ORIGINAL ARTICLE

Evaluation of Recycled Sludge for Production of a Ceramic Company that Affects an Agroecosystem

Evaluación del lodo reciclado para producción de una empresa cerámica que afecta un agroecosistema

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ABSTRACT: Taking into account the importance that the uncontrolled expulsion of industrial waste into the environment has for agriculture, this work is carried out with the aim of assessing the possibility of recycling solid waste (residual sludge) of Cerámica Blanca Company located in San José de las Lajas Municipality, Mayabeque, Cuba, through its reuse during the production process, to achieve clean production and reduce the waste load that is expelled into the environment. This company, despite being an economic source in the country, represents a source of environmental contamination due to the residuals that it expels to the neighboring agroecosystem dedicated to the cultivation of vegetables, medicinal plants and free grazing, affecting local food security, since these residuals They have high content of heavy metals. The physical-mechanical properties of the mixtures used in the production were determined and an economic evaluation was carried out taking into account the daily production and the unit costs. It was verified that with the mixture of 15% of the residuals, the preparation of paste in the production process of the company allows obtaining the best results and they are among the recommended standards, which represents an annual profit of more than $ 111 MPMN.

***Keywords*:** Heavy Metals, Pollution, Environment.

RESUMEN: Teniendo en cuenta la importancia que tiene para la agricultura la descontrolada expulsión al medio de residuales industriales, se realiza el presente trabajo con el objetivo de valorar la posibilidad de reciclaje de los residuales sólidos (Lodo residual) de la empresa Cerámica Blanca ubicada en el municipio San José de las Lajas, Mayabeque, Cuba, mediante su reutilización durante el proceso productivo, para lograr producciones limpias y reducir la carga de residuales que se expulsa al medio. Esta empresa a pesar de ser una fuente económica en el país, representa un foco de contaminación ambiental por los residuales que expulsa al agroecosistema aledaño dedicado al cultivo de hortalizas, plantas medicinales y el libre pastoreo, afectando la seguridad alimentaria local, ya que estos residuales contienen altos contenidos de metales pesados. Se determinaron las propiedades físico-mecánicas de las mezclas empleadas en la producción y se realizó una valoración económica teniendo en cuenta la producción diaria y los costos unitarios. Se pudo comprobar que con la mezcla al 15% de los residuales la preparación de pasta en el proceso productivo de la empresa, se obtuvo los mejores resultados, y se encuentran entre los estándares recomendados, lo que representa en el año una ganancia de más $ 111 MP MN.

***Palabras clave*:** metales pesados, contaminación, medioambiente.

INTRODUCTION

Currently there is a level of awareness about the need to have an acceptable environment in all orders, pollution being one of the most sensitive environmental problems from the social and human point of view. The most evident consequences are presented in the current agricultural and rural environments Soto *et al.* (2020), fundamentally caused by the implementation of development strategies that have paid little attention to ecological processes (Valdés *et al.*, 2018).

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The concern to have guaranteed food led man to study and cultivate any plant species without taking into account the conditions of the soils that are dedicated to this work and the contamination with heavy metals of agricultural areas near industrialized or polluted areas is a reality worldwide, so one of the research objectives would be to study the toxic effects that the different groups of pollutants produce in the food chain, analyzing the phenomena of translation, bioavailability, bioconcentration and biomagnification, to implement strategies that help mitigate such effects on the safety and innocuousness of food described in Decree-Law No.9 (Gaceta Oficial de la República de Cuba, 2020).

Consequently, the National Environmental Strategy (EAN) 2021-2030 constitutes the implementing document of the Cuban environmental policy, which enhances local management in the preservation of the environment (CITMA, 2021).

The achievement of these objectives is influenced by the development of certain industrial activities that constitute a moderate risk of environmental contamination, not only due to atmospheric emissions but also due to poor waste management, which can cause leaks of components that accumulate in the soil and as a consequence, a "contaminated soil" may appear Valdés *et al.* (2018), understood as such, that soil that, due to the accumulation of persistent toxic compounds, has changed its original characteristics and whose new nature can cause unacceptable risks for human or ecosystem health (Bonilla, 2013).

Despite all that has been said, according to Peñate (2018), there are 14 426 identified polluting sources in Cuba and the technologies to solve these cases are very expensive, so the available resources cover only 2,3% of those identified ONEI-Cuba (2019). In Mayabeque (the smallest province of Cuba, with 3 743,8 km² and, despite this, the most industrialized) is San José de las Lajas Municipality, which concentrates the largest number of industries and companies in the territory (78% of the economic sector) ONEI-Cuba (2019), considered sources of environmental contamination and of possible repercussion on the food security of the municipality (Valdés *et al.*, 2018).

In the work, a possible solution is presented that contributes to the reduction of the contaminant load that is expelled to the environment from empresa Cerámica Blanca SANVING S.A., which, despite an economic source, is considered a source of environmental contamination. The objective of the work is to assess the possibility of recycling the company's solid waste (residual sludge) by reusing it during the production process, to achieve clean production and reduce the waste load that is expelled into the environment.

MATERIALS AND METHODS

Geographic location of the study site

The source of contamination selected for the study was Cuba-Vietnam White Ceramics SANVIG, S.A. Mixed Company, located at 22º97' north latitude and 82º17' west longitude according to the North Cuba coordinate system.

Determination of physical-mechanical properties of the sedimentary residuals of the production process in Ceramic Company

The study of the physical-mechanical properties of the sedimentary residuals was carried out from the preparation of nine test bars of dimensions 200x20x10 mm obtained from combined mixtures of 15%, 30% and 40% of the residual sludge with the paste (material used in the production process). The bars were dried in an oven for 24 h at 110±5 ºC, calcined at a temperature of 1060 ºC in a standard Sacmi electric oven, followed by a firing process as established for sanitary products. In each production run, the following properties were analyzed and determined, according to the Ecuadorian Technical Standard 652:2000 (NTE INEN, 2000) and the German Standard DIN 51061 (2003) cited by Diedel & Link, (2006):

DENSITY: It was determined using a mechanical stirrer, a 100 mL pycnometer and a 120 g analytical balance with a precision of 0,1 mg.

TIXIOTROPY: A Gallenkamp viscometer was used.

INSTANT THICKNESS and VISCOSITY: The samples were taken from the dissolver and from the reactors, they were placed in the variable speed diluter, to stir and homogenize up to a speed of 765 rpm, for 5 min; then it was allowed to stand for one minute to continue with a brief agitation.

RUPTURE MODULE AFTER DRYING (N cm-2): the formula was applied:

$$MOR = \frac{3*P*L}{2*h^2*b} \quad (1)$$

Where:

P: Force value (N) read on the dynamometer scale.

L: Distance between the two blades that hold the test bar (cm).

h: thickness of the sample (1 cm).

b: Length of the test bar (2 cm).

MODULE OF RUPTURE AFTER FIRING: The same procedure described above was carried out.

DRYING CONTRACTION: The length (L2) of the recently unmolded bars was measured with a centesimal caliper, with a precision of 0.05 mm; subsequently, they were dried for 12 hours at room temperature and for 24 hours in a dryer with a ventilated chamber at a temperature of 110 ºC and (L1) was determined after drying. Applying the following formula, the results are obtained.

$$C.S. = \frac{L2 - L1}{L2} * 100 \quad (2)$$

COOKING CONTRACTION: The centesimal caliber was used. The sample was initially measured (L1), then it was dried (L2) and with the support of the formula the results were obtained.

$$C.C. = \frac{L1 - L2}{L1} * 100 \quad (3)$$

WATER ABSORPTION: The samples, cooked at different temperatures, were weighed using a 120 g analytical balance with a precision of 0.1 mg for dry weight (P1). They were boiled in a container for three hours and then cooled at room temperature for 20 hours. The samples, once removed from the water, were rinsed with a damp cloth and weighed again (P2). The percentage of absorbed water is obtained from the following formula:

$$A = \frac{P2 - P1}{P1} * 100 \quad (4)$$

Analysis of the impact of contamination with heavy metals from the recycling of residual sludge

Due to the importance of minimizing the environmental impact caused by solid waste that can be reused, an economic analysis was carried out in the production process of the company, estimating the value in monetary terms, based on the information obtained, which report 549 average pieces per day with an average weight of 15 kg, the unit cost of the products and the transportation of the components per day of production.

Statistical analysis

The organization and processing of the information was carried out in the Microsoft Office 2010 Excel program and STATGRAPHICS Plus version 5.1 as statistical software. The simple ANOVA test was used, for which a significance level of 0,05 was established for a 95% confidence interval and comparison tests were performed by Duncan to determine between which levels the significant difference was established, and for those mean values that presented significant differences, different letters were assigned.

RESULTS AND DISCUSSION

Characterization and evaluation of the polluting source, Company SANVING S. A. In the company's production process, pollutants and different types of solid effluents are generated, such as enamel mud from the processes of grinding, enameling or enamel preparation. Even when these muds are, in general, technically recoverable, they are not from the operational point of view, hence, constitute potential contaminants when they are dumped in unsafe and poorly managed places (Goya & Rodríguez, 2020).

The Cerámica Blanca Company, a source of contamination that is the object of the investigation, is divided into two sections for its production process. The one it occupies, identified as Subdivision 1, has been in continuous operation for 62 years and its production is aimed at making white sanitary furniture or white ceramics, without the use of dyes. It has a discharge rate of liquid waste of 0,2 L s^{-1}, that accumulates a volume of 17 000 L per day Informe Técnico CAM San José (2017) and inside, it has a trap to collect mud mixtures, which come from the beginning of the production process. Figure 1 presents a diagram of the company's format regarding its external waste traps.

The first trap is divided into three sections, where the abundant presence of liquid waste and sludge composed of petroleum, oil and sediments, coming from the boilers and the kitchen (Trap 1) is observed. Liquid and solid waste is discharged into a Trap 2, which accumulates sediment and wastewater that travels across the central highway through a canal. This drainage channel has been destroyed towards its end, allowing the uncontrolled flow of residual waters, towards lands surrounding the patios of the town. These waters are used for agricultural irrigation of crops with economic and nutritional importance, mostly vegetables, capable of accumulating in their tissues, high volumes of heavy metals, toxic to most plants Guzmán *et al.* (2021), without showing symptoms of toxicity, which according to Berazaín (2017) is characteristic in areas contaminated with heavy metals.

According to the visual inspection carried out, the operation of the traps is inefficient since the residuals

FIGURE 1. Scheme of the system of traps for residual of the company.

expelled from the production process are not adequately filtered. It was possible to verify the excessive accumulation of sediments at the beginning of the dumping area. That white sludge (mixture of wastewater and sediments) consists of a mixture of kaolin and other raw materials, as well as a small amount of gypsum, which are the result of items broken during the process and that could also be recycled according to Bünemann *et al.* (2018).

Evaluation of the physical-mechanical properties of sedimentary residuals

Table 1 shows the results of the chemical analysis of the different mixtures with residual sludge for their reuse in the company's production process. It can be seen that, as the dosage of residual sludge increases in the mixtures, the losses on ignition (LOI) increase, which is attributed to a possible organic contamination of the same. The other parameters are within the permissible limits in this type of manufacturing, since the ranges of the pattern used coincide with Arias *et al.* (2018).

Since the percentages of chemicals in the mixture were found to be at acceptable levels, the parameters that define the quality of the paste to be used in the production process were measured (Table 2).

It can be seen that in most of the evaluated indicators, except for the Modulus of Rupture after drying, Modulus of Rupture after firing and Water Absorption, statistically significant differences were found for a 95% probability between the samples with 15 and 30 % of residual sludge with respect to the sample with 40% of residual sludge. These differences coinciding with respect to the paste without residual sludge. Sample with 15% of residual sludge, obtained the best values in its indicators, due to that, all the properties studied, are among the recommended standards, as indicated by Arias *et al.* (2018).

The slip obtained with the aforementioned mixture complies with the standard cooking cycle and the water absorption required for paste, attributing to it the best results for its use in the start-up of production, taking into account that Arias (2018) states that part of the materials lost during the entire manufacturing

TABLE 1. Chemical composition of the mixtures with different percentages of residual sludge

Compounds analyzed	Pattern	Recycled sewage sludge		
		15	30	40
	%			
LOI	5,5	6,3	6,9	7,2
SiO_2	67,6	65,3	63,5	62,6
Al_2O_3	20,3	22	23,3	24
TiO_2	0,5	0,6	0,7	0,7
Fe_2O_3	0,9	0,9	1,0	1
CaO	0,4	0,3	0,3	0,3
MgO	0,3	0,4	0,3	0,3
K_2O	2,9	2,6	2,3	2,6
Na_2O	1,6	1,5	1,7	1,3
Total	100	100	100,0	100

TABLE 2. Results of the physical-mechanical tests with different percentages of sedimentary residuals mixed with the paste for the production of ceramic pieces

Parameters	Values Standard	Paste without residual sludge	Sample with 15 % residual sludge	Sample with 30 % residual sludge	Sample with 40 % residual sludge
Density (kg L^{-1})	1,79-1,83	1,81 a	1,81 a	1,81 a	1,76 b
Viscosity (kg m^{-1} S^{-1})	310-330	323 a	311 ab	310 b	300 c
Thickness after 60 min (mm)	8,5-10	8,7 a	8 ab	7,4 b	5 c
Thixotropy (°G) after 1 min	18-23	23 ab	22 abc	25 a	19 c
Thixotropy (°G) after 6 min	55-90	83 a	75 a	83 a	55 b
Modulus of rupture after drying (N cm^{-2})	≥ 235,2	294 b	321,44 a	245 c	176,4 d
Modulus of rupture after firing (N cm^{-2})	≥ 3 920	6 468 a	5 782 b	3 136 c	1 470 d
Drying shrinkage (%)	2-3	2,6 a	2,5 a	1,86 ab	1,05 b
Firing shrinkage (%)	9,5-12	11,5 a	10,03 ab	8,6 b	7,5 c
Water absorption (%)	≤ 0,5	0,2 b	0,45 b	0,90 a	0,85 a

Unequal letters differ significantly with $p<0.05$ according to Duncan's Dócima process can be reused within the facility, according to product specifications or process requirements.

It does not occur in the same way for the sample with 30% residual sludge, because the paste does not reach the adequate vitrification (water absorption greater than 0,5%), since the gray kaolin (used for the elaboration of ceramic products) reduces the tendency of the paste to vitrify, which, according to Arias *et al.* (2018), is characterized by high porosity and, the glassy phase that develops during firing, is not enough to close the present porosity.

In the case of the sample with 40% residual sludge, the mixture obtained is not suitable for the manufacture of ceramic pieces, because the viscosity is below that required, so it is necessary to increase the amount of deflocculating agent, as explained by López & Ramírez (2019). The modulus of rupture after drying was excessively low (light paste) due to the amount of residual sludge used and a great difference is also observed with respect to the optimum degree of vitrification (high water absorption), with respect to the recommended standard value.

Economic valuation. Impact of the reuse of residual sludge in the company's production process

An economic analysis of this research derives from the importance of minimizing the environmental impact caused by solid waste that can be reused.

Table 3 shows the comparison of the production costs of the process without the reuse of solid waste and after it, where a decrease of them can be observed.

The reuse of part of this solid waste (15%) is a possible saving in the company; it avoids the need to transport them from one company to another, it benefits because it does not pay to get rid of them and it is economically feasible, since a profit of $ 306,35 per day^{-1} is obtained, which represents a profit of $ 111 817,75 in the year. In addition, these results confirm what Bünemann *et al.* (2018) state that, the expulsion of solid waste to the environment, can be reduced by combining different techniques such as regeneration of unmixed raw materials, regeneration of broken items in the manufacturing process, utilization of solid losses of the process in other industries and application of optimized parameters.

CONCLUSIONS

The results obtained guarantee that the production of a paste including residual sludge from the industry, with optimal characteristics for reuse in the production process, is obtained when the mixture is combined with 15% of that sludge, which allows reducing the economic cost of the components to be used in the mixture for the manufacture of ceramic products, the contaminant load that is expelled into the environment and, in turn, it constitutes a viable and sustainable solution for obtaining cleaner productions.

The implementation of this reuse process leads to a reduction in environmental problems and to a better productive performance of the entity, with the consequent positive effect on the agricultural areas around the company.

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TABLE 3. Cost of production in the company using 15% residual in the production process

Production type	*Cost of Production t^{-1}	Production cost for 549 pieces day $^{-1}$
	$ t^{-1}	$ day $^{-1}$
Slip without residual sludge	243,87	2 289,45
Slip with 15% residual sludge	211,24	1 983,10

*Production Cost: $/Ton of finished product

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