Drinking water treatment sludge as a partial substitute for clays in non-structural brick production

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Abstract. The sludge as by-products of the water treatment is composed of particles of sand, silt and clay, colloidal organic matter and chemical substances that have been added to the water source during the treatment processes, this has aroused interest in its study as an economic and sustainable alternative in the making of non-structural and ornamental materials, among others. This research was carried out in a water treatment plant in the municipality of Ocaña, Colombia, which does not have a system for the adequate treatment and final disposal of the sludge generated, resulting in the discharge of this waste directly into the body of water, Algodonal river. Sampling of the sludge was taken from the plant for the analysis of its physical properties; subsequently, bricks with different mixing ratios are made and subjected to resistance tests according to national and international standards. It was found that the sludge generated in the sedimentation tank of the water treatment plant has a potential for the manufacture of non-structural brick, taking into account that the results of the tests showed similar or superior properties in comparison with a commercial brick produced in the region.

1. Introduction
The generation of sludge in a drinking water treatment plant (WTP) is a by-product of the coagulation process, mainly with aluminum sulfate or ferric compounds, which makes the sediment considered as residual waste. Both the quality and quantity of treated water, as well as the type and dose of chemical agents used are factors that affect the quantity, composition, and properties of sludge [1,2]. This sludge as by-products of drinking water treatment comprises particles of sand, silt and clay, colloidal organic matter and chemical substances (geopolymers) that have been added to the water source during the treatment processes [3,4].

Recently, these wastes have been heavily studied as raw material in the production of green building materials [5,6] and have been widely suggested as an economical and sustainable alternative in different applications such as in the manufacture of cement, in the military and aeronautical field; in high-tech ceramic materials such as thermal insulators, fire-resistant, protective coatings, refractory adhesives and inorganic hybrids [7,8].

Different investigations have been carried out in the world on the use of new materials for the manufacture of bricks, generating new materials specifically in the area of construction, with the objective of minimizing the costs, creating innovative alternatives that positively impact the
constructions of tomorrow [9]. In the case of Colombia, the information published on experiences of reuse and treatment of sludge from WTP, in many cases, is insufficient [10].

The use of waste materials from a WTP as a possible replacement of clay in brick production is a promising strategy for manufacturing an environmentally friendly building material that favors cleaner production practices [11]. To take advantage of the aluminous or ferrous sludge in the manufacturing of bricks, it is necessary to evaluate physical properties such as particle size, plasticity and mineralogical composition, which determine the behaviors of compressive strength and absorption [12,13].

Solid bricks are made in a series of processes that include mixing preparation, molding, and cooking. The preparation consists of a mixture of the material with specific percentages of sand and clay. In molding, enough water is added to the material to produce the plasticity necessary to obtain the desired shape; taking into account that this type of sludge has characteristics of plasticity similar to clay, the alternative of its implementation as an alternative material in the manufacture of bricks was considered. This investigation was carried out in a WTP of the municipality of Ocaña, which, does not have a system of treatment and/or adequate final disposal of sludge, the waste is discharged directly to the body of water of the Algodonal river without a prior process that guarantees the minimal impact to the aquatic ecosystem. This situation has aroused great interest because the Algodonal river is one of the main sources of water for the municipality of Ocaña and its surroundings.

2. Methodology
A quantitative methodology with an experimental descriptive approach was used for this study. The mixing ratios that were used and the mechanical characterization of the specimens were defined, taking into account their compressive strength and in this way evaluate the mixture with the best behavior.

Sampling was carried out in the summer and winter times within appropriate periods for sampling, which is relevant in the impact on ecosystems since in wintertime the concentration of sludge parameters is higher, although in summertime a breach of parameters is perceived in some maximum permissible limits. In order to make the brick, the sample was homogenized by means of a mechanical mill and dosed according to the mixtures initially established where the amount of clay, mud, and sand was taken into account. The materials were mixed homogeneously and water was added until a suitable, smooth and cohesive texture was obtained.

The bricks were made according to the method of an artisanal brick workshop in the municipality. Once the appropriate mixing conditions were obtained it was introduced into a mold to give the necessary dimensions to the brick, the mold was removed to let it dry in the sun for a week, turning periodically to allow even drying, then they were introduced to the artisanal oven for a week. Once the drying and firing process was finished, the bricks were left at room temperature for three days giving as a final product a solid brick.

Table 1 presents the data related to the type of test, method, and standard implemented in the investigation, this in order to perform the physical-mechanical characterization of the sludge and artisanal brick according to the corresponding technical standards of the country.

| Table 1. Physical tests performed on the sludge sample. |  |
| --- | --- |
| Test | Standards |
| Laboratory determination of moisture content in samples of soil, rock and soil-aggregate mixtures | ASTM D 2216-10 [14] |
| Granulometric analysis of soils by sieving | I.N.V. E -123 [15] |
| Determination of liquid limit of soil | ASTM D 4318 [16] |
| Plastic limit and plasticity index | ASTM D 4318 [16] |
| Determination of the specific gravity of solid soil particles and mineral filler, using a pycnometer with water | ASTM D854 [17] |
| Modulus of rupture and load of rupture to flexion | NTC 4017 [18] |
| Compressive strength |  |
| Absorption |  |
3. Results

The granulometric analysis of soil by sieving and hydrometer determines the balance of the percentage of gravel, silt, sand, and clay that soil may contain, which allows the understanding of its composition and possible use. The analysis was performed with 300 g of soil, with a loss of 5.50 g, in the end, the results of the total grain size of the material are obtained and a normalized curve with a particle distribution as shown in Figure 1.

![Figure 1. Normalized granulometry curve.](image)

In Figure 1, three values are located where the curve is normalized and allows to see the behavior of the particles in terms of their diameter (D), below the sieve 200 is clay, between the sieve 40-200 are sands and between the sieve 10-40 are gravel. These three points are chosen because they are the intermediate points of the curve, while the others are outside the range, being greater than D60 very large particles and less than D10 very fine particles obtaining values of 0.04 mm for D10, of 0.09 mm for D30 and of 0.52 mm for D60. Taking into account the values from the diameters mentioned above, the coefficient of curvature (Cc) and the coefficient of uniformity (Cu) were calculated, which shows the variety of particles in the soil, obtaining values for the Cc of 0.4 and the Cu of 13.0.

The Determination of the plastic limit (PL) and the plasticity index (PI) is of great importance to understand the behavior of the soil with a certain water content, which serves to classify the sludge in the soil category systems. A PL value (%) = 46.3 was obtained and a PI (%) = 19.4 was obtained. The liquid limit (LL) was determined by using portions of sample scattered on a bronze casserole, dividing it into two parts, and striking it until these parts come together by repeatedly falling. Taking into account the data obtained in the test a graph is generated that relates the moisture content vs. the number of strokes, Figure 2.

![Figure 2. Moisture content vs number of strokes](image)

Where a value of LL = 65.7% is obtained; as indicated in the unified system of classification of soils (USCS) a percentage > 50 indicates the soil is of high plasticity and < 50 low plasticity, the value
obtained indicates that our soil is of high plasticity. The average value obtained in determining the specific gravity was 2.65, which was used as a complement for the calculations in the hydrometer test. The tests of liquid limit, plastic limit, and plasticity index were necessary to know the behavior of the sludge classifying it with a silty sandy texture (SM).

Taking into account the previous analyzes, the data is verified according to the classification system of the American Association of State Highway Transportation Officials (AASHTO) [15] and is classified as A-2-7 (0); this taking into account the percentage that passes through the sieve N10 = 94.7%; N40 = 55.0% and N200 = 26.6% and additionally taking into account consistency limits.

For the flexural test analysis, the calculation of the flexural fracture load was made taking into account the maximum load indicated by the test machine in N (Newton) and the effective cross-sectional area (mm$^2$). Figure 3 shows the variation of the real flexural stress of the specimens tested, where it is identified that the specimen with 15% of added sludge obtained the best behavior with a value of 2.99 MPa; followed by the specimen with 25% of added sludge with 1.95 MPa.

![Figure 3. Relationship real flexural effort vs percentage of added sludge.](image)

For the determination of the compressive strength, it was necessary to establish the dimensions and weight of each of the specimens. Regarding to compression, the best behavior is presented by specimens with 25% and 35% of added sludge, with values of 16.3 MPa and 15.9 MPa respectively. Porosity and absorption are directly proportional, this test is performed to determine the property of the durability of the bricks once it is saturated, such as quality and behavior. It was evident in the results of the absorption test, according to the mixtures implemented in artisanal brick that only the specimens with 45% and 45% of added sludge fail to comply with NTC 4205-02 [18].

Initially, it was necessary to classify the type of specimen according to NTC 4205-02 [18] where three basic types of non-structural masonry units of baked clay are defined, this according to the arrangement of their perforations and the volume they occupy, horizontal drilling (PH), vertical drilling (PV) and solid (M). For the particular case of specimens manufactured with sludge, it was determined that these are of solid type (M) considering that they are units without perforations, which commonly includes the construction of partition walls and non-structural closing walls. In total, three types of tests were performed on the manufactured specimens, Figure 4 relates the general results, the specimens were considered as non-structural masonry units, taking as reference the specifications in the NTC 4205-02 [18], in the same way, they show the limits and the minimum condition for the tests carried out.

For the absorption test, only 3 of the 5 proposed mixtures comply with the parameter of being less than 20%, which are 15%, 25% and 35% of added sludge, in the case of resistance to compression the specimens that meet the condition of being greater than 10 MPa are those of 15%, 25%, and 35% of added sludge. Taking into account the analysis performed on the different mixtures, it is recommended to use the brick with 25% of added sludge, this being the specimen that exhibits the best compression behavior of the three mixtures, with a value of 16.3 MPa exceeding the required NTC-4205-02 (10 MPa) [18] and also is within the range of the percentage of absorption with 17.89%, additionally it is considered that it has a flexural strength of 1.9 kPa.
With regard to the commercial specimen (CE), a substantial improvement can be identified, both in compressive strength and flexural strength, in Figure 5 the variations in compressive strength with respect to the initial one are shown corresponding to a value of 12 MPa, a 38% increase in the resistance of the specimen was achieved for the mixture with 25% of added sludge reaching a resistance of 16.3 MPa.

4. Conclusion
According to the characterization of the sludge generated in the sedimentation tank of the WTP, it is concluded that the sludge has a potential of use in the manufacture of bricks considering the results of the tests carried out according to the Colombian regulations, a better performance of the brick was evidenced with 25% of sludge substituted in the clay mixture compared to a commercial artisanal brick.
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