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ORIGINAL ARTÍCLE

Procedure for sustainable operation natural drying technology of lateritic ore

Procedimiento para la explotación sostenible del sistema de secado solar de menas lateríticas

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Abstract

This study presents a procedure designed and implemented for the sustainable operation of the solar drying system at the Basic Mining Unit (UBM) of the nickel and cobalt producing company *Ernesto Che Guevara* (ECG) in Moa, Cuba. Its is based on studing and evaluating ISO 9001-2015 standardization regulations, the company's quality management system, as well as the results obtained from its application over 5 years (2019-2023). This work offers practical and methodological support that demonstrates the interconnectivity and importance of the variables and components influencing the drying system. The results contribute to business strategic planning, the improvement of desing, as well as the sustainable construction and operation of the base grounds (plazas) used for the natural drying of laterite ores.

Keywords: solar drying, sustainable operarion, laterite ores, drying yards

Resumen

Se diseñó e implementó un procedimiento para la explotación sostenible del sistema de secado solar en la Unidad Básica Minera de la empresa productora de níquel y cobalto *Ernesto Che Guevara* de Moa, Cuba, a partir del estudio y valoración de normativas de estandarización ISO 9001-2015, el sistema de gestión de la calidad de la empresa, así como los resultados obtenidos en su aplicación durante 5 años (2019-2023). Se ofreció un soporte práctico y metodológico que mostró la interconectividad e importancia de las variables y componentes que influyen en el sistema de secado. Los resultados contribuyen a la planeación estratégica empresarial, al perfeccionamiento del diseño, así como a la construcción y explotación sostenible de los terrenos base (plazoletas), utilizados para el secado natural de menas lateritas.

Palabras clave: secado solar, menas lateríticas, explotación sostenible, plazoletas de secado

1. INTRODUCTION

The solar drying process is one of the most widely used methods in the extractive industry for materials. The scarcity of energy resources, high fuel prices, and accelerated environmental degradation make this method widely applicable in various productive spheres worldwide. It is a process in which materials are directly exposed to solar radiation by placing them on the ground or in specific devices (Retirado-Mediaceja, 2012; Retirado-Mediaceja et al., 2016).

Cuba is one of the largest producers of lateritic nickel, possessing deposits of this type, mainly in Moa, whose reserves rank among the four largest worldwide (Guerrero-Almeida et al., 2024). A large amount of raw material from nickel mining is dried using solar radiation, given the advantages this method presents, although its use has been mostly directed towards the food, coffee, and wood industries.

Retirado-Mediaceja (2012), Retirado-Mediaceja et al. (2018), Estenoz (2009), among other researchers, demonstrate that the conventional drying of lateritic ores uses about 20% of the energy consumed by the metallurgical industry; however, using natural sun drying reduces this indicator, thereby minimizing operating costs and preserving and reducing the weight or volume for transporting the extracted material. Regalado-Urquía (2023) and Fonseca-Aguilar (2024) assert that with the application of solar drying in the exploitation of the lateritic deposits leased to the nickel and cobalt producing company Ernesto Che Guevara (ECG) in Moa, it is possible to reduce the moisture of the mineral supplied to the metallurgical process.

Due to its composition, complexity, and importance, the solar drying method has a systemic nature (Guerrero-Almeida, 2025). It requires mining constructions called base grounds (drying yards) formed by layers of waste material with their own structures and functions, on which piles of lateritic ore are distributed. These interact with multiple variables (climatic, geological, geotechnical, technological, economic, social) that guarantee its operation and allow rationalizing the carbonate-ammoniacal leaching (CARON) technology applied at ECG (Figure 1).

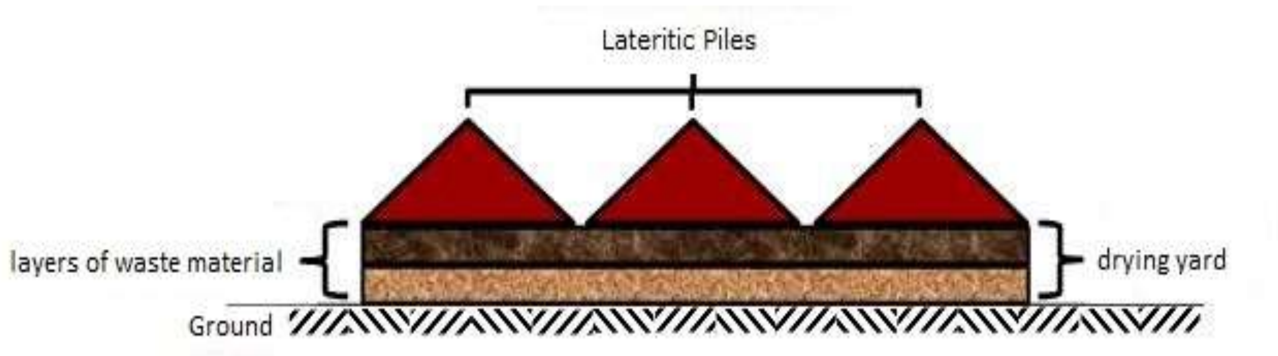

Figure 1. Solar drying system scheme. Source: Fonseca-Aguilar (2024).

Although it has multiple advantages, the solar drying system has shown difficulties that prevent obtaining the best technological quality indicators required by the CARON process for nickel extraction from ferruginous laterites. In the first two installed yards (1 and 6), a lack of control and monitoring in the selection of the zone and the waste material used was evident, along with deficient design and construction, occurrence of geodynamic phenomena, increased fuel consumption due to higher moisture of the extracted mineral, poor quality of mining roads, and increased transportation distance of the ore from the faces to the old deposits; all of which result in unsustainable exploitation of the ores (Fonseca-Aguilar, 2024).

To date, ECG lacks a comprehensive procedure that corrects the mentioned deficiencies and serves as a methodological instrument for planning the sustainable exploitation of nine other projected yards. From this approach, the need for a useful management tool to make decisions and take preventive measures for its improvement is identified.

The present work constitutes a step forward in this regard, aiming to design a procedure that guarantees the sustainable exploitation of the solar drying system applied at the Ernesto Che Guevara Basic Mining Unit (UBM-ECG).2. generalidades.

2. GENERALITIES

2.1. Location of the drying area

The solar drying system for lateritic ores covers 63.1 Ha of the Punta Gorda deposit leased to the UBM-ECG in the municipality of Moa. Its yards border to the north with the company's buildings, to the south with a part of the Punta Gorda deposit, to the west with the mine of the joint venture Moanickel S.A. "Pedro Sotto Alba", and to the east with the Yagrumaje Norte deposit. The selected area is within the Mining Blocks known as R, Q, and P (quadrants R51-53, Q52-54), P52-55, S51-53, O53-55, and N-53-54 (Fonseca-Aguilar, 2024; Figure 2).

2.2. Geographical characteristics

The climate is tropical with abundant rainfall; the relief is mountainous, where trade winds from the Atlantic Ocean loaded with moisture predominate, with an irregular distribution of rainfall within the rainy season. It presents two maximums; one main in October-November and a secondary one in May-June. Similarly, it presents two minimums; one in February-March and another in July-August. The number of days per year with rainfall exceeding 1 mm is over 100, the annual average precipitation reaches 2,000 mm, and evaporation is close to 1,600 mm (Retirado-Mediaceja, 2012).

The average annual temperature is 27 ºC, in summer it fluctuates between 30 ºC and 32 ºC, with maximums ranging between 34 ºC and 36 ºC; in winter it varies between 14 ºC and 26 ºC with minimums around 12 ºC. The average annual relative humidity at 7:30 hours is 85% to 90%; at 13:00 hours it is between 70% and 75%.

Figure 2. Location of the study zone.

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The wind regime reflects the predominant occurrence of trade winds reinforced by sea breezes and counteracted by land breezes. Winds blow over the eastern area coming from the NE in the months of October-January; from the ENE, during February-May; and from the E, in June-September.

The vegetation is characterized by the presence of Pinus cubensis forests on the lateritic crusts and thorny scrublands typical of serpentinized ultramafic rocks (charrasco) where the crusts are thinner. On gabbros and alluvial deposits, some palm trees, coconut palms, and fruit trees may appear. The low coastal areas are covered by typical coastal vegetation, among which mangroves stand out.

The region is located within the Sagua-Moa-Baracoa orographic group, which makes the relief predominantly mountainous, mainly towards the south, where it is more rugged in the Sierra de Moa with a submeridional direction. Towards the north, the relief becomes gentler with elevations ranging between 40 m and 50 m maximum, gradually decreasing towards the coast.

Several permanent rivers and streams appear, including the Moa, Los Lirios, Cabañas, Cayo Guam, Quesigua, Yagrumaje, Aserrío, and La Vaca rivers, which affect the central part of the deposit (Almaguer-Carmenates, 2005).

2.3. Geological characteristics

The area is bounded by two large regional faults passing through the valleys of the Moa and Cayo Guam rivers. The first is represented by the Moa River, from which second-order fractures develop, among which the Los Lirios and La Vaca streams and the Yagrumaje River stand out. The ultrabasic complex outcropping in its entire central and southern portion is predominantly composed of harzburgites, dunites, lherzolites, and pyroxenites. These rocks, dark green to greenish-gray in color, exhibit high fracturing with a variable degree of serpentinization. The Punta Gorda deposit, where the solar drying system is located, is characterized by a basement, a lateritic weathering crust, and redeposited laterites. The weathering crust constitutes the predominant soil in the region, and the mineral raw material is represented by nickeliferous laterite.

Permeability in these sequences ranges between 0.004 m/day and 0.430 m/day, although in areas of intense crushing, anomalous values greater than 2.00 m/day can be found. Aquifer thickness values range from 0 m to 27.6 m. The lowest correspond to natural drains and the exploited area, while the highest represent the highest areas of the deposit.

2.4. Particularities of the mining operation

The UBM-ECG supplies mineral raw material to the metallurgical plant, whose technological scheme is based on the carbonate-ammoniacal leaching of the reduced ore (CARON process). It began operations in 1985, with the exploitation of minerals from the Punta Gorda deposit and annual productions up to 1996 between 1.5 and 2.3 million tonnes. The exploitation system applied in the mine is open-pit mining.

An exploitation system with excavation and direct loading onto motorized transport is used, in one and/or several steps, through the combination of walking draglines, or draglines, and trucks (Figure 3). The mining process includes clearing, overburden removal, road construction, extraction by multiple parallel benches with hydraulic excavators, transport with articulated or rigid trucks, waste dumping, and environmental protection (García-De La Cruz, 2018).

Figure 3. Open-pit exploitation system. Source: Fonseca-Aguilar (2024).

3. METHODOLOGY

The research was conceived from qualitative and quantitative methodologies, due to the flexibility and variability of their methods for obtaining the necessary information. This enabled the application of analysis-synthesis to define the research problem, synthesize and incorporate scientific knowledge contributions, and review the published bibliography on the topic. The inductive method was applied to determine the inference from the general to the particular of the lateritic ore drying process.

The systemic method served to determine the theoretical foundation supporting the research. The historical-logical method allowed understanding the development and evolution of publications describing the origin and operation of the ECG solar drying system. The deductive method was assumed for carrying out logical reasoning about mining technology.

Furthermore, information compilation and bibliographic analysis were applied to gather and systematize data through the review of bibliographic, oral, digital, or other sources. These were of great importance during the study of environmental legislation, national and international standards, specialized literature, archive consultations, methodological guides, project analysis, work areas, field data, as well as for preparing the final research report. Observation and measurement allowed the identification of variables, geotechnical characterization of the base grounds, and problems presented in the area.

Interviews conducted during visits to the UBM-ECG ensured contact with workers and managers to familiarize with the subject of study, search for information, and determination of the causes that led to the need to develop the procedure. Experimental methods allowed sampling, analysis, and verification of results obtained in the field as part of geotechnical studies. The case study served to characterize the solar drying technological process and its particularities.

To define the main components of the procedure (stages, steps, duration, variables), the general systems theory was applied. This enabled a comprehensive analysis of the geological and mining characteristics of the region, ISO 9001:2015 standardization regulations, the UBM-ECG quality management system, required legal documents, as well as the main problems presented and the variables influencing the sustainable operation of the solar drying system.

3.1. Procedure design

For the procedure design, it was considered that the sustainability of the solar drying system is a function of variables that intervene before, during, and after its operation (Equation 1; Guerrero-Almeida, 2025), namely: climatic (rainfall, temperature, humidity, solar radiation, and wind); geological (hydrogeology, weathering processes, and tectonic of the rock mass); geotechnical (soil friction angles and cohesion), technological (material characterization, parameters required for yard construction, homogenization, resource management, planning, control, and monitoring), economic (cost of the yards, energy savings, production increase), and social (use of research, use for other purposes, others).

$$f(IS) = \sum_{i=1}^{n}(C_i + G_i + l_i + T_i + E_i + S_i) \quad (1)$$

Where: IS- Sustainability Index of the solar drying system, %

C_i- Influence of climatic variables, %

G_i- Influence of geological variables, %

l_i- Influence of geotechnical variables, %

T_i- Influence of technological variables, %

E_i- Influence of economic variables, %

S_i- Influence of social variables, %

The procedure begins with the review of existing information about the area and continues with the characterization of the waste material to be used, construction and geotechnical characterization of the test embankment, data analysis and interpretation and report preparation, construction, certification, handover, and sustainable operation of the yards. It includes an internal control and monitoring system that serves to detect deficiencies and propose timely measures to achieve better quality indicators and project an efficient and effective mining-metallurgical technological process (Figure 4).

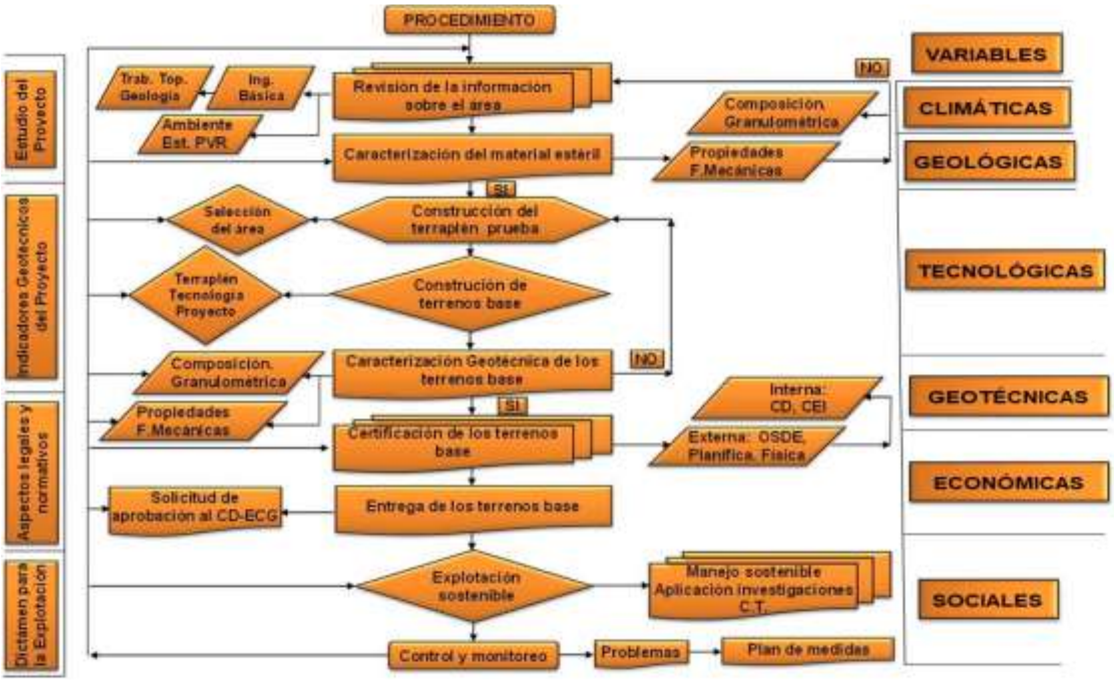

Figure 4. Procedure desing for a sustainable drying solar system of laterites ores (adapted from Fonseca-Aguilar, 2024).

3.2. Procedure application

The procedure was implemented from 2019 to 2023 at the UBM-ECG, a period during which support was available from the facilities and laboratories of ECG, the National Company of Applied Research (ENIA), the Nickel Project Center (CEPRONIQUEL), and the Nickel Research Development Center (CEDINIQ). The results achieved in each stage were as follows:

1. *Review of information and location of the base ground area*

In this stage, detailed engineering projects, geological and mining reports were reviewed. The main climatic, geological, relief variables, closest extraction faces, mineralogical composition, among others, were characterized for the construction and assembly of nine yards covering an area of 63.1 Ha. The solar yards were located within the mining concession area of the Punta Gorda deposit in Blocks R, Q, and P, with quadrants R51-53, Q52-54, and P52-55, as well as S51-53, O53-55, N-53-54 if necessary. All were authorized by the National Office of Mineral Resources.

2. Characterization of the waste material used for the construction of the base grounds

Once the area of each yard was defined, geotechnical parameters such as the soil friction angle and cohesion, and technological parameters such as material characterization, resource management, as well as the morphological and functional properties of the waste material were determined, aiming to understand their degree of resistance and reliability. The waste material used in their construction came from waste dumps, other grounds, overburden removal operation faces, borrow pits, and slopes excavated within the yards themselves.

3. Construction of the test embankment and geotechnical characteristics

This stage involved earthmoving and geotechnical soil investigation, aiming to control its most efficient compaction parameters. The wet density (f) and maximum dry density (dmax), as well as the percentage of compaction, were determined for the material used. Its execution was preceded by clearing the embankment location area, loading, hauling, watering of the waste material in the work area, determination of the layer thickness, delineation of the lines to be compacted, checking of pass frequencies (between 4-8) and compactor speed. Additionally, an excavator, two bulldozers 250-350 HP, a front loader of 4.5 m^3-6 m^3, three Volvo trucks, a motor grader, and a water tanker truck from the UBM were used.

4. Construction of the base grounds

This stage began with the topographic survey of the area and transfer of the waste material. During embankment works, a walking dragline (Komatsu) was used to prepare the area. The waste material was transported by trucks from the borrow area to the yard. The bulldozer performed the hauling of the deposited material in layers 30 cm thick. Then, the material was compacted to achieve resistant layers, with maximum quality requirements (eight passes), applying water spraying on the already formed layers (Figure 5).

To access the yards, the construction of auxiliary mining roads was later included, according to their technical and project specifications. Finally, embankment leveling, fuel closure certification, topographic survey, and digital terrain model design were carried out.

Figure 5. Construction of the base grounds. Source: Fonseca-Aguilar (2024).

5. Geotechnical characterization of the solar drying base grounds

As part of the company's quality control system and the established procedure, the morphological and functional properties of the waste materials used were determined (ECG, 2023). Through geotechnical studies, their degree of resistance and reliability for refilling in each layer of the base grounds could be known (Fonseca-Aguilar, 2024). Among the main geotechnical characteristics determined (Table 1) are their granulometry, specific weight, and plasticity [liquid limit (L.L.), plastic limit (L.P.), and plasticity index (I.P.)].

Table 1. Main physical properties determined for the waste material used for the construction of the base grounds

Granulometry	**Value (%)**	**Soils specific weight (KN/m^3)**	**Plasticity (%)**		
Grava	33.2	35.5	L.L.	P.L.	**P.I.**
Arena	29.4		50.00	41.57	**8.43**
Limo, arcilla	**37.4**				

In this stage, other in situ geotechnical investigations were also carried out to determine their density ($^{\gamma d}$), moisture (w) and compaction (Comp.), achieving the following results (Table 2).

Table 2. Geotechnical characteristics of the test embankment

Essays *in situ*			**Comp. (%)**
γ^f (kn/m^3)	**W (%)**	**γ^d (kn/m^3)**	
18.4	20.4	15.3	95.4
19.8	26.6	15.6	97.3
19.9	21	16.4	100

Similarly, in the final construction phase of the base grounds, measurements were made to determine their geotechnical behavior through simple random soil sampling and compaction tests, which allowed verifying the quality of the materials used and the topographic works performed.

6. Certification of the base grounds

For the certification of the base grounds or yards, compliance with their technological parameters was checked. For this purpose, a company Commission was created, with the participation of professionals from different specialties, which verified compliance and legality of the documentation regarding the execution, accounting, and control of the construction works carried out during the investment process.

It was approved that the construction object (yard) with partial commissioning can be operated independently and, therefore, was certified as a tangible fixed asset of the UBM-ECG with a monetary value ranging between 500,000 CUP and 1,230,000 CUP. Subsequently, the corresponding file for the solar drying system was reviewed by the governing bodies to obtain the corresponding rulings, as it complies with the aspects established in Decree Law 327. Finally, the partial entry into accounting and the habitable-usable certificate were approved by the Provincial Physical Planning Directorate (IPF).

7. Handover of the base grounds

In this stage, the constructor handed over the documentation (final file) to the investor (UBM-ECG), certifying the square meters occupied by each yard, according to the Executive Project. Topographic surveys, soil compaction test result reports, and photos of the yards in their different execution stages were attached. Then, the ECG Board of Directors, the Economic Procurement Investments Committee, and the Economic Investments Committee were requested for the Agreement to use the yards for mineral filling (operation), which, once approved, was delivered to the lessee (Figure 6).

Figure 6. Base grounds ready for solar drying of latrites ores. Source: Fonseca-Aguilar (2024).

8. Sustainable operation of the base grounds

With the partial commissioning of the finished yards, the deposition of mineral on them began, according to content and quality of the mineral (Ni, Co, Fe, Fe_2O and Si_2O), in rows to form the piles, complying with the storage scheme planned in the project and guaranteeing the reduction of moisture in these deposits (Figure 7).

Figure 7. Mining operations in base grounds. Source: Fonseca-Aguilar (2024).

Likewise, in this stage, the company's Board of Directors was requested to promote the implementation of other research by authors such as Estenoz (2009), Retirado-Mediaceja (2012), and Regalado-Urquía (2023), who also propose the mathematical modeling of the solar drying process, the sustainable use of handling, windrowing, and removal technology for solar and wind drying using highly productive mining equipment, among others.

The procedure included a control and monitoring system from the start of the investment operations. In this stage, insufficiencies were identified that allowed taking timely measures during the operation of the solar drying system. Once the mineral was transferred, yard maintenance works were carried out through topographic survey, control of homogenization of the stored mineral, and its average input moisture in the yards, which should not exceed 37.95%. After its removal, its moisture decreased to 33.00%, representing a 4.95% reduction relative to the input and savings of fuel oil in the Dryers, as well as an improvement in the metallurgical efficiency of the ECG plant (Fonseca-Aguilar, 2024; Table 3).

Table 3. Results of the procedure implementation

Indicator	**Years**			
	2020	2021	2022	2023
Electric energy saving (MWh/año)	6 534.8	7 824.4	8 663.7	9 062.4
Average Production of Ni + Co (t)	72.6	109.2	130.4	167.2

Finally, as part of the system's sustainability, it was proposed to the UBM-ECG that once its functions are completed and the lateritic mineral reserves of the leased deposits are exhausted, these mining constructions be used for other purposes (warehouses, housing, organoponic gardens, others), taking into account their efficiency, economic viability, and the environmental and social impacts produced by each proposal (Guerrero-Almeida et al., 2024). Likewise, the need to rehabilitate these grounds and the construction of new mining facilities for the exploitation of other deposits was pointed out.

4. CONCLUSIONS

- The proposed procedure identifies the main climatic, geological, engineering, technological, economic, and social variables that influence the construction and assembly of nine yards covering an area of 63.1 ha and forming part of the solar drying system for lateritic ores at the Basic Mining Unit of the nickel company Ernesto Che Guevara.
- During its implementation in 2019-2023, the problems presented before, during, and after the operation of the solar drying system were

identified, facilitating the implementation of a set of measures leading to better results in the metallurgical process of the ECG in Moa.

- The results are very useful in guaranteeing the selection, design, construction, characterization, certification, handover, sustainable operation, control, and monitoring of these mining constructions, necessary to ensure an efficient and effective mining-metallurgical process, as well as to improve the quality control system at the Basic Mining Unit of the nickel company Ernesto Che Guevara

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Additional Information

Conflict of interest

The authors declare no conflicts of interest

Contribución de los autores

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