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Wind erosion monitoring at the site of a filtered iron tailings deposit in the Atacama Region, Chile

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ABSTRACT

The Compañía Minera del Pacífico produces iron pellets in a plant located in the city of Huasco in the Atacama Region of northern Chile. The generated tailings (5,000 t/day) will be disposed of in a filtered tailing deposit (FTD), which will begin operations in 2023. The closure law (Law 20,551) indicates that the FTD must be physically and chemically stable at the time of closure of the facility. Additionally, environmental commitments with nearby communities have favored the engineering project incorporating the progressive closure of the FTD, complemented with a Phytotechnological program that includes control of wind erosion and landscape rehabilitation of the area where the facility is located. To avoid problems associated with the emission of particulate matter during operation, closure, and post-closure, a series of measures have been, such as the application of dust suppressants and plant covers, considered. Wind erosion control involves establishing a baseline by monitoring the material moved by saltation before the start of the FTD operation. Wind erosion monitoring using Leatherman traps will be, during operation and upon facility closure, maintained. This paper presents the results obtained in wind tunnel tests and in-situ monitoring with Leatherman traps of wind erosion in the area where the FTD is located, for two years. An analysis of the measurements has been, and the areas most affected by erosion have been determined in the site area, which will serve as input to implement the erosion control measures of the facility, in the operation and closure stages, carried out.

Keywords*: tailings deposit, wind erosion*

1 INTRODUCTION

Chile is a significant producer of both metallic and non-metallic minerals, including metals such as copper, iron, gold, silver, and others. The Antofagasta Region in Chile is home to the oldest iron mine in the Americas, which to be approximately 12,000 years old, has been dated (Castro et al, 2012). The Chilean mining industry currently faces a range of challenges, including a growing and sustained global demand for metals, stricter environmental requirements, the inclusion of community interests in mining projects under development and in those that will be in the future, as well as other sustainable development goals (SDGs), developed.

To address these challenges, Chile has implemented the mining works closure law (Law 20,551) (Ministerio de Minería, 2011), which requires that all projects in operation and new projects ensure the chemical and physical stability of facilities such as mines and massive mining waste deposits, including tailings deposits, during both the closure and post-closure stages, since 2012.

Compliance with the mine closure law, along with the new challenges and trends facing the mining industry, has made it necessary to include the mine closure stage in the design stage. In the case of facilities such as tailings deposits, it is increasingly common to consider the progressive closure of the facility, which begins during the operation stage.

Wind erosion affects soils and mining waste deposits, causing the emission of particulate matter into the atmosphere that affects the environment, productive activities and the inhabitants of the areas near the

facilities. This problem affects massive deposits of mining waste such as tailings deposits and is of concern to mining companies and affected communities. The filtered tailings deposit of the Pellets Plant in the city of Huasco, which will start operating in 2023, must face the challenge of operating while controlling the emission of particulate matter into the urban area at all stages of the life cycle of the facility.

To determine the emissions of particulate matter, a methodology was developed that considered the geotechnical characterization of the materials that are in the site area of the filtered tailings deposit and the tailings that will be stored, along with wind tunnel tests to evaluate the performance of the materials against wind action. Subsequently, a simulation of the wind effect on the site area with and without the project was developed using computational fluid dynamic modeling (CFD), which considered the information generated in the wind tunnel tests. The results of the modeling allowed the design of a wind erosion monitoring program during the entire life cycle of the filtered tailings deposit, which provides information on the baseline of wind erosion in the site area of the facility and background information to define measures to control wind erosion during the operation and closure stages of the facility.

This article presents the preliminary results of the wind erosion monitoring program, implemented from 2020 to date, in the area of the filtered tailings deposit site, which is carried out using Leatherman traps (INN, 2012) and will be maintained during the operation and closure stages of the facility.

2 WIND EROSION AND ITS ASSESSMENT

2.1 Wind erosion

Wind erosion of soil is a natural geological process of landscape evolution, which, due to human activity, has accelerated and become an agricultural and environmental problem worldwide (Memoria Chilena, 2021).

The terms wind erosion and dust emissions are used to describe the interaction of wind and a sediment surface, although they are sometimes used interchangeably, they indicate characteristic but complementary aspects of the same phenomenon. The effects of erosion and the consequent emission of particulate matter into the atmosphere are associated with environmental and productive sector impacts.

In wind erosion, the particles deposited on the surface are set in motion by the wind and then transported and sedimented again at a certain distance, depending on the particle diameter and wind speed. Three types of transport can be identified: rolling, saltation, and suspension, as seen in Figure 1.

Grain saltation initiates the movement of larger, heavier grains, and small dust particles. In saltation, the moving grains collide with other grains, causing the disintegration of the set of grains on the surface, presenting different degrees of mobility. Wind erosion only occurs when there are soil grains that are capable of moving in saltation. The severity of the occurrence of wind erosion depends on the balance between soil, vegetation, and climate conditions.

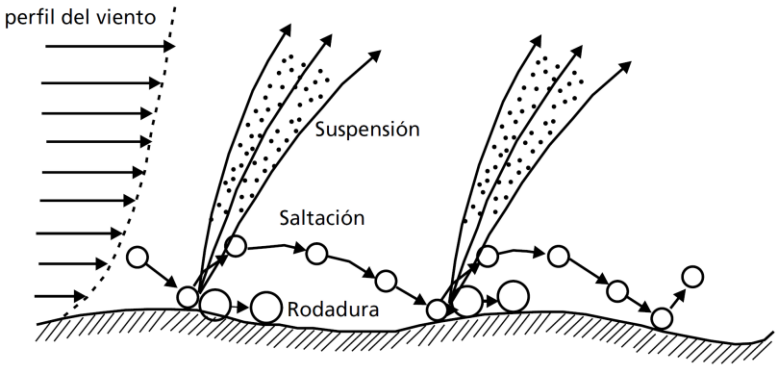


***Figure 1**. Types of aeolian particle transport (Buschiazzo and Airmar, 2003)*

In Chile, mine tailings deposits are generally composed of granular materials, whose granulometries, in general, classify them as silty sands, clayey sands, or poorly graded sands.

2.2 Tailings impoundment evaluation

The evaluation of wind erosion in tailings deposits during the design, operation, and closure stages is a useful decision-making tool when it is necessary to define and implement mitigation measures. Evaluating wind erotion to avoid impacts on the environment, the productive sector, and the population centers located in the area of influence of the deposits.

The proposed methodology for the evaluation of wind erosion in tailings deposits is based on NCh 3266-2012 "Tailings Deposits - Characterization of the particulate matter suppressant product - Evaluation of performance properties of tailings treated with particulate matter suppressant," proposed from the development of research projects carried out at the Pontificia Universidad Católica de Valparaíso, in the period 2007-2012, and includes in situ and laboratory evaluations.

To carry out the wind erosion assessment, a characterization of the tailings deposit site and aspects of the construction project must be performed, including the location of the tailings deposit, type of deposit, geotechnical characteristics of the tailings, topography, and meteorological information of the site, among others.

2.2.1 Laboratory evaluation

The laboratory evaluation of wind erosion requires the implementation of a wind tunnel, which allows the generation of different wind speeds and the material at which its performance is to be evaluated.

Laboratory tests have applications in the different stages of development of a tailings deposit project, as they allow evaluating the behavior of granular materials under different wind speed conditions, allowing to define the baseline and the behavior of the tailings, which can be very beneficial in the design stage of the deposit, allowing to incorporate mitigation measures at this stage. Similarly, in the operation stage when the tailings are already being affected by the wind, and it is expected to quantify the problem more quickly, or when it is required to evaluate the performance of tailings treated with different technologies to suppress dust emission.

The proposed methodology considers the analysis of the wind speeds of the site, the geotechnical characterization of the material to be evaluated and the determination of the wind exposure time. With this information, the laboratory tests will be designed to determine the material performance against wind effects.

2.2.2 On-site evaluation

Measurements at the project site will determine contributing factors for, and establish a baseline of, wind erosion. Specifically, a time-series implementation – i.e., before and throughout all stages – will allow for contrasts of all stages of project development.

Indeed, this study will sample the area where future tailing deposit will be situated, gathering data on speed and direction of the predominant wind, as well as growth stages of tailings deposit following their establishment. To this end, Leatherman traps – among the technologies proposed in NCh 3266-2012 – will be deployed to evaluate the material that moves by saltation, and to measure wind direction and speed. This approach will inform the number, placement, and periodicity of future monitoring sites, as well as establish the validity of this work methodology for monitoring wind erosion at the tailings deposit site.

3 FILTERED TAILING DEPOSIT PROJECT

The Compañía Minera del Pacífico (CMP), a subsidiary of the CAP Group, is the primary producer of iron ore on the American Pacific coast. The company, based in Chile, conducts its main operations in the Atacama and Coquimbo regions. CMP extracts a variety of products from its mining deposits and

plants, which are exported and used as raw materials in the production of steel. The company is responsible for producing 99% of the iron exported from Chile.

Iron is through a magnetic selection process, which generates tailings as a byproduct, extracted. Tailings are composed of a mixture of finely ground solid mineral, water, and other compounds. For years, it has been a challenge for companies to safely dispose of tailings in order to avoid environmental contamination, either due to catastrophic failures or dust emissions caused by wind erosion.

The Huasco Pellet Plant is a mining facility that dates back to 1978, whose objective is to process and add value to the iron-mining product. The plant receives pre-concentrated iron ores from mines located in the Chilean iron belt, and submits them to grinding and concentration through physical processes (gravimetric and magnetic) to generate a commercial product called iron concentrate or pellet feed, with a concentration of magnetite (F_3O_4) over 90%. As a result of this processing, iron tailings are obtained (5,000 t/day), which must be disposed of in a tailings deposit as of September 2023. The tailings produced at the plant will be filtered and transported through a closed belt to the storage area located south of the pellet plant, where it will be loaded onto trucks and transported to the disposal point in the tailings deposit. The filtered tailings will be spread and compacted in layers with heavy machinery according to the design configuration. The design configuration considers arranging the filtered tailings in terraces to minimize the visual effect and ensure the physical stability of the deposit. Figure 2 shows the sector where the filtered tailings deposit is planned to be located.

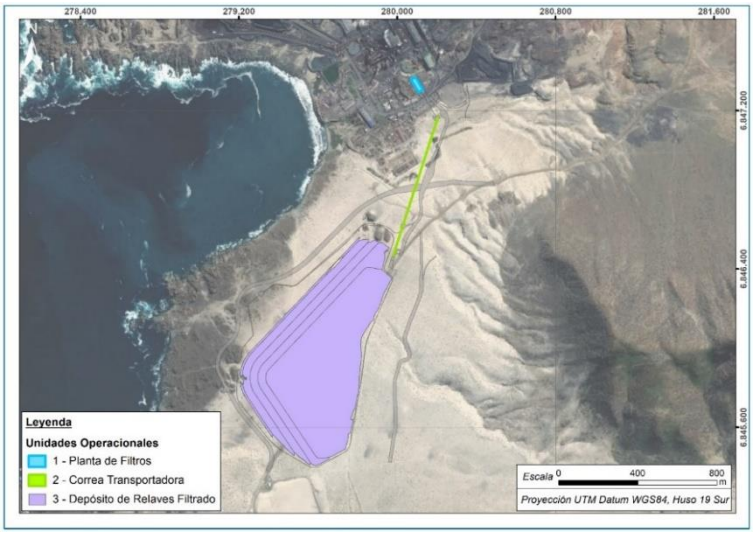


***Figure 2**. Main operational units of the filtered tailings deposit project, CMP (CAP Minería, 2019).*

4 RESULTS

4.1 Laboratory evaluation

The performance of the dune sand, the tailings deposit site, and the iron tailings were evaluated in regards to wind action in order to determine the threshold wind speed at which particle movement begins on the ground. To achieve this, a geotechnical characterization of the dune sand was performed and the amount of material capable of movement at various wind speeds was determined through wind tunnel testing.

4.1.1 Geotechnical characterization of materials

a) Dune sand

The grain size distribution of the dune sand revealed that 100% of the material passed through the #10 mesh, 89% passed through the #40 mesh, 14% passed through the #100 mesh, and 6% passed through the #200 ASTM mesh. This corresponds to a poorly graded sand (silty sand) of the SP-SM classification according to the USCS. The specific gravity (Gs) of the dune sand was determined to be 2.8, with a

minimum density of 1.5 g/cm^3, a maximum dry compacted density of 1.8 g/cm^3 (Proctor Standard), and an optimum moisture content of 18%.

b) Iron tailings

The granulometry of the iron tailings shows 100% of material passing the #200 ASTM mesh, corresponding to a clay of low plasticity (CL), according to the USCS classification. Specific gravity (Gs) 3.18; minimum density 1.0 g/cm^3; maximum dry compacted density 1.9 g/cm^3 (Standard Proctor) and optimum moisture content 18%.

4.1.2 Wind tunnel tests

The tests were conducted in the wind tunnel of the laboratory at the School of Construction and Transportation Engineering of the Pontificia Universidad Católica de Valparaíso. The specimens were prepared by filling metal molds with the material to be tested at a defined density, then installing them in the tunnel, and exposing them to the established wind speed ranges for each material under study, in half-hour increments. For each test, the initial weight of each specimen was recorded, and the weight of the material remaining in the mold was recorded after each half-hour wind application cycle was completed. Each test was performed in triplicate, as shown in Figure 3.

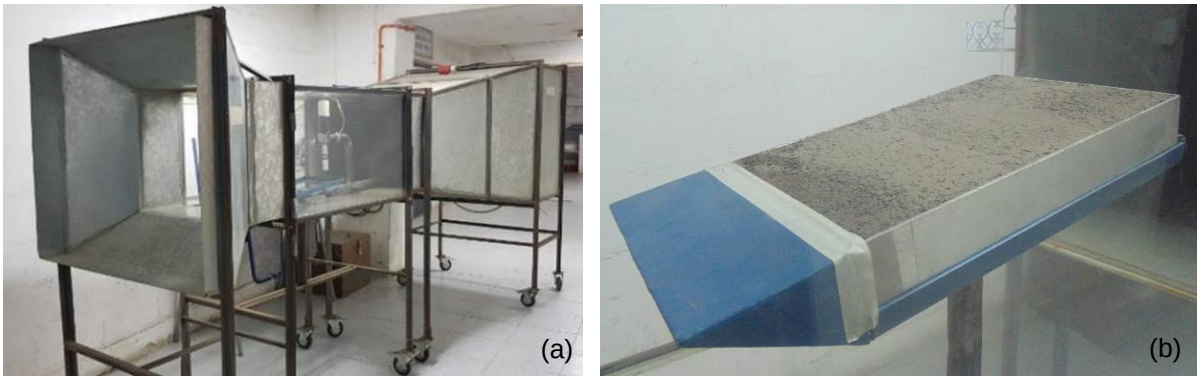


Figure 3. *(a) Wind tunnel, (b) iron tailing specimen filtered in wind tunnel.*

a) Dune sand

Figure 4(a) illustrates the results of the performance of dune sand specimens prepared in a dry state and at minimum density, exposed to wind speeds of 2 m/s, 3 m/s, 4 m/s, 5 m/s, 6 m/s, 7 m/s, 8 m/s, and 9 m/s, in half-hour increments. It can be observed that the threshold velocity, for dune sand at minimum density and in a dry state, is above 6 m/s.

b) Dry iron tailings at minimum density

Figure 4 (b) shows the results of the performance of iron tailings specimens prepared in dry state and at minimum density, subjected to wind steps with velocities of 1 m/s; 3 m/s; 6 m/s; 7 m/s; 8 m/s; 9 m/s; 10 m/s; 11 m/s; 12 m/s; 13 m/s; 14 m/s and 15 m/s; in periods of half an hour per velocity range. It can be seen that the threshold velocity, for the iron tailings at minimum density and in dry state, is above 8 m/s.

c) Compacted filtered iron tailings

The test specimens were prepared by reproducing the layout conditions according to the design project, for which the filtered tailings were compacted to 95% of the maximum compacted dry density (Standard Proctor) and with 18% moisture, and left to rest for approximately 15 hours before submitting them to the wind tunnel test. Figure 4(c) illustrates the results of the performance of compacted filtered tailings specimens exposed to wind speeds of 1 m/s, 3 m/s, 6 m/s, 7 m/s, 8 m/s, 9 m/s, 10 m/s, 11 m/s, 12 m/s, 13 m/s, 14 m/s and 15 m/s, in half-hour increments. A better performance of the compacted filtered tailings against wind action is observed and the low percentages of material loss correspond to losses of surface moisture of the specimen due to wind action. Therefore, it was considered that the wind does not mobilize compacted filtered tailings and a defined value of the threshold velocity is not determined for this material.

4.1.3 Estimated emissions

The results obtained in the laboratory regarding the performance of the dune sand and filtered iron tailings under the action of wind, together with the information on wind characteristics in the site sector, allowed determining the erosion potential and emissions of particulate matter in the situation without the project and for each stage of the project using the friction velocities obtained through computational fluid dynamic simulations (CFD). Figure 5 illustrates the erosion potential defined for the sector in the initial situation and in the final stage of the project, showing that the areas of greatest erosion correspond to the western zone and the upper edges of the reservoir in the final stage of the project.

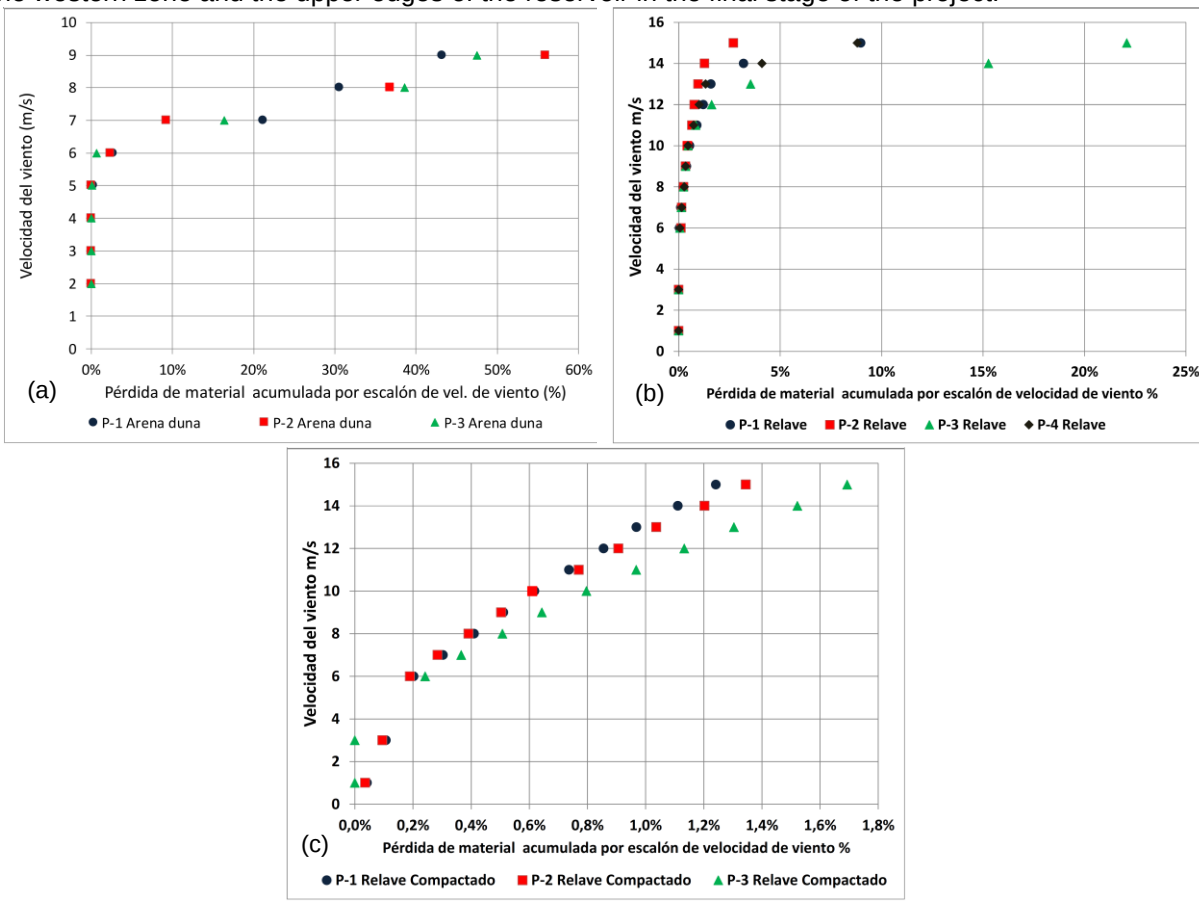


Figure 4. *Percentage weight variations by speed step and cumulative weight variations by wind speed step (a) dune sand in dry state at minimum density (b) dry iron tailings at minimum density (c) filtered and compacted iron tailings (PUCV 2018, PUCV 2019)*

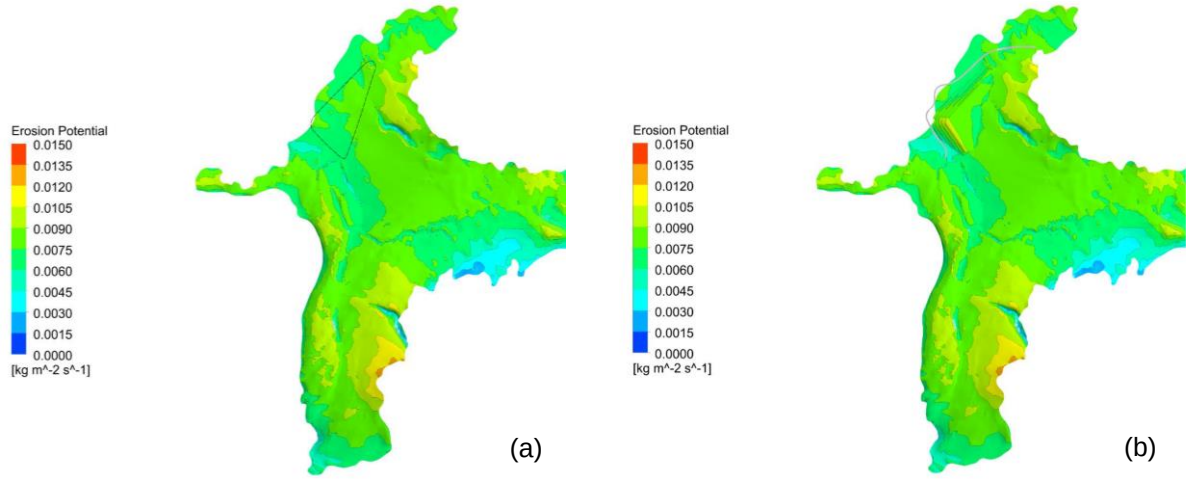


Figure 5. *Erosion potential in the filtered tailings deposit site sector, (a) situation without project, (b) final stage of the project (SYNTEC Ingeniería, 2019).*

On the other hand, the estimation of particulate matter emissions in the site area made for each stage of the project allowed to establish that when the filtered tailings deposit project is implemented, there will be a reduction in total emissions compared to the situation without the project, both during the construction stage and in the final stage of the deposit.

4.2 On-site evaluation

The analysis of the tailings deposit site sector identified seven monitoring points, three within the area where the deposit will be located (points 4, 5 and 6) and four outside this sector, so that the measurement at these points will be continuously monitored over time (points 1, 2, 3, and 7), as illustrated in Figure 6. The analysis of the wind data recorded at the meteorological station located in the study sector established that the predominant wind direction is south-west, which defined the orientation of the Leatherman traps. Additionally, the study of wind speeds identified that these vary according to the season of the year, thus, seasonal measurements were established, conducted every three months.

The seven Leatherman traps were in October 2020 installed, in order to establish a baseline for the sector, as the reservoir is scheduled to begin operation in September 2023. Thus, seasonal measurements have been taken until September 2022, which have confirmed that the predominant wind direction is south-west, indicating that the conditions established in the modeling are accurate.

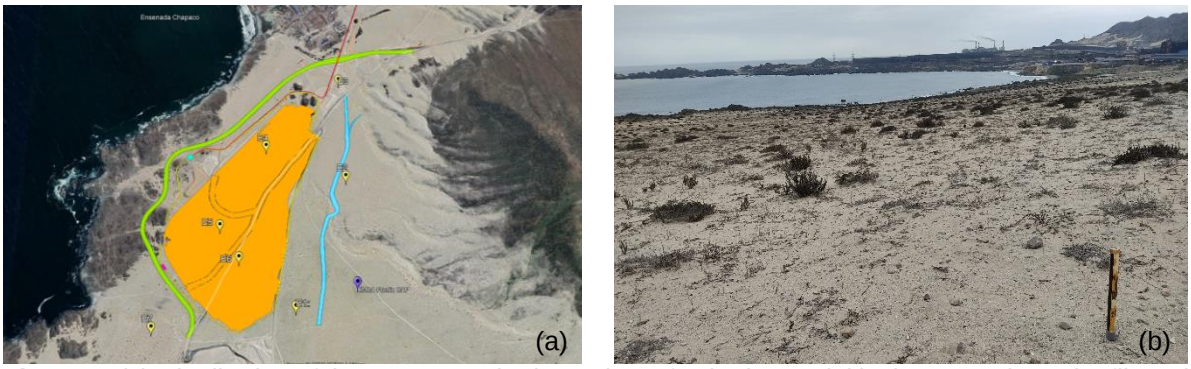


***Figure 6**. (a) Distribution of the seven monitoring points of salted material in the area where the filtered tailings deposit of the Pellet Plant is located, (b) Leatherman trap point 3.*

The results obtained up to September 2022 in the seasonal measurements are illustrated in Figure 7, which depicts the distribution of material collected by each measurement point during the period studied. The preliminary analysis of these results allows for the establishment that point 6 is the one that has presented the greatest amount of material mobilized by saltation, followed by points 3 and 1. When comparing the location of these traps with Figure 3(a), it can be observed that these results correspond

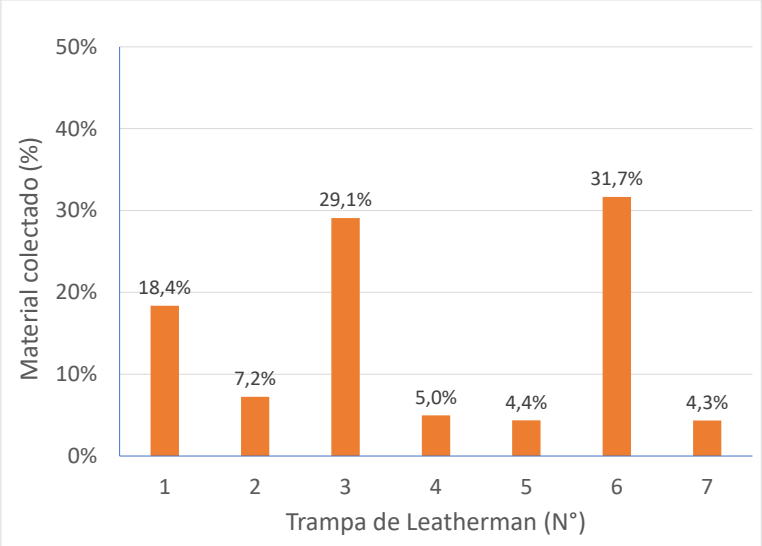


***Figure 7.** Distribution of total particulate matter collected in the study area during the entire sampling period (PUCV, 2022).*

to the erosion potential determined in the modeling. Similarly, points 4, 5, and 7 present a lower erosion potential. A unique situation is presented at point 2, where the modeling indicates erosion potential similar to the points of greater material collection, however, the in-situ measurements do not reflect this situation. Therefore, it is expected to continue with the measurements at this and the other six points to establish the baseline of the project.

5 CONCLUSIONS

The methodology designed enabled the determination, in the laboratory, of the wind speed at which the movement of particles begins, as well as the loss of material generated for each speed step for each material and condition analyzed, such as loose and dry dune sand, loose and dry tailings, and filtered tailings. This information allowed for the CFD simulation of the sector in the situation without the project, during the construction and final stage of the filtered tailings deposit project, which was incorporated in the environmental studies required by the authority for the environmental authorization of the project. These results guided the selection of the Leatherman trap test to measure the saltation material in situ. The results achieved in September 2022 have allowed for the verification of the considerations made during the design stage of the project, and have raised others that are expected to be explained when more information is obtained from the monitoring of wind erosion at the site of the iron filtered tailings deposit. This information will serve as input to implement erosion control measures of the facility, during the stages of operation and closure of the deposit.

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