Uso productivo de lodos de plantas de tratamiento de agua potable en la fabricación de ladrillos cerámicos

Productive use of sludge from a drinking water treatment plant for manufacturing ceramic bricks

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Resumen

Uno de los problemas más importantes en el tratamiento de agua con coagulación química es la generación de lodos, cuya disposición final es predominantemente en cuerpos de agua, afectando su calidad y usos potenciales; el uso productivo de lodos puede ayudar en la recuperación de los recursos naturales y disminuir la contaminación ambiental. En este estudio se evaluó el uso de lodo aluminoso en la fabricación de ladrillos cerámicos; los resultados muestran que es viable incorporar estos lodos en reemplazo parcial de uno de los materiales constitutivos del ladrillo, en este caso la arena en un porcentaje del 10%; sin embargo, para evitar comprometer la resistencia a la compresión debe optimizarse la deshidratación previa del lodo para aumentar el potencial de aprovechamiento. El ladrillo obtenido cumple características adecuadas para uso no estructural.

Palabras Clave: Absorción de agua, deshidratación de lodos, ladrillos cerámicos, lodos aluminosos, resistencia a la compresión.

Abstract

One of the most important problems for water treatment systems based on chemical coagulation process is the sludge generation, whose final disposition is made predominantly onto water, affecting their quality and potential uses. The productive use of this sludges represents a way to relieve some of the problems of solid waste management that helps in the recovery of natural resources and reduces the environmental pollution. This study allowed the evaluation of the use of aluminous sludge for the manufacture of ceramic bricks. The results show that it is feasible to use these sludges in partial replacement of one of the constituent materials of brick, in this case the sand in percentages above 10%; however, to avoid compromising the compression resistance it should be optimized the previous sludge dewatering to increase the potential waste-to-energy scheme. The brick obtained has appropriate characteristics for non-structural use.

Keywords: Aluminous sludge, ceramic bricks, compression resistance, dewatering sludge, water absorption

1. Introducción

The sludge management generated in the treatment processes at a water treatment plant (WTP), with chemical coagulation, significantly affects the treated water production costs, which are directly related with the type and amount of coagulants employed. Coagulants vary between 0.3 and 1% of treated water volume (Sandoval et al., 2008) and they have a high content of humidity and mechanical dewatering resistance, which are accentuated as long as higher coagulant dosages are employed (Sandoval et al., 2008; Knocke and Walkeland, 1983).

In conventional systems, the settlement process produces between 60 and 70% of total solids (Arboleda, 2000); because of their physical, chemical and microbiological nature. Solids' non-treated disposition impacts water bodies, soils and produces risks for human health (Taylor, 1989; George et al., 1991; Kagga et al., 2001; Novaes et al., 2003).

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Although there had been experiences applied on farming soils (Zhao and Bache, 2001; Franco and Salvador, 2004), such sludge is not considered as an optimal material because of its poor nutrients level, thus its use has been basically restricted for forestry activities (Grabarek and Krug, 1987; Scambillis, 1997) and the recovery of deteriorated soils, abandoned mine sites and quarries (Geertsema et al., 1994). The potential use of aluminum recovery demonstrates that by reducing pH by means of sulfuric acid, a recovery of about 65 to 75% is achieved (Bishop et al., 1987; Rosero, 1998; Lin and Lo, 1998; Franco and Salvador, 2004).

In the construction sector sludge is used for manufacturing Portland cement (Wang et al., 1998; Mangialardi, 2001), clinker (Geertsema et al., 1994) and for ceramic bricks production (Mejia and Delvasto, 1998; Nuvalori, 2002; Guimarães and Morita, 2003; Andreoli, 2005 and Hernández, 2006). By partially replacing one component material by sludge may lead to important benefits such as a safe potentially-dangerous-residues environmental disposition; water pollution reduction caused by its disposal; lower energy, transportation and manufacture costs; lower natural resources use; reduction of existing vegetation compromised in clay extraction process (main brick component); thus increasing quarries' life span and possibly reducing costs of replacing native vegetation (Novaes et al., 2003; De Araújo et al., 2005).

Ceramic brick is an essential element in the construction sector. Although bricks are small and simple pieces, their elaboration takes a long and complex process. Raw materials correspond to flux and structural materials such as clay and sand, respectively. They shall fit and endure casting, drying and firing processes. Finally, they undergo a normalization process according to standard regulations, which include variables such as compression resistance and water absorption (CAP, 2012).

Application studies on aluminous sludge for ceramic bricks elaboration indicate the need of evaluating humidity content, particle size, plasticity and mineralogical decomposition that determine the behavior of critical variables, such as compression resistance and water absorption. Best results were achieved by using a sludge percentage of 10% approximately (Nuvalori, 2002; Hernández, 2006) and previously reducing humidity content, which should be optimized in each case.

In Colombia ceramic brick manufacture usually employs red clays, black clays and river clays depending on geological characteristics of the site where quarries are located, thus showing a variation on material composition, which directly affects the units' resistance and absorption (CAP, 2012). The present study evaluated the productive use of aluminous sludge coming from sedimentary units in a WTP for ceramic bricks elaboration.

2. Discussion and development

2.1 Experimental Stage

2.1.1 Characteristics of sludge and component materials of ceramic bricks

The study was conducted at a conventional WTP using aluminum sulfate coagulation, flocculation, sedimentation, filtering, disinfection and pH fitting out, with a volume flow of 600L/sec. Sludge resulted from washing and dumping sedimentary units, which were subjected to a sedimentary process during a 24-hour period. Afterwards they were dewatered on sand drying beds during 48 hours to reduce humidity and they were characterized in terms of mineralogical decomposition by x-ray diffraction (after 24-hour drying process at 105°C); particle size was determined by means of a hydrometer and, plasticity by using Atterberg's limits.

Sludge mineralogical characteristics were compared to bricks' component materials in the study field (red clay – 40 to 60%; black clay – 20 to 30%, sand – 20 to 30%) to select the material with the most similar characteristics so as to partially replace it by aluminous sludge.

2.1.2 Elaboration of experimental units

Specimens of 4 x 4 x 8 cm were employed; for the statistical analysis a unifactorial Complete Randomized Block Design (DBCA) was used (percentage of sand replaced by sludge). For the validation process the Kolmogorov – Smirnov, Durbin–Watson and Levene's tests were applied to check assumed normality, inter-correlation, homoscedasticity of the respective residues—(Kuehl, 2001; Montgomery, 2002). The percentages of red clay and black clay kept their constant level (50 and 25%, respectively). Sludge samples were taken, which are typical in winter season (rainy periods) and summer season (dry period) by executing ten repetitions per sample. Table 1 shows the sand and aluminous sludge evaluated percentages.

Table 1. Levels and Factors according to Sand Percentage to be replaced by Aluminous Sludge*

Niveles/Levels	% Arena reemplazar por lodo aluminoso <i>Sand percentage to be replaced by aluminous sludge</i>	Arena/Sand (%)	Lodo alum (%) <i>Alum sludge</i>
1	0	25	0
2	10	22,5	2,5
3	20	20	5
4	30	17,5	7,5
5	40	15	10
6	100	0	25

*El porcentaje de arcilla roja y negra se mantuvieron constantes (50 y 25% respectivamente)

*The percentages of red clay and black clay kept their constant level (50 and 25%, respectively)

For specimens' humidity, a 20% final mass was ensured. They were casted and dried at room temperature during 6 days. Afterwards they were dried by a muffle furnace thus increasing temperature at 100°C per hour, until achieving 700°C and, then directly rising up to 900°C during 6 hours. Cooling was executed by means of an inverse dynamic to heating. The response variables were compression resistance and water absorption (ICONTEC, 2003).

2.2 Results and Discussion

2.2.1 Characteristics of sludge and component materials of ceramic bricks

Washing and dumping sedimentary units generate the highest amount of sludge (90.1% in total); having a 99.77% of humidity, which typical aluminous sludge value is 73 to 99% (Espejel et al., 2008). The applied conditioning process enabled a humidity reduction down to 72.69%, which is the closest value to the one achieved by Reynolds and Richards, (1995), Guimarães and Morita, (2003). They were able to obtain concentrations between 29 and 30% by applying natural dewatering methods. For incorporation into the clay mass purposes, humidity values from 55% (Guimarães and Morita, 2003; Andreoli, 2004) up to 100% (Nuvalori, 2002) are reported.

In regards to mineralogical composition, Figures 1 to 3 show diffraction of aluminous sludge compared to red clay, black clay and sand clay diffraction, respectively.

Figure 1. Mineralogical comparison of aluminous sludge to red clay

Figure 2. Mineralogical comparison of aluminous sludge to black clay

Figure 3. Mineralogical comparison of aluminous sludge to sand

The granulometric analysis sludge showed a high quartz content in regards to the other elements, as well as the absence of silicates and low kaolin content. The presence of quartz might be associated to materiales swept by the treatment system, which is typical from the region (De Araújo et al., 2005). Aluminous sludge analysis from a sedimentary unit, at a WTP in Brazil, also showed a low kaolin content (Nuvalori, 2002). Studies reported by Mejía and Delvasto (1998) and Guimarães and Morita (2003) in Colombia and Brazil, respectively, show similar mineralogical compositions to the ones found in the evaluated aluminous sludge. Being sand the element that has the closest similarity to aluminous sludge.

Sieve analysis showed that solid particles comprised in sludge are fine and small particles; the 55% has a size lower than 0.025mm, where lime is predominant over clays. Guimarães and Morita (2003) reported that 70% of sludge particles have diameters between 0.002 and 0.20 mm. Mejía and Delvasto (1998) reported sizes between 0.040 and 0.060 mm. According to Pracidelli and Melchiades (1997), ceramic bricks must have from 20 to 30% of particles, which diameter must be lower than 0.002 mm; from 20 to 50% between 0.002 and 0.020 mm and; from 20 to 50% higher than 0.020mm. In accordance with these values, aluminous sludge is adequate for its potential incorporation in ceramic bricks manufacture.

Sludge Atterberg's limit showed a Liquid Limit (L.L) of 78.2%, a Plastic Limit (P.L) of 74% and a Plasticity Index (PI) of 4.2%. Taking into account that the latter is lower than 7, sludge is regarded as a poorly plastic material and partially cohesive material, which characteristics are typical from sand. In general mineralogical composition, grain size distribution and Atterberg's limit show that sand is the brick component material that has the closest similarity to aluminous sludge. Therefore, the evaluation for replacing sand by aluminous sludge it is considered appropriate.

2.2.2 Effects from replacing sand by aluminous sludge

ICONTEC (2003) states physical properties for masonry units made up from fired clay; bricks and ceramic blocks for structural and non-structural use (minimal resistance 150 to 100 kg/cm² respectively; water absorption between 14 and 16% and 14 and 20% for outer and inner use, respectively). It also considers that not fulfilling compression resistance and absorption as the primary and secondary defects, respectively. In control units (0% sand replaced by sludge), the obtained values would rate the constructed blocks as suitable for non-structural use. However, the Spanish regulation (AECOM, 2005) and Brazilian regulation (ABNT, 1992) establish less than 100 kg/cm² for compression resistance at 16% and absorption between 8 and 25%, respectively, which indicates that control blocks meet the requirements. Figure 4 shows the response variables behavior in function of sand percentage replaced by sludge.

Figura 4. Dispersión Resistencia media a la compresión y Absorción de agua
Figure 4. Dispersion of Average Compression Resistance and Water Absorption

The first aspect to be highlighted on above figure is the high dispersion of experimental units containing sludge compared to blocks not containing sludge (0% sand replaced by sludge). This behavior may be caused due to the differences of aluminum sulfate dosages, which are increased during winter season thus leading to higher amounts of aluminum hydroxides contained in the sludge, which increases its alumina content (Al_2O_3). According to studies developed by Chen-Feng and Yung-Chao (1994), Salvini et al. (2001) and Stamenković et al. (1977) above would lead to more resistant final products.

CAP (2012) states that alumina content of 20 to 30% provides clay plasticity, but exceeding such percentages may lead to high contractions during ceramic bricks' dry process. Such studies suggest the need to define adequate ranges of alumina concentration in aluminous sludge to increase its use in the elaboration of ceramic bricks. The figure also shows a downwards trend of compression resistance and water absorption as long as sludge percentage was increased. Table 2 Summary for variance analysis and assumptions validation

Table 2. Summary for variance analysis and assumptions validation DCA

Prueba/ Test	Resistencia media a la compresión/ Average Compression Resistance	Absorción de humedad/ Water Absorption
Transformación/ Transformation	Y	log(Y)/ log(Y)
Análisis de Varianza/ Variance analysis		
Valor p/ p Value	0.045	1.967E-13
R ² (%)	19.73	78.02
Coef. Var (%) / Var Coeff. (%)	29.87	3.03
Validación de Supuestos/ Assumptions validation		
Kolmogorov - Smirnov	0.846	0.759
Levene	0.097	0.023
Durbin-Watson	0.994	0.000

In the model applied to average compression resistance, it was found that at least one of evaluated percentages has a statistically different effect (p value $0.045 < 0.05$). Assumption validation tests show that there is no evidence demonstrating that the model is inappropriate. The post-ANOVAs test on Honestly Significant Differences developed by Tukey, under 5% significance, indicates that only a 100% replacement leads to a compression resistance statistically lower compared to samples with 0% replacement.

On the other hand, it was discovered that the percentage of sand replaced by aluminous sludge has a statistically significant effect on water absorption. However, the employed model is inappropriate to conduct such calculations, since variance homogeneity assumptions and the errors correlation were not satisfactorily validated (values $p < 0.05$); which lead us to employ a non-parametric test developed by Kruskal – Wallis, thus finding a p value equal to $8.79e-08$, which indicates that sand percentage replaced by sludge significantly affects water absorption on the experimental specimens. By employing multiple contrast media, we can conclude that 100% replacement maximizes absorption while percentages from 10 to 10% minimize it. Similarly percentages between 30% and 40% do not represent significant differences between them, but they do have a higher effect on absorption than the one achieved by a 20% replacement.

In general, although the only percentage showing significant differences is 100% replacement, since sludge incorporation increase generates an upwards trend in terms of water absorption and downwards in terms of compression resistance, the most appropriate sludge percentage to be incorporated in ceramic bricks elaboration would be 10%.

Specimens that replaced percentages equally or higher than 40%, turned out to be darker after the sixth drying-process day (before firing), which indicates a lower humidity loss, possibly due to hygroscopic characteristics of aluminous sludge, which delay drying process; thus suggesting that for applying this alternative at full scale, it is recommended to increase drying period before firing or to increase sludge's humidity reduction before incorporating it to ceramic bricks elaboration. Chen-Feng and Yung-Chao (1994) evidenced that, in spite of the fact aluminous sludge has a high compressibility, it also retains humidity. Stamenković et al. (1977) indicate that sludge compressibility produces an independent filtered flow of applied pressure, thus confirming one of the characteristics reported by Chen-Feng and Yung-Chao (1994), Kaggwa et al. (2001) and Salvini et al. (2001) as far as the high mechanical dewatering resistance endured by aluminous sludge is concerned.

Andreolli (2004) obtained compressive resistances between 80 and 100 kg/cm² by incorporating 4.17% of aluminous sludge to ceramic bricks, with 55% humidity. Nuvalori (2002) achieved a 250 kg/cm² compression resistance by adding 10% of sludge and 250 kg/cm² by adding 20, 30 and 40%. However, sludge was totally dewatered before adding it to the clay mass. Guimarães and Morita (2003) quoted that it is possible to mix up to 90% of aluminous sludge with only 10% of clay, as long as sludge is completely dewatered. With 40% humidity, it would be possible to add 45% of sludge; and with 75% humidity it would only be possible to add 10% of sludge. Although in this study specimens were elaborated by incorporating red clay, black clay and sand; a high appropriated sand replacement percentage of about 10% was also achieved for sludge humidity of 73% approximately.

Espejel et al. (2008) found a 29% of humidity absorption in the ceramic experimental units elaborated with 50% of purification sludge and they confirmed the bricks' porosity increase when employing aluminous sludge as aggregate. So as to minimize these negative impacts, which might reduce compression resistance and increase humidity content, Zhao (2002) highlighted the need of counting with physical conditioners to obtain a stiffer structure. Benitez et al (1994), Moehle (1967) and Zouboulis and Guitonas (1995) quote materials such as incinerator ashes, cement, limestone, hydrated lime, fine coal, bagasse, wooden chips and wheat residues to optimize aluminous sludge dewatering.

3. Conclusions and Recommendations

Mineralogical composition, granulometric analysis and Atterberg's Limit for sludge coming from the stage of sedimentation processes on purifying water with aluminum sulfate, show that among component materials of the evaluated brick (red clay, black clay and sand) the sand is closely similar to sludge, thus suggesting its potential and partial replacement.

The dosage of aluminum sulfate for purifying processes associated to raw water characteristics (summer and winter conditions), influences the sedimented sludge features, which can affect its characteristics as far as its potential use for ceramic bricks elaboration is concerned, because such dosage affects compression resistance and water absorption.

Although a preliminary sludge conditioning, (consisting of a 24-hour sedimentation process and a dewatering process on drying beds during 48 hours) enabled the reduction of humidity content down to 72.69 %; more effective dewatering techniques shall be explored so as to significantly reduce sludge humidity and increase its potential by partially replacing sand. This could reduce units' porosity, without affecting compression resistance.

Results show that a sand replacement by 10% of sludge can be considered as an appropriate percentage for ceramic bricks elaboration, since higher values significantly affect water absorption and mainly compression resistance. Such implementation would lead to lower production costs, besides minimizing environmental impacts due to sludge disposal onto water bodies as it uses to occur nowadays.

It is recommended to continue exploring this alternative to define optimum conditions for the addition of aluminous sludge on the elaboration of ceramic bricks.

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