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Handling the Sludge When Using Polyaluminum Chloride as a Coagulant in the Potable Water Treatment Process

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ABSTRACT

The sludge produced in the treatment process depends on the type of coagulant and other chemicals used and the suspended particles present in raw water. Discarding this sludge in the landfills poses pollution of both ground and surface water, disturbing the lives in the water and the water quality. The primary potable water provider in Sri Lanka is the National Water Supply and Drainage Board. It focuses on finding ways of disposal, sustainable practices, and possible applications of the water treatment sludge. This research aims to identify the aluminum level in the potable water treatment sludge of the Konduwattuvana water treatment plant in Ampara and to utilize that sludge as an alternative raw material in burnt clay brick manufacturing. The national standards and limitations of the sludge content and the standard brick manufacturing process were followed. To reach the aim, a sequence of tests was conducted, and the brick characteristics are subjected to test for different sludge ratios according to the Sri Lankan Standard of 36:1978 for burnt clay bricks. Experimental results show that the aluminum content in liquid sludge and sludge cake was found to be 231.6 $mg.L^{-1}$ and 54.9 $mg.L^{-1}$, respectively, which implies that the sludge contains aluminum. The optimum sludge ratio to produce burnt clay bricks was found to be 10% of the total weight of the brick.

INTRODUCTION

Water treatment aims to provide a safe and adequate quantity of drinking water to people that do not contain any undesirable taste, odor, and color. Water is one of the essential valuable natural resources on earth for the survival of life. While water is being treated, a considerable quantity of water is drained as wastewater. So, it is crucial to treat the wastewater before discharging it anywhere else; thus, it cannot harm the environment and can be used for purposes other than drinking, such as irrigation. And also, a large quantity of sludge is generated each year from the water treatment process. The amount of sludge produced depends upon the amount of wastewater and the type of treatment practiced for treating the wastewater. Sludge management in water treatment plants becomes a severe problem due to its negative impact on the environment and people (Świerczek et al. 2018, Gomes et al. 2020). The common method adopted for disposing of the sludge is landfilling. Landfill disposal of the sludge has drawbacks such as high transportation costs, difficulty getting suitable sites for landfilling, heavy metal contamination of the land, emission of foul gases, etc. (Świerczek et al. 2018). So, disposal of sludge has become a major issue. Sludge usage in the construction industry is considered to be the most economical and environmentally sound option (Abdel-Gawwad et al. 2020, Breesem et al. 2014, Johnson et al. 2014, Ramadan et al. 2008, Mymrin et al. 2019, Limami et al. 2021).

Various researchers have carried out research worldwide regarding the sludge produced in water treatment processes (Abdel-Gawwad et al. 2020, He et al. 2021, Godoy et al. 2019). The suitability of water treatment sludge as a raw material for the local clay brick production industry was investigated using sludge from the Meewatura water treatment facility in Kandy, Sri Lanka. (Illangasinghe et al. 2014). Air-dried sludge at the Meewatura sludge drying lagoons was collected and mixed with clay in the proportions of 25:75 and 50:50 percentages, respectively of its volume. To evaluate the quality, the manufactured bricks were tested for dimensions, compressive strength, water absorption, and efflorescence concerning the SLS 39:1978. The results revealed that all of the sets of bricks, including the control sample, exceeded the tolerance limit in terms of dimensions, and the compressive strength was lower than the standard strength. And also, the brick samples were made using the sludge that exceeded the definite water absorption limits. The study concluded that the bricks produced with dried sludge with the above combination with clay could not adhere to anticipated standards.

In 2013, Victoria (2013) had done a similar study in Nigeria, where water treatment sludge was used to supplement clay. The sludge had used in five various mixing ratios of 0%, 5%, 10%, 15%, and 20% of total weight. These bricks were burnt at five different temperatures of 850, 900, 950, 1000, and 1050°C. The research concluded with the findeings that the proportion of sludge in the mixture and the temperature of firing are the two main factors influencing the consistency of the bricks and that the water treatment plant sludge can be used as a replacement for clay in the brick industry to increase its workability and physical appearance by enhancing environmental sustainability.

According to a report on brick making by Hegazy et al. (Hegazy et al. 2011), where water treatment sludge was combined with varying amounts of Silica Fume (SF) and used as a complete substitute for brick clay, the sludge was combined with varying amounts of SF and used as a complete substitute for brick clay. The study aimed to use the sintering process to create a lab-scale brick device constructed from sludge and SF mixtures in various ratios that met Egyptian standard specifications (ESS). For the measured samples, the sludge: silica fume ratios were 25:75, 50:50, and 75:25 percent of the overall weight of the mixture. As a controlled study, 100 percent of clay bricks were also produced. These bricks were burned at temperatures of 900, 1000, 1100, and 1200°C. Using the ESS standard, the physical and mechanical parameters of the bricks were assessed and compared to control samples composed solely of clay. Based on the findings, 50 percent of the optimal sludge was added to the sludge-SF combination by working at a temperature similar to that used in a brick kiln. The produced bricks outperformed the control clay brick in terms of characteristics.

Another similar study had done by Hegazy et al. (2012) in which water treatment sludge was combined with varying amounts of Rice Husk Ash (RHA) and used as a complete substitution for clay. The RHA was one of the most common agricultural wastes in Egypt. RHA contains high amounts of silica. The study's objective was to provide an environmentally friendly way to reuse water treatment sludge and rice husk ash. The samples considered in the study were in the following ratios of sludge: rice husk; 25: 75, 50: 50, 75: 25 percentages of the total weight of the mixture. And 100 percent of clay bricks were also made as to the control sample. Then they were fired at 900, 1000, 1100, and 1200°C. The properties of the produced bricks were determined and evaluated according to ESS standards and compared with control samples made entirely from clay. It was concluded from the results obtained that, by operating at the temperature commonly practiced in the brick kiln, 75 percent was the optimum sludge addition to produce brick from sludge: RHA mixture.

The whole substitution of brick clay with water treatment sludge combined with different ratios of RHA and SF was examined by Hegazy et al. (2012) in Egypt. The SF is a byproduct of producing silicon metal or ferrosilicon alloys in smelters using an electric arc furnace. Three different series of sludge: SF: RHA ratios of 25:50:25, 50:25:25, and 25:25:50 percentages of the total weight of the mixture were prepared. And 100 percent of clay bricks were also prepared as the control sample. Every four series of bricks were burnt at temperatures of 900, 1000, 1100, and 1200°C. It was concluded from the results obtained that, by operating at the temperature commonly practiced, a mixture consisting of 50:25:25 of WTP sludge:SF:RHA was the optimum sludge addition to produce brick.

A study was done by Ramadan et al. (2008) in Egypt, where water treatment sludge was used as a partial substitute for clay. The samples were considered with the following sludge: clay ratios; 50:50, 60:40, 70:30, and 80:20 percentages of the total weight of the sludge clay mixture. These bricks were burnt at temperatures of 950, 1000, 1050, and 1100°C. The study concluded that 50 percent was the optimum sludge addition to produce brick from sludge; clay mixture operating at the temperature commonly practiced in the brick kiln.

To improve efficiency, some water treatment plants switched from conventional alum to poly aluminum chloride (PAC) as a coagulant (Nansubuga et al. 2013). PAC is increasingly preferred as lower alkalinity consumption as well as its lower dose requirement. From a chemical point of view, PAC is similar to alum, except that it contains highly charged polymeric aluminum species as well as monomers. The solubility characteristics of PACs and alum are different such as PACs are more soluble and have a higher pH of minimum solubility than alum, making PAC the preferred coagulant nowadays.

Several studies have already given insight into the reuse of alum sludge (Huang & Wang 2013, Kizinievičet al. 2013, Victoria 2013, Tay 1987), but many water treatment plants are now adopting PAC, whose sludge characteristics differ from alum sludge. It is, therefore, necessary to study the possibility of reuse of sludge derived from water treatment where PAC is used. This study focuses on the possibility of using PAC water treatment sludge as brick material. The sludge for this study was collected from the Konduwattuvana water treatment plant (KWTP), Ampara, Sri Lanka, which runs under the National Water Supply and Drainage Board (NWSDB) Sri Lanka. The main coagulant used in this plant for the treatment process is PAC. Analyzing and determining bricks' properties were conducted according to the Sri Lankan Standard (SLS) of 39:1978, which defines the specifications for common burnt clay building bricks in Sri Lanka.

MATERIALS AND METHODS

This research aims to determine the aluminum content in the sludge produced in the KWTP through conducting laboratory tests and to examine the possibility of sludge being used as a construction material as clay brick.

Aluminum Test

The aluminum test was carried out for two sludge samples to check whether they satisfy the Industrial wastewater tolerance limit set by the Central Environmental Authority (CEA) of Sri Lanka to be discharged into inland surface water. The sludge samples in two different places were collected in 200 ml sample bottles at KWTP and safely taken to the energy laboratory of the Faculty of Technology, the University of Sri Jayewardenepura for sample preparation.

Water treatment sludge samples were prepared at the energy laboratory of the Faculty of Technology, University of Sri Jayewardenepura, to test the aluminum content. Then the prepared samples were given to the Instrument Center of Faculty of Applied Sciences, University of Sri Jayewardenepura.

As the first step, the water treatment sludge samples were digested with nitric acid to comply with EPA recommendations (Agoro et al. 2020, Feizi et al. 2019). A sample of 2 g of already treated water sludge sample was put in a conical flask containing 20 mL of HNO_3 (55 percent) and heated at 90°C for 45 minutes.

Then the temperature was then raised to 150ºC and kept for about 10 minutes. The periodic addition of 10 mL of HNO_3 (55%) when heating the sample mixture was made three times to avoid dryness. Once the mixture is cool to room temperature, it was filtered through Whatman Number 1 filter paper. The digested sample was then moved into a 100 mL standard flask and made up to the mark with double distilled water as required.

The water treatment sludge samples prepared at the energy laboratory of the Faculty of Technology, University of Sri Jayewardenepura, were taken to the Instrument Center of Faculty of Applied Sciences, the University of Sri Jayewardenepura to test the aluminum level in the samples. The aluminum was measured using a deuterium lamp in flame mode by AAS (iCE 3000 AA05121002 v1.30 spectrophotometer), and results were obtained.

Brick Manufacturing

For this study, the sludge was obtained from the sludge drying bed of KWTP, Ampara, in a gunny bag and transported to the local brick manufacturing site. The sludge collected was air-dried for more than 14 days in the sludge drying bed. The local commercial clay procured from a selected local brick company in Attappalam, Nintavur, Ampara was used in this study to mix with the sludge. Although the sludge had been dried, both the sludge and the clay were air-dried for 24 h at the brickyard, as per the manufacturer's standard process. As the batching method, the total weight of the mixture was used for mixing the sludge and clay to produce the bricks with the size of 220 mm in length, 105 mm in width, and 65 mm high as per the Sri Lankan standard of SLS 39:1978. Table 1 shows the percentage of sludge used as a supplement for clay. 100% of clay bricks were also prepared as the control sample. A total of 70 bricks were produced by having ten separate bricks in each mixing ratio.

The sludge and clay samples were measured and spread evenly, and then thoroughly mixed until a homogeneous mix with uniform color was obtained. The mixing took place on a clean, non-hazardous surface. The water was added gradually to the dry mixture while mixing until optimum moisture content was obtained.

The hand mold method with the wooden mold with five bricks casting at once with the size of 205 mm x 88 mm x 65 mm was used for brick casting. The inner faces of the wooden mold were lubricated with water for easy removal and to get a smooth surface. The mixture was placed in a mold and compressed. The remaining mixture was scraped down, and the surface was smoothed. Six sludge-clay bricks and six control bricks containing only clay were made as reference specimens, with each brick being marked and numbered for easy identification.

Casted bricks were stacked at the site for 10 days for air drying and the regular batch and loaded to the kiln for burning by operating at the temperature generally practiced in the brick kiln. After finished burning, the bricks were cooled and transported to the South Eastern University of Sri Lanka for testing.

Table 1: Group of composition sludge-clay mixture.

	Sample No	Sludge Percentage [%]	Clay Percentage [%]
Control Brick	1	0	100
Sludge-Clay Brick	2	2	98
	3	4	96
	4	6	94
	5	10	90
	6	15	85
	7	20	80

Analyzing and Determining the Properties of Bricks

All the tests were conducted in accordance with the Sri Lankan Standard of 39:1978, a specification for common burnt clay building bricks. All four parameters stated in the specification, like dimensions, water absorption, compressive strength, and efflorescence, were tested to evaluate the quality of bricks.

Dimension Test

All ten bricks (10) were selected from each sample and grouped. The overall dimension was measured by placing each set of samples of 10 bricks lined up in a straight line upon a smooth surface, and any small projections or loose particles of clay adhering to each brick blisters were removed. The overall dimension (length, width, high) of each set of samples was measured to the nearest millimeter using steel tape.

Water Absorption Test

Three random bricks (3) out of 10 for each sample were selected and dried thoroughly in an oven at a temperature between 100°C to 115°C and then let to cool to room temperature and weighed separately, and the dry weight (W_d) was noted. The dry bricks were fully immersed in cold water at room temperature for 24 h. Then each brick was removed from the water, excess surface water was wiped off with a damp cloth and weighed separately, and the wet weight (W_w) was noted. The water absorption percentage (W_a) of each brick was calculated using Equation 1. The average of these three bricks was taken as the water absorption capacity for the bricks of a sample.

Water absorption percentage,

$$Wa = (W_w - W_d)/W_d \times 100\% \qquad \ldots(1)$$

Efflorescence Test

Typical clay bricks may include some alkaline components, and the higher the quantity, the greater the risk of efflorescence, which appears as fine whitish layers as deposits on the brick surfaces. They are difficult to handle and can lead to other long-term issues in the structure, particularly cosmetic issues.

So, to determine that three random bricks (3) out of 10 for each sample were selected and placed in a shallow flat bottom dish, distilled water was poured into the depth of 25 mm as at least one inch of the bricks must be underwater. Then it was placed in a well-ventilated space at room temperature until all the water in the dish evaporates. When the water had been absorbed, and bricks appeared dry, a similar quantity of water was poured into the dish and allowed to evaporate as before. Then the bricks were examined for efflorescence.

Compressive Strength Test

Three random bricks (3) out of 10 for each sample were selected. The overall dimension of each bed surface was measured, and area (A) was calculated. Then bricks were immersed in water for 72 h at room temperature. After 72 h, bricks were removed from the water and allowed to drain at room temperature, and surplus moisture was wiped.

Then, sample brick was placed between two similar plywood sheets and carefully centered between the compressive strength test machine (MATEST- 3000kN Compression Testing Machine). Then the load was applied axially and uniformly to the brick until it failed. Then the maximum load (F_{max}) at failure was noted. Then the compressive strength of the brick was calculated from Equation 2. The average of the three readings was calculated and taken as the compressive strength of the bricks of a sample.

Compressive strength of brick,

$$Compressive\ strength = F_{max}/A \qquad \ldots(2)$$

RESULTS AND DISCUSSION

Aluminum Test

Table 2 shows the summary of the results obtained from the test. The Aluminum contents of both sludge before and after were found to be approximately 232 $mg.L^{-1}$ and 55 $mg.L^{-1}$, which can be acceptable since they are using an Aluminum-based coagulant to treat raw water. This result confirms the doubt that was present before conducting the test that 'Aluminum content may be higher in the sludge produced.' Therefore, it was concluded that the sludge contains Aluminum in it and it should be minimized before disposal.

Dimension Test

The average individual and cumulative dimension test results of each proportion of sludge mixture are given in Tables 3 and 4. Fig. 1 and 2 show the trends of average individual and cumulative dimensions. Both Fig. 1 and 2 clearly show that the bricks' dimension decreases with the increase of sludge content.

Table 2: Aluminum contents of water sludge

Sample Name	Results obtained [$mg.L^{-1}$]
Sludge before centrifuge (Sludge holding tank)	231.6
Sludge after centrifuge (Sludge cake)	54.9

Water Absorption Test

The water absorption test results for different proportions of sludge mixture in Table5 and its trend is shown in Fig. 3.

It shows that the water absorption for the bricks increases with the increased sludge content. Water absorption is a key factor that affects the durability of bricks. Hence the lesser amount of water infiltrated into the brick makes the brick more durable.

Efflorescence Test

Normally salts like Na, K, $CaCl_2$, Sulphates, etc., may be present in typical clay brick.

Efflorescence is a fine whitish layer of salt deposition on the surfaces of bricks where water dissolves salt and moves them to the surface of the brick. They can lead to some potential moisture problems that can cause structural damage to building materials esthetic problems in a structure. The

Table 3: Average individual dimensions of each sample.

Sample No	Sludge: Clay Ratio [%]	Length [mm]	Width [mm]	Height [mm]
SLS 39: 1978 Requirement (1 Brick):		220	105	65
1	0: 100	193	83	60
2	2: 98	190	81	57
3	4: 96	188	81	62
4	6: 64	187	80	60
5	10: 90	186	79	59
6	15: 85	184	79	59
7	20: 80	181	77	56

Table 4: Average cumulative dimension of 10 bricks of each sample.

Sample No	Sludge: Clay Ratio [%]	Length [mm]	Width [mm]	Height [mm]
SLS 39: 1978 Requirement (10 Bricks):		2200 ± 30	1050 ± 17	650 ± 17
1	0: 100	1944	837	609
2	2: 98	1906	818	584
3	4: 96	1891	818	631
4	6: 64	1879	812	611
5	10: 90	1874	803	599
6	15: 85	1855	798	597
7	20: 80	1823	776	565

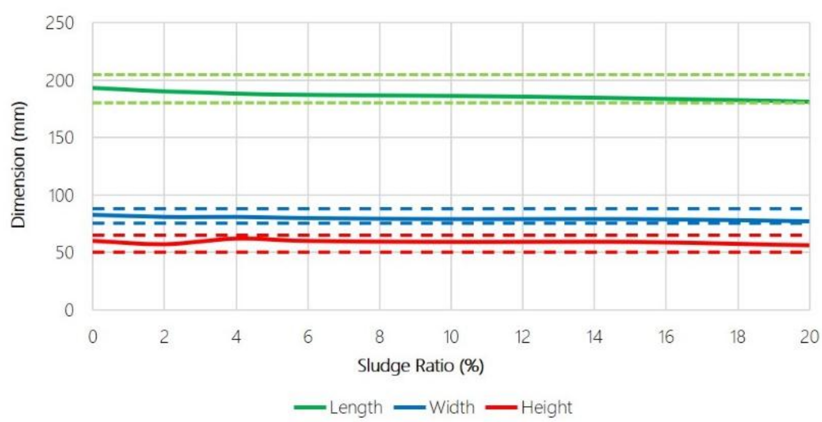

Fig.1: Trend of avg. individual dimension of bricks with different sludge ratios.

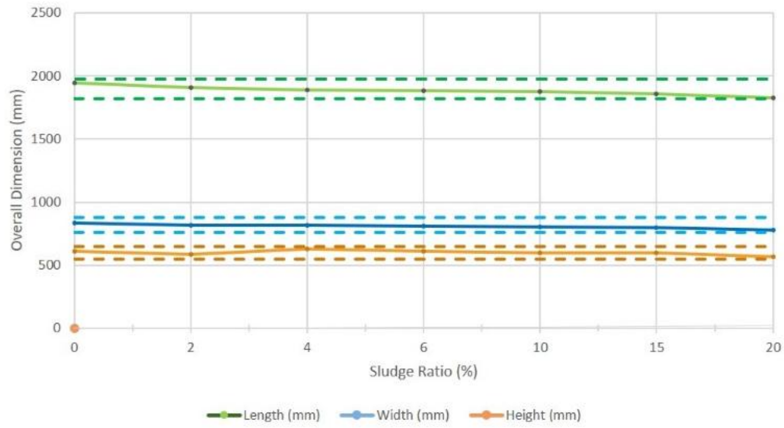

Fig. 2: Trend of avg. cumulative dimension of 10 bricks with different sludge ratios.

summary of the efflorescence test results is shown in Table 6, and from this, it can be shown that all the brick samples satisfy the minimum requirement of efflorescence stated in the SLS 39: 1978 standard.

Compressive Strength Test

Table 7 shows that the compressive strength is greatly dependent on the amount of sludge in the brick. Fig. 4 shows the trend of compressive strength with different sludge portions. The strength of brick decreases with the increased sludge content. The average compressive strength of the control sample is 5.20 $N.mm^{-2}$. The average compressive strength of WTP sludge clay brick is varied between 3.70 and 1.65 $N.mm^{-2}$. With the addition of 10% sludge to clay, the sludge clay brick strength met the minimum requirement of 2.8 $N.mm^{-2}$ (SLS 39:1978) as building brick.

Table 5: Avg. water absorption percentage of brick samples.

Sample No	Sludge: Clay Ratio [%]	Avg. Water Absorption [%]
SLS 39: 1978 Requirement (Type 2, Grade II):		< 28
1	0: 100	13.50
2	2: 98	13.27
3	4: 96	14.98
4	6: 94	15.01
5	10: 90	16.71
6	15: 85	19.00
7	20: 80	19.87

Fig. 3: Trend of water absorption percentage of different sludge ratios.

CONCLUSION

Under the settings and manufacturing methods utilized in this study, sludge produced at the Konduwattuvana water treatment plant was successfully used as a successful substitute in the manufacture of burnt clay construction bricks, which is environmentally sustainable and useful. The aluminum content in the sludge was measured using a deuterium lamp in flame mode by AAS (iCE 3000 AA05121002 v1.30 spectrophotometer). The Aluminum content in the thickened liquid sludge was 231.6 mg/L. The Aluminum content in the solid sludge cake was 54.9 $mg.L^{-1}$ which denotes that the sludge containing aluminum in it should be minimized. Dimension, water absorption, efflorescence, and compressive strength of the brick were all investigated. When the sludge percentage was increased, the overall dimensions of the brick shrank. With the increase in sludge percentage, the water absorption percentage of bricks increased. The efflorescence of the bricks, on the other hand, was satisfactory in comparison to the standard. At the same time, when the sludge ratio increased, the compressive strength of the bricks declined. Finally, it was determined that a 10% sludge addition to the total weight of a brick is the best sludge ratio for producing burnt clay brick from a sludge-clay mixture when the kiln is operated at the normal temperature. It can also be concluded that the amount of aluminum content in the sludge does not affect the quality of the brick. Therefore, water treatment plant sludge can be considered a suitable raw material for the brick manufacturing industry while providing a sustainable sludge handling method.

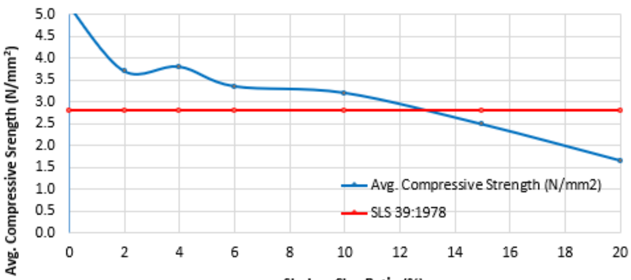

Fig.4: Trend of avg. compressive strength for bricks.

Table 6: Efflorescence test results of brick samples.

Sample No	Sludge: Clay Ratio [%]	Efflorescence Result
SLS 39: 1978 Requirement (Type 2, Grade II):		Moderate
1	0: 100	Slight
2	2: 98	Slight
3	4: 96	Slight
4	6: 64	Slight
5	10: 90	Slight
6	15: 85	Nil
7	20: 80	Slight

Table 7: Average compressive strength of brick samples.

Sample No	Sludge: Clay Ratio [%]	Avg. Compressive Strength [$N.mm^{-2}$]
SLS 39: 1978 Requirement (Type 2, Grade II):		2.8
1	0: 100	5.20
2	2: 98	3.70
3	4: 96	3.80
4	6: 64	3.35
5	10: 90	3.20
6	15: 85	2.48
7	20: 80	1.65

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