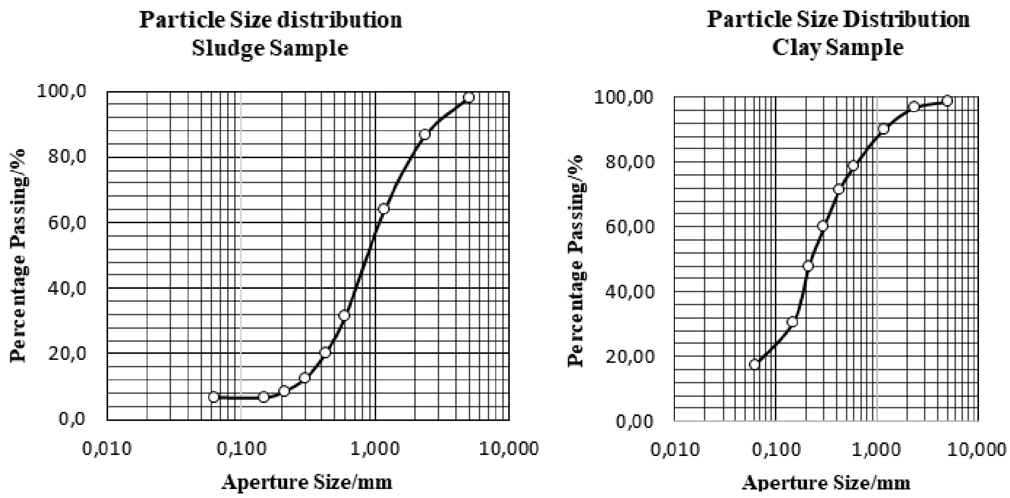

FIGURE 5: Particle size distribution of sludge and clay.

TABLE 2: Liquid Limit, plastic Limit and Plasticity Index of different clay and sludge mixtures.

Specimen	0%	5%	10%	20%	30%	50%
Sludge (% weight)	0	5	10	20	30	50
Clay (% weight)	100	95	90	80	70	50
LL, %	42.0	42.4	42.8	43.5	44.4	45.3
PL, %	20	23	25	27.7	31	34.5
PI	22	19.4	17.8	15.8	13.4	10.8

the Ugandan Standard specification for burnt clay bricks, US 102: 1995. Bricks with 10% sludge addition fired for all the temperatures above 980⁰C met the compressive strength requirement of 3 N/mm^2 and were classified as common bricks.

3.8 Water Absorption

Water absorption is one of the key parameters that affects the durability of brick. The less water infiltrates into brick, the more durability of the brick. Thus, the internal structure of the brick must be compact enough to avoid the intrusion of water. The water absorption results obtained for the bricks with different sludge content were plotted against the firing temperatures in the figure below. From Figure 7, the water absorption of the bricks increased with increasing sludge dosages and decreased

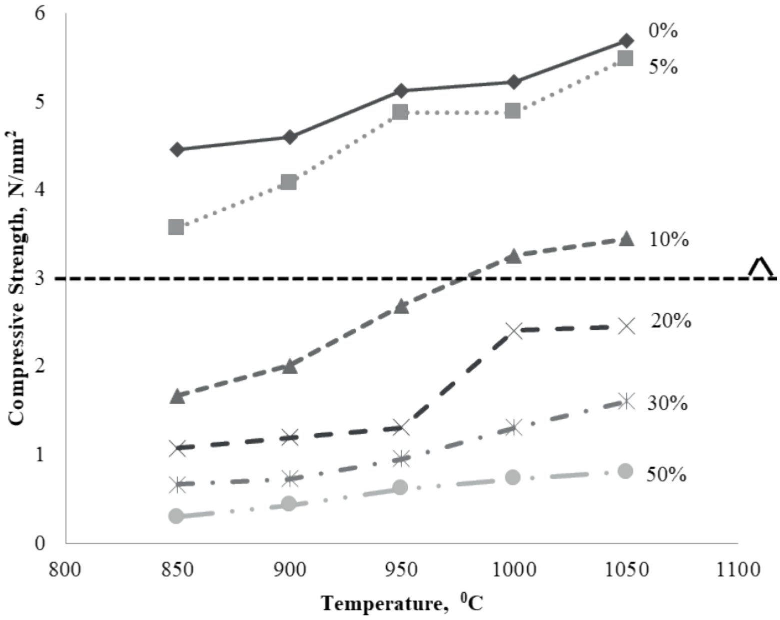

FIGURE 6: The compressive strength of bricks.

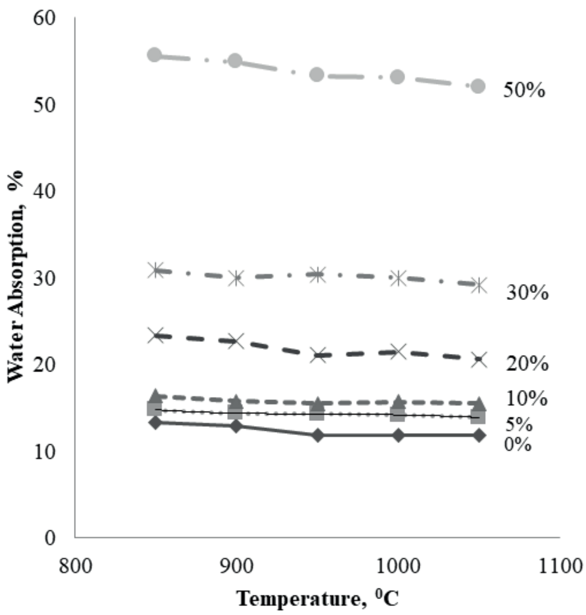

FIGURE 7: Water absorption of bricks.

with increasing firing temperature. The latter behavior may be explained hypothesizing that at the highest firing temperatures the degree of crystallization is enhanced, thus causing a reduction of pores size in the brick. Conversely, the increase of sludge content may be able to reduce the adhesiveness of the mixture, so that the internal pore size of the brick increases. All the bricks had higher water absorption in comparison to engineering bricks (less than 6.3%), industrial bricks (6.3%) and facing bricks (7%) according to the Uganda Standard (US) 102: 1995 standard. The standard did not specify limits for common bricks. According to Chiang et al. (2009), lightweight bricks with relatively high water absorption have been applied widely in the inner walls of green buildings, hence the water absorption of lightweight bricks is an insignificant factor in considering their application.

3.9 Shrinkage of bricks

There was no direct relation between the percentage of sludge content and shrinkage of the brick. A similar relationship was reported by Jordán et al. (2005) while studying the effect of substitution of clay for sewage sludge in different proportions on the technological properties of a ceramic material.

3.10 Bulk density of fired bricks

The bulk density as illustrated in Figure 8 decreases with increasing sludge dosages, and increases with increasing firing temperature. The bulk density of the bricks made of clay was between 1.8 and 1.814g/cm^3, in the range of 1.8-2.0 g/cm^2 for bricks made of clay (Weng et al., 2003) at temperatures between 960^{0}C to 1000^{0}C. At higher sludge additions, the bricks were lighter.

The decrease in bulk density of the fired bricks with increasing sludge dosage may be related to volatile organic content of the sludge (Babatunde and Zhao, 2007). As the combustible fraction is lost upon firing, pores are created within the bricks (Chiang et al., 2009) hence providing a lighter weight and good thermal insulation properties for green building applications. Weng et al. (2003) attributed the decrease in bulk density to the increasing amounts of water required for mixing at higher sludge additions, which leads to larger pore sizes on firing.

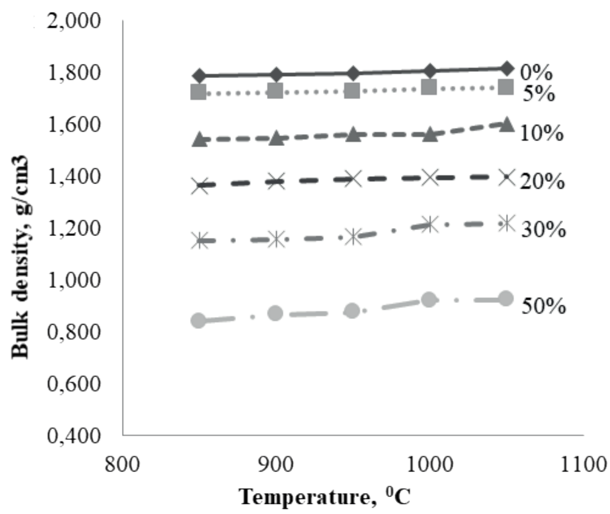

FIGURE 8: Bulk density of fired bricks.

3.11 Weight loss on ignition of bricks

The weight loss on ignition of bricks during the firing process is mostly due to the organic compounds and the inorganic Calcium carbonate, $CaCO_3$. Figure 9 shows the results of weight loss on ignition of bricks. It shows that increasing the sludge proportion and temperature resulted in increase in brick weight loss on ignition. The Ugandan standard did not give any comparison of the weight loss on ignition. When compared to available standards as Chinese National Standards (CNS, 1999), the weight loss criterion for a normal clay brick is 15%.

Bricks 0% and 5% sludge addition fired at all the firing temperatures, met the criteria according to CNS, 1999. However, upon the addition of sludge in the mixture, the loss of weight apparently increased as a result of organic matter loss from sludge. Furthermore, the brick weight loss on ignition also depends on the inorganic substances in both laterite and sludge being burnt-off during the firing process. The relationship between the compressive strength and weight loss on ignition at various temperature series is presented in Figure 10. From this figure, the compressive strength of the produced bricks of the sludge/clay mixture decreases with increase in weight loss on ignition. The relationship between compressive strength and bulk density at various temperatures is shown in Figure 11. According to Figure 11, the compressive strength is directly proportional to the bulk densities of the bricks produced from the sludge/clay mixture but is inversely proportional to the percentage of sludge additions.

4. CONCLUSIONS

The aim of this study was to determine the potential of water treatment sludge from Ggaba III as a building material and as a raw material for energy. The following conclusions are supported by the results of this study:

- The rate of production of the WTS was 2,140 tons TSS/year and this rate of sludge production cannot be managed by using the available sludge drying beds. Recycling this WTS by using it as substitute for clay in the production of common bricks is a possibility to reduce treatment and disposal costs. The rate of production of the WTS will also ensure that the business of using it with clay to produce bricks is reliably available in quantity.
- From the comparison of the elemental compositions of the WTS with clay, major elements appeared to be similar and hence the two materials were compatible when mixed together. The content of critical elements (Arsenic, Mercury, Cadmium and Lead) was low and hence the use of sludge is expected to pose no danger to the environment.
- The higher heating value of the WTS was obtained as 8.44 MJ/Kg TSS. This value is low although comparable to the 8.0-23 MJ/kg observed with other biosolids

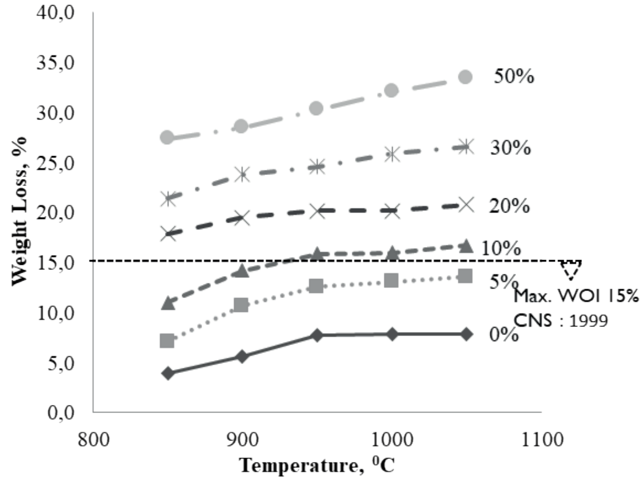

FIGURE 9: Weight loss on ignition of bricks.

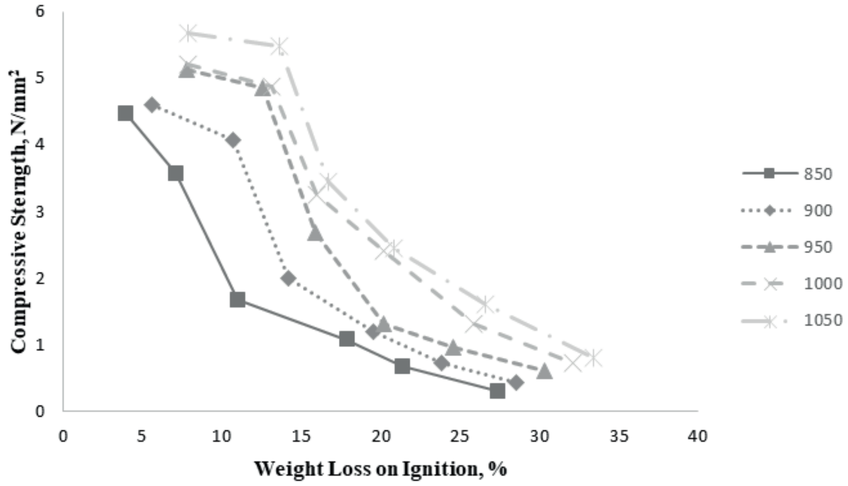

FIGURE 10: A graph relating the compressive strength to weight loss on ignition at various temperature series. The data points of the graphs are arranged with increasing sludge additions.

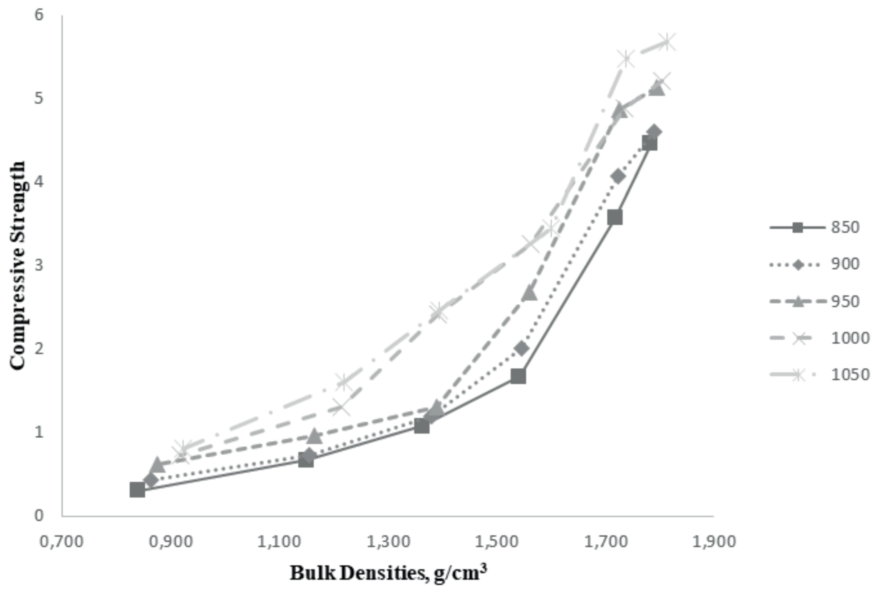

FIGURE 11: A graph relating the compressive strength to bulk densities at various temperatures. The data points of the graphs are arranged with decreasing sludge additions.

obtained from previously published literature.

- The compressive strength of the bricks decreased with increasing the sludge content and increased with the firing temperature at each tested sludge content; the water absorption increased with increasing sludge content of the bricks and decreased with increasing the firing temperature at each sludge addition; the weight loss on ignition increased with increasing both the sludge addition and the firing temperature.
- At temperatures of 980˚C and above, the optimal sludge dosage to meet the compressive strength requirement of 3N/mm^2 for common bricks (according to US 102: 1995) appeared to be 10%; at 5% sludge dosage, the requirements of attaining a water absorption value less than 15% (according to US 849: 2011) was met. The major factors affecting the engineering quality of the bricks were found to be the proportion of the sludge to be added to the clay and the firing temperature.
- Consequently, the WTS is more suitable for use in the production of common bricks than using it as an energy source due to its low value of the higher heating value in comparison with other readily available wastes.

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