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OPTIMIZATION OF PARTICULATE SALT FLOW ON A SCREW CONVEYOR USING DEM

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Abstract. *The mining sector is one of the main activities of the Brazilian economy and has been investing in the optimization and improvement of its processes. Screw conveyors are important equipment for transporting raw materials in industries at controlled and constant rates from one environment to another. With the advancement of numerical simulation, it became possible to use models capable of predicting the behavior of the phenomena present, constantly seeking their efficiency, optimization and reduction of project costs. In this context, the present work aims to present a computational modeling study focused on optimizing the flow of salt in a screw conveyor through the Discrete Element Method (DEM). The simulations were performed using the Rocky DEM software and using the same process in all situations, such as screw conveyor length (1 m), axis rotation (350 RPM), inlet flow (10 t/h) and grain diameter (2.5 mm). The results allowed an analysis of the behavior of the salt flow in the screw conveyor, making it possible to detect regions of accumulation. Based on the studied parameters and geometries, also it was observed that the modifications carried out promoted improvements in the screw conveyor performance, increasing the salt flow by approximately 3%.*

Keywords: *Salt industry, Discrete Element Methods, Processes optimization, Rocky DEM.*

1. INTRODUCTION

The Mining activity is one of the main pillars of the Brazilian economy. For this reason, over the years, the mining sector has invested in improving production processes to increase their yield (G1, 2015).

Since the mid XIX century, Brazil began to encourage international companies to settle in the national production park to improve salt production in the Brazilian territory, culminating in the mechanization of the sector (Jales, 2014). In the sea salt production operation, the bottleneck is transportation, despite many advances. Thus, developing and optimizing conveyor projects is of paramount importance to ensure the economic growth of the sector.

The conveyors are important machines for the productive functioning of various industries, since those machines is used to move the raw material throughout its transformation process until it becomes a finished product. Given this, the execution of the production activity through the transportation of materials is made in a shorter time interval when compared to the animal or human labor used before mechanization (Rudenko, 1976).

Before the computational evolution, there was a high expense and time due to repeated experimental realizations by designers in search of optimizations, and, currently, in the designs of screw conveyors is possible to propose changes several geometric parameters/configurations, in order to, through simulation tools, explore the best performance for a given material grain during its transport. Among the existing techniques to predict phenomena of granular materials, the Discrete Element Method (DEM) stands out for providing expressive results and information within the so-called black box in which the helical conveyors are inserted (GVE, 2022).

Within this context, the present work aims to perform the optimization of screw conveyors through simulations through the Discrete Element Method (DEM) using the Rocky DEM software in order to design a geometry that solves problems of particle accumulation inside the equipment, thus increasing the material flow.

2. THEORETICAL REFERENCE

2.1 Salt

The salt can be obtained through two forms, the traditional and the industrial, the first presenting advantages for preserving a greater amount of minerals in its composition, a purer flavor, in addition to not causing damage to health and the environment (Mendes et al., 2012). The production process of salt by solar evaporation (traditional way) is done through steps, these being: capture of seawater, evaporation, crystallization, harvesting, washing, storage and beneficiation (Salinor, 2023). The industrial form is basically carried out with the crystallization of the salts dissolved in seawater through industrial evaporators, the crystallization of sodium chloride and the harvesting and washing (Mendes et al., 2012).

In the market, one can find a variety of types of salt for different types of applications. However, salt is classified according to its composition, processing and characteristics of the grains, following the laws established by the legislation (Brasil, 1975). The main and most used types are: table salt, sea salt, kosher salt, sifted salt or barbecue salt and rock salt.

2.2 Screw Conveyor

According to CEMA (ANSI/CEMA#350, 2019), screw conveyors (T_{Hel}) are machines responsible for transferring materials and are basically composed of a circular tube or U-shaped channel in which, inside, there is a helical spindle that rotates and pushes the materials, transferring them from one point to another. These machines can be designed to operate in a horizontal, vertical or inclined position. Therefore, it is important to identify the direction of rotation and the type of helical control, since both indicate the direction of transport of the materials that occurs by drag.

The T_{Hel} is a machine widely used to transfer materials, which can be through independent transport systems such as loading and/or unloading of certain elements, or as part of a production line, for example, in the industries in salt, mining, agriculture, among others (BSC, 2023).

The T_{Hel} are made up of several components that together perform the function of transporting materials. The main components are illustrated in Figure 1.

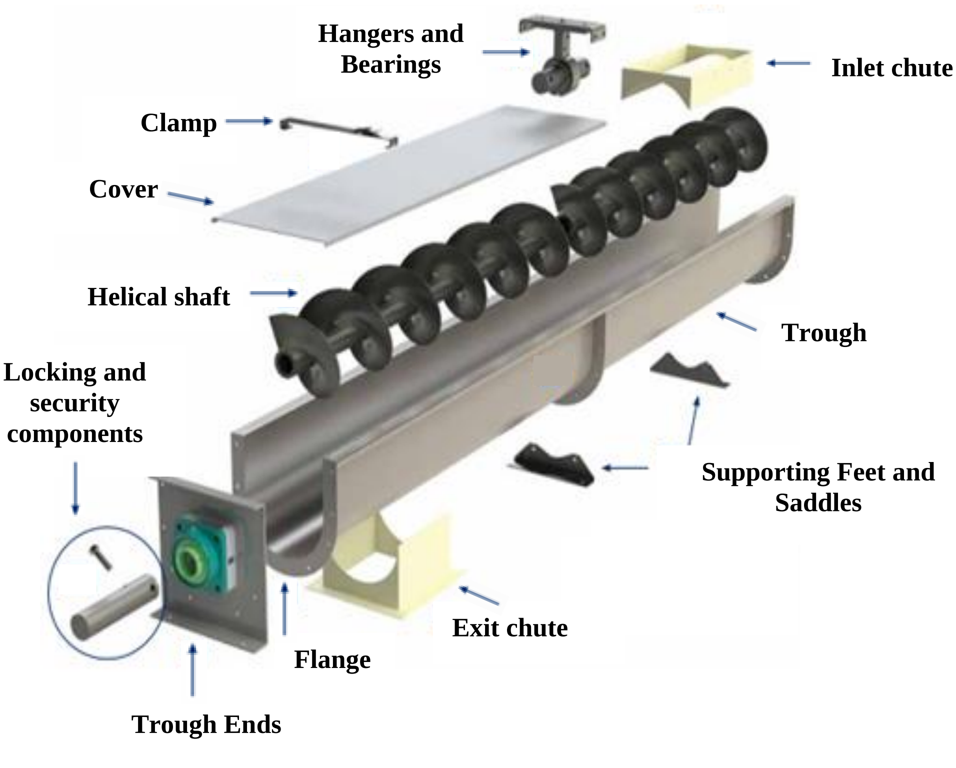

Figure 1. Components of the screw conveyor.

The operation of the THel begins by driving the reducing motor grouped to the helical shaft making the shaft rotate in any direction (clockwise or counterclockwise), transporting the load in a range of rotation depending on the type of material transported. Thus, with the particles goes into through the inlet chute and accumulate inside the trough, until that, when rotating the helical shaft, a portion of materials is displaced, not meeting at the point that was previously, being these materials transferred between the shaft blade and the trough until the point of discharge is reached (McGuire, 2009).

2.3 Discrete Element Method

The Discrete Element Method (DEM) was created by Cundall and Strack (1979) and is considered a numerical model responsible for monitoring and detailing the individual action of a particle in contact with another particle(s) or component(s).

According to Mesquita et al. (2012), DEM is a method of numerical simulation of the movement of various particles (in most cases, developed from easy geometries) inside a fixed or mobile container that varies with time.

The method considers a limited number of discrete particles interacting through contact and non-contact forcesTherefore, at first, the calculation of the relationship between force and motion is performed from information collected from the interaction forces between particles, calculated between the contacts of their components (Zhu et al., 2008).

According to Neves (2009) and Mesquita et al. (2012), in the next moment, Newton's second law is used to establish the velocities and accelerations of each particle, and then the new location of these elements.

For Langston et al. (2004), the use of DEM has some limitations, being the computational cost the main limitation, since the method uses a clear and precise of time integration scheme, repeating the calculations in sequential ways over a delimited period, requiring very low time steps. Another negative point of DEM is the complication when you want to simplify problems or build/analyze ideas considering only a part of a whole.

The DEM is becoming a reference as a method used to analyze and evaluate engineering problems containing granular materials, especially in situations involving particular flow, being possible the application in different branches, such as: soil mechanics, mining, rock fracture, and etc. (Mesquita et. al., 2012).

In summary, the formulation of the DEM exerts a series of supposition in order to facilitate the real problem by despising less important parameters, authorizing the creation of a physical and mathematical model of the problem under study (Huaman, 2008).

The DEM consists of a basic calculation cycle, as shown in Figure 2, in which the main phases of the method are realized.

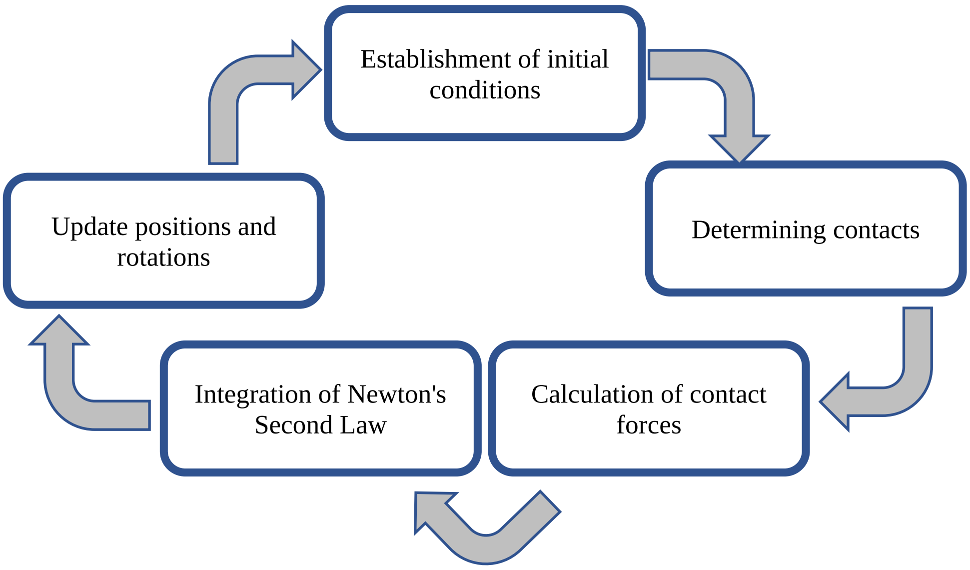

Figure 2. DEM calculation cycle.

Currently, a variety of software use DEM. The software used in the work and that stands out in the market is Rocky DEM®, a powerful 3D particle simulation software that belongs to the company Ansys and can quickly and accurately simulate the behavior of the flow of bulk materials from simple to complex formats, for the most diverse applications such as mills, conveyors, etc. In a comparison between Rocky DEM® and other programs used by DEM, such as PFCTM, STAR-CDTM, EDEM® and among others, Rocky presents more important characteristics, regarding the multi-sphere model used in the aforementioned software (Ansys, 2023). The so-called multisphere is a model of representing a single particle by a composition of connected spheres that can vary in size and even overlap. Furthermore, the model features a contact detection facility, where only minor modifications are required, as opposed to the spherical DEM. Rocky is currently one of the best software for multisphere analysis, as it presents several particle models and can also import models developed in other software.

3. METHODOLOGY

3.1 Object of Study

The object of study of this work is a T_{Hel}, as shown in Figure 3, used in the salt industry during the salt extraction process, precisely in the refinery sector.

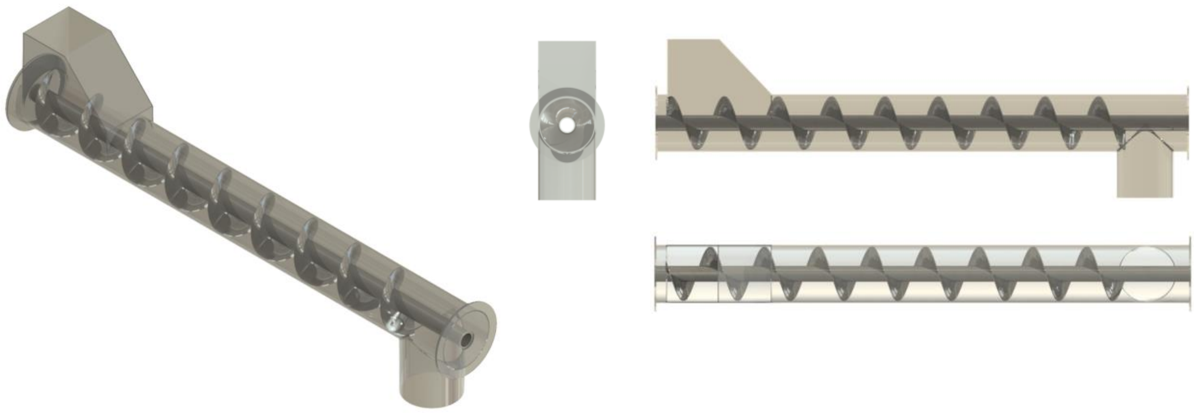

Figure 3. T_{Hel} Project – Original

In the industry, the current T_{Hel} present anomalies regarding the flow of grains, such as discontinuous flow and petrification of salt inside, which causes the accumulation of salt inside the machinery, affecting the productivity of the manufacturing plant. However, because of these bottlenecks related to grain flow, the equipment has successive stops for maintenance where a washing process must be carried out periodically. Thus, in order to reduce the setbacks presented in the T_{Hel}, a study was carried out in the project in order to investigate some geometric parameters (gaps between components of the project at the entrance, output or anywhere that causes accumulation of matter) presented in Figure 4.

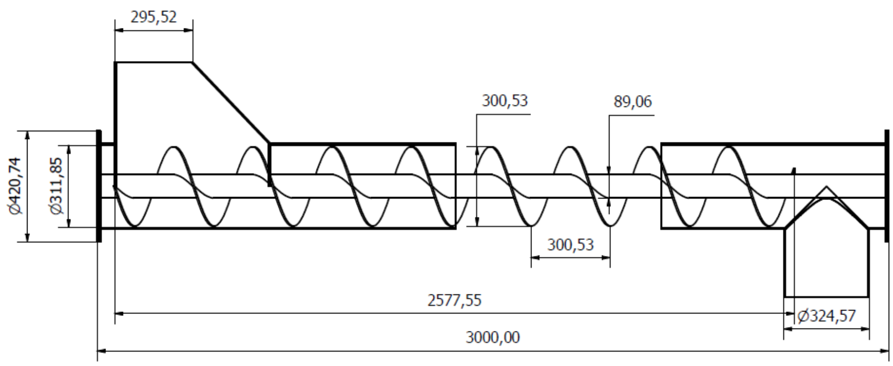

Figure 4. Geometric dimensions of T_{Hel} – Original (dimensions in mm).

Given of the project to be studied, it was found that conducting numerical studies with the DEM would increase the computational cost, making it unfeasible. Therefore, to reduce the computational cost and circumvent this inconvenience was used dimensional analysis and incomplete resemblance as proposed by FOX & McDONALD (2014), where the design of T_{Hel} - Original suffered a reduction of 1:3 in its geometries. Figure 5 shows the dimensions of the main components (trough and Helical shaft) used to perform the computer simulations, called T_{Hel} - Reference.

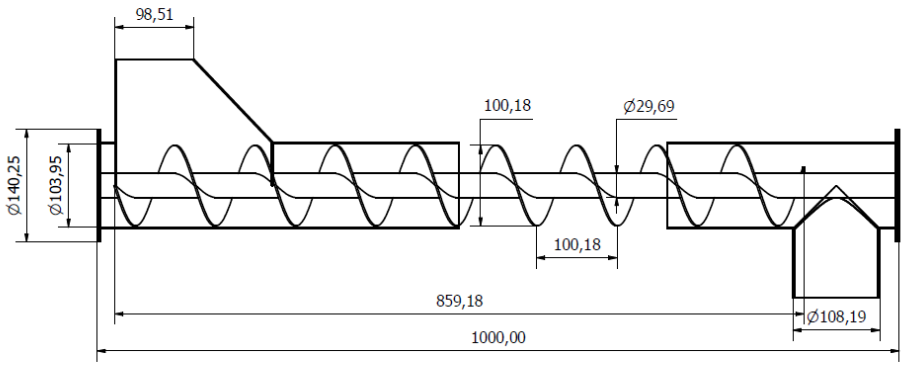

Figure 5. Geometric dimensions of the T_{Hel} – Reference (dimensions in mm).

During the refining process, T_{Hel} is responsible for the transport of grains of various sizes and shapes, being used in this work the salt of the barbecue type, which has a density of 1160 kg/m3 and modulus 20 GPa. To perform the simulations, the hypothesis of spherical shape with a diameter of 2.5 mm (estimated experimentally) for the grains was also adopted.

3.2 Computational Methodology

The computational methodology was divided into four steps that are shown in the flowchart of Figure 6, with the description of each stage presented below.

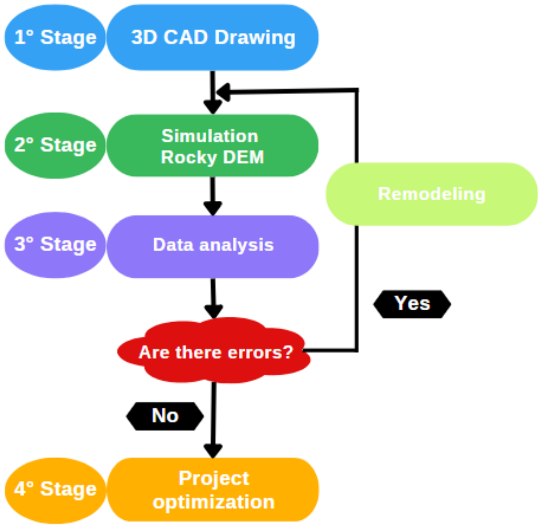

Figure 6. Flowchart of computational methodology.

The first stage consists of the development of the 3D CAD design (modeling and assembly) and modifications (remodeling) of geometric parameters of T_{Hel} - Original through Autodesk Inventor software, educational version of 2023.

In the second stage, the simulations of the granular flow of salt in helical spindle occurred using the Rocky DEM software, which had its license granted as a courtesy by ESSS for the development of this work. In the Rocky software, the project geometries are imported, the parameters to be evaluated and existing configurations are defined in the software.

After the simulations, the third stage began, where the T_{Hel} data analysis was performed. However, after the first simulation with T_{Hel} – Original, it was verified through the flow gradient in the study domain that the transporter presents possible regions of salt accumulation, as well as zones susceptible to productivity gain. A posteriori, changes in the geometric were made to minimize the inconveniences detected, always seeking to optimize the process and increase productivity. This analysis was based on the investigation of the following aspects:

1. Behavior of salt flow within the helical conveyor;
2. Graphical analysis of the curves generated by the software itself.

In the last stage, the optimization of the project was performed based on the best results obtained for each variable analyzed, being called T_{Hel} - Optimized. This result was compared with the T_{Hel} - Reference in order to estimate the increase in plant productivity.

3.3 Boundary Conditions

To perform the simulations, some boundary conditions were defined responsible for defining how the salt interacts inside the THel. Among the conditions used are: input region (inlet chute), shaft rotation (350 RPM) and load flow (10 t/h). The analyses were always evaluated in a time span of 0-2s with each output frequency 0.05 seconds in order to obtain a more accurate analysis.

4. RESULTS

4.1 Flow Analysis at the T_{Hel} - Reference

The Figure 7 shows the flow lines of the salt particles from the entrance in the transporter (red region) to the exit (blue region). It is noticed that in the region near the entrance, there are grains that should have already left, but due to the anomaly of the flow, it could not maintain the trajectory until the exit and was in a region of stagnation.

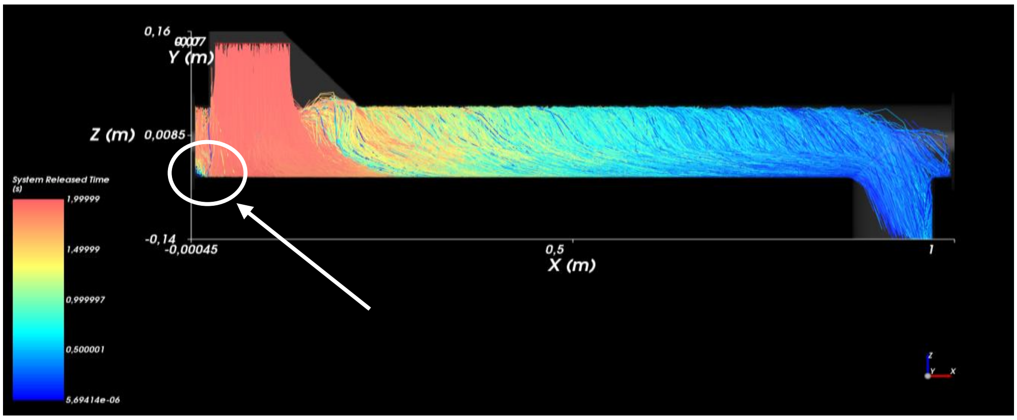

Figure 7. Trajectory of particles.

The Figure 8 shows the amount of total grains used in the simulation and the amount of particles inside, where the difference shows the amount of salt that came out of the T_{Hel} (40346 grains). This parameter is important to estimate/quantify the proposed improvements.

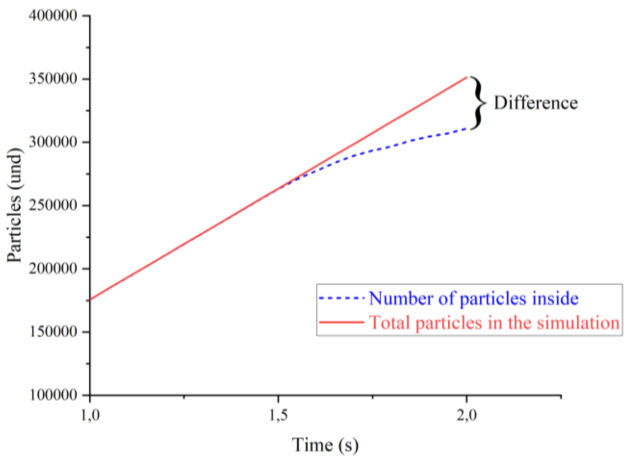

Figure 8. Amount of grains throughout the simulation.

The Figure 9 shows the behavior of the velocity of a particle inside the T_{Hel} – Reference, which had its maximum of approximately 2.57 m/s, with an average of 2.32 m/s over the entire time studied. The characteristic of formation of valleys and peaks presented, most likely reports the interaction of the particle with other particles, as well as the particle with the structure of the trough and/or the helical shaft that rotates at 350 rpm.

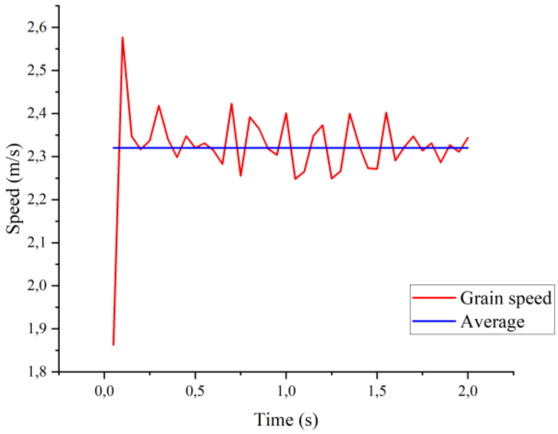

Figure 9. Behavior of the speed of a grain inside the machinery.

The Figure 10 shows the cumulative sum of the mass of the particles present inside the T_{Hel}, at time 2s, where it is possible to estimate a value of 4.92 kg of salt, which consequently predicts a flow of 8.86 t/h, showing that there is accumulation, because the inflow is 10 t/h. From time 0 to 1.6 seconds the curve presents a linear trend, which over time tends to stabilize as the flow appears at the THel exit, that is, the flow is in the transient state tending to stationary.

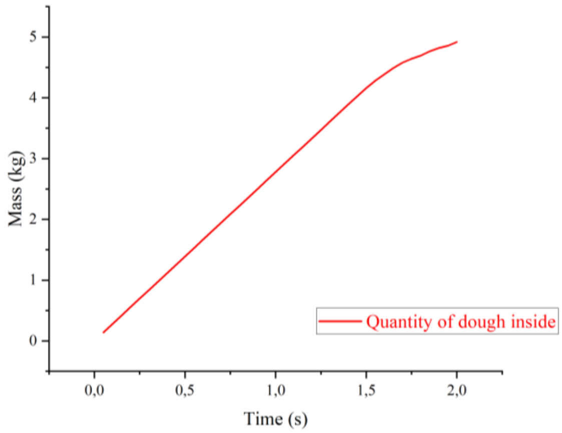

Figure 10. Mass present inside the machinery.

In the exit chute, a survey of the grains can be made at the exit of the machinery. The Figure 11 shows that the first particles leave the output region in approximately 1.40 seconds. The behavior of the line demonstrates an oscillation of particles that occur due to the passage of the propeller, this happens when the axis rotates transporting each step a quantity of particles, being not uniform because it is not yet with stabilized flow.

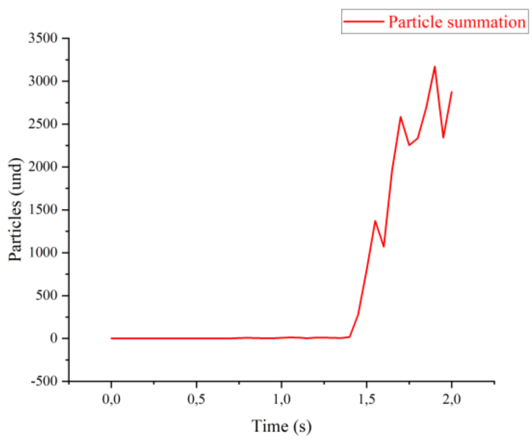

Figure 11. Behavior of the grains at the exit of the machinery.

4.2 Analysis and Evaluation of Geometric Modifications of Possible Accumulation Regions

From the simulation of T_{Hel} – Reference, it was possible to identify zones of accumulation in three different regions by means of different colors, as observed in Figure 12.

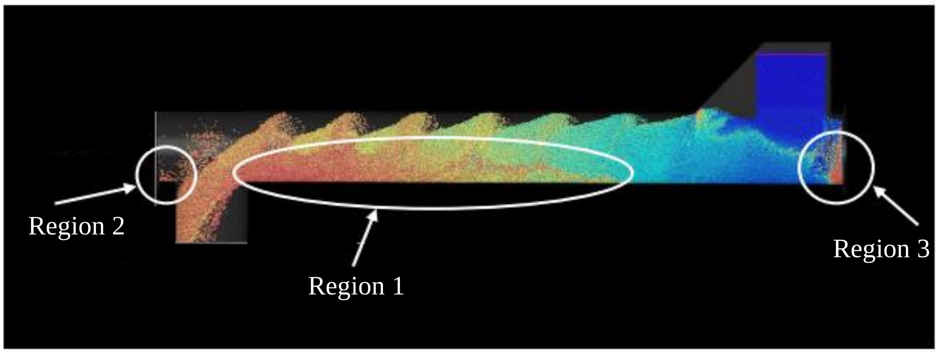

Figure 12. Accumulation regions (left side view).

Based on the Figure 12, it was possible to identify the regions of accumulation. The regions are: Region 1 (Clearance R1: Gap existing between the trough and the propeller, this clearance being greater than the diameter of the grain what causes the accumulation); Region 2 (Clearance R2: Clearance between the inlet trough and propeller, obtaining the same justification as region 1); Region 3 (Profile R3: Space in the trough after the exit chute, where some materials become "stuck" in place).

Therefore, the remodeling of the T_{Hel} – Thus, 2 new projects were analyzed from the T_{Hel} - Reference for each condition (region), where the clearance belonging to the regions shown in Figure 12 were changed. The modifications made started from the idea that the gap between the components must be smaller than the diameter of the grain, which justifies the solution of the problem, since the grain will not stay or pass between that intermediate.

The Table 1 shows the variables of the original design and those that were modified for analysis in region 1, being developed two new projects with modifications made in the diameter of the helical shaft, in order to combat the accumulation generated by the space between the trough and the propeller. After the modifications in the geometry, the simulations were made and then the data analyses were performed. Through the results obtained, it was possible to conclude that R1.2 presented the best result of the three projects regarding the flow of particles that left the T_{Hel}.

Table 1. Variables of the clearances of Region 1 for the study in mm.

	Clearance R1	Clearance R2	Clearance R3	Nomenclature of project	Total particles that came out of T_{Hel}
Region 1	3,12	16,67	R_{ef}	R.Ref	40346
	2,50	16,67	R_{ef}	R1.1	39679
	1,88	16,67	R_{ef}	R1.2	47162

With the geometry that presented the best result in region 1, two more new projects were developed with modifications made in region 2 (length of the propeller in relation to the inlet trough ends). The variables to be modified are presented in Table 2, as well as the values referring to the amount of flow in each nomenclature acquired at the end of the simulation data analysis, with R2.2 presenting the best performance.

Table 2. Variables of the clearances of Region 2 for the study in mm.

	Clearance R1	Clearance R2	Clearance R3	Nomenclature of project	Total particles that came out of T_{Hel}
Region 2	1,88	16,67	R_{ef}	R1.2	47162
	1,88	9,34	R_{ef}	R2.1	47345
	1,88	2,00	R_{ef}	R2.2	49862

Finally, the modification was carried out in region 3, that is, the implementation of geometry at the exit of the trough in order to direct the flow of particles that are trapped in the region after the T_{Hel} exit trough. The modification occurred in the geometry of the R2.2 project since it presented better flow performances in region 2 and the geometric shape implemented can be seen in Table 3. Thus, comparing the results obtained for Regions 1 and 2, it was possible to observe that the R2.2 project pointed out the best particle flows.

Table 3. Variables of the clearances of Region 3 for the study in mm.

	Clearance R1	Clearance R2	Clearance R3	Nomenclature of project	Total particles that came out of T_{Hel}
Region 3	1,88	2,00	R_{ef}	R2.2	49862
	1,88	2,00	Prismatic	R3.1	47358

4.3 Optimized Screw Conveyor Global Efficiency Analysis

The Figure 13 shows a comparison of T_{Hel} - Optimized (R2.2) with T_{Hel} - Reference (R.Ref) in relation to the amount of particles that are located inside the screw conveyor and the total used during the simulation at the time instant of 2 seconds. In the analysis, R2.2 presents a greater difference than R.Ref in relation to the total, since in the end it transported a greater number of particles. Thus, the T_{Hel} – Optimized presented approximately 2.71% of global gain in relation to the particles that left the equipment, which implies a gain in the company's productivity.

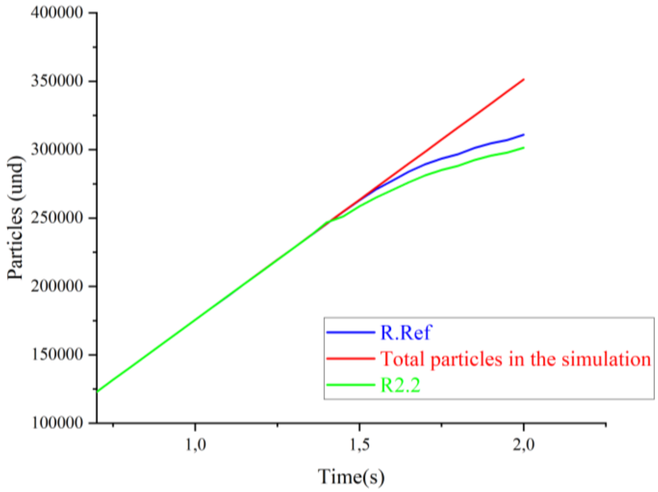

Figure 13. Comparison between T_{Hel} - Optimized and T_{Hel} - Reference.

With the results related to the flow of grains, it can be stated that the R2.2 contributes to possible improvements in the production process, with a flow of approximately 9.1 t/h, precisely 2.71% more than the T_{Hel} – Reference, which presented 8.86 t/h. Therefore, the company with small investment, can make the modifications in T_{Hel} – Reference, thus increasing the production due to the flow and obtaining a faster financial return.

5. CONCLUSION

Based on the results, it can be concluded that the computational model and the methodology employed were able to predict the behavior and phenomena present in a granular flow during the operation of a screw conveyor used in the refinery sector of the salt industry.

The change in clearance for the R1.2 configuration presented the best results in region 1, implying a 2% increase in the overall flow in relation to R.Ref. In the change of clearance of region 2, R.2.2 showed better responses with an increase in global flow in relation to R1.2 of 0.77%. In region 3, R3.1 presented a drop in flow compared to R2.2 of 0.71%, which impaired the efficiency of the process.

Therefore, R2.2 is the geometry that presented the best results, being considered T_{Hel} – Optimized and presenting a percentage of efficiency in the conveyor of 2.71%, indicating improvements inside the screw conveyor. The optimization of geometric parameters in the screw conveyor is of great importance, as it helps to eliminate errors and/or bottlenecks in the process, avoiding periodic stops and maintenance.

Finally, it can be concluded that the present work managed to achieve its objectives, being possible to reduce the accumulations inside the screw conveyor, generating a greater efficiency of the equipment and a greater productivity process.

6. ACKNOWLEDGEMENTS

Due thanks to the company ESSS for granting the license of the Rocky DEM software for the accomplishment of this work.

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8. RESPONSIBILITY NOTICE

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