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Assessment of Iron Ore Loss in the Rainwater Drainage Process: A Qualitative Approach to Railway Transport

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Abstract

The transport of ore between the mine and the port by railways is normally done using open wagons. Atmospheric environmental effects as the accumulation of rainwater along with the cargo is a typical problem in countries with tropical climates, such as Brazil, and must be addressed carefully. Depending on the volume stored, there will be extra fuel consumption or even cargo loss during movement through the drainage systems installed at the head or floor of the wagon. This work evaluated the mass loss of pellet feed iron ore during water drainage using a reduced-scale experimental setup. Drains printed on a 3D printer with 0.6 mm openings were used, arranged in an acrylic tower with side and bottom compartments for drainage. The study focused on analysing the effects of the cargo height above the drains, since channelling can lead to a significant mass loss. It was observed that for a height of 100mm, the laterally positioned drain allowed the channelling formation with a mass loss of ore above 11%, while for the bottom drain, the loss was less than 5%. As the ore loading column increased, the mass losses during drainage were significantly lower.

Keywords: heavy haul transport, pellet feed, drainage, gondola-type wagon, vibration, water.

1 Introduction

Some advantages of transporting iron ore by railways, compared to other modes, include the cargo volume per wagon, speed, and energy efficiency. However, cargo losses during rail transport can be significant if not properly managed, leading to concerns such as continuous contamination of the railway track, corrosion of components, and environmental impacts that may result in fines from regulatory authorities [1,2].

In the specific case of iron ore, two important aspects must be considered when evaluating the efficiency of rail transport, yet they are scarcely addressed in the scientific literature: water accumulation over the ore load (referred to as free water) and mass losses during drainage. Once rainwater enters the wagons, it penetrates the material via capillary forces. Finer particles lead to greater pore saturation and reduce intergranular air. Natural saturation or surface moisture retention can occur when the absorption capacity of the material is exceeded by the precipitation rate [3].

When particles mix with water, the drainage process can induce sudden flow movements toward the outlet along preferential paths within the load. Preferential flow paths of water, hereby referred to as water channelling, can induce erosion near drain openings, since the fine ore particles are equal to or much smaller than the designed drain openings. In the case of ore wagons, accumulated rainwater induces water channelling through the drain openings, with contact between the free water at the surface and the drain potentially directing flow more strongly.

Figure 1 shows the placement of drains in a typical gondola-type wagon (a), illustrating cases of partial loading due to track limitations that prevent full utilization (b), as well as overload beyond the wagon's available volume (c). Additionally, the figure depicts the formation of free water (d) on the load at the end of transport. When drainage is inefficient due to clogging of the drains by internal accumulation of ore in the slit openings, rainwater accumulates on the surface of the load, resulting in the formation of free water.

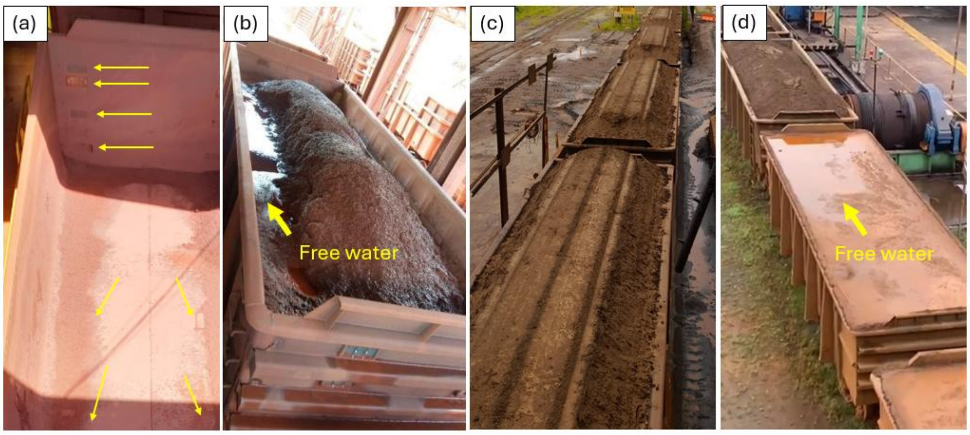

Figure 1: (a) Headboards and floor drains of the wagon, (b) partial and (c) overloaded ore loading, and (d) free water formation at the end of transport.

As illustrated in Figure 1(b and c), ore loading does not always fill a wagon to its maximum capacity. This means that the internal volume of the wagon may be filled to varying degrees, depending on factors such as railway capacity. Figure 2 illustrates two typical loading scenarios showing partial loading (brown) and overloading (gray). The distances D1 and D2 between the top of the load and the drain can vary both

during loading and after vibration from movement along the railway track, influencing the drainage of free water. Top drains at the headboard may be fully exposed to air, partially covered by ore, or completely covered, even for the same loading. This distance directly affects rainwater drainage, as it requires percolation through the ore particles before the water can reach the drains located below the top of the load. Field observations of erosion near the wagon heads indicate ore loss and subsequent ballast contamination at some points along the track.
Some studies in the literature suggest that increasing the openings of drain slots for the drainage of this type of ore to prevent clogging is not always desirable, as the loading approach may be more important than the design of the drain itself. [4,5].

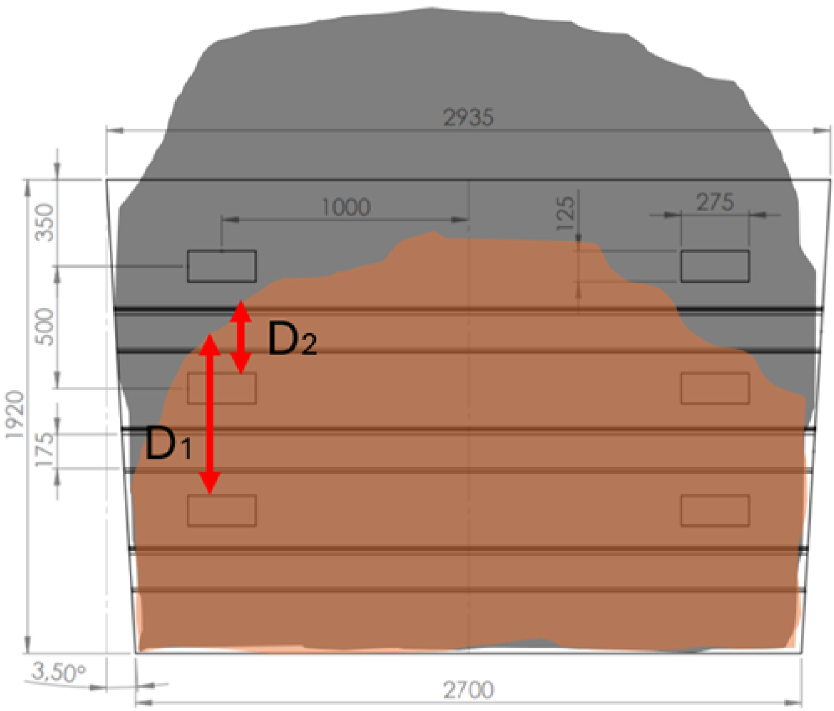

Figure 2: Distance between drains and the surface of the loaded ore after compaction.

The present study aims to evaluate these scenarios of the percolation and drainage behaviour of pellet feed iron ore considering different loading heights above lateral and bottom drains. A reduced-scale experimental setup was employed, consisting of an acrylic column to facilitate the identification of water channelling formation. Drains with slot openings of 0.6 mm, corresponding to those used in field applications, were utilized to identify potential waste ore.

2 Materials and Methods

2.1 Particle size distribution and experimental setup

The iron ore used in the experiments was of the pellet feed type. The granulometric test was performed using an electromagnetic sieve shaker (model SP-1100, SPLABOR). The analysis employed a series of sieves with mesh sizes ranging from 0.045 mm to 0.710 mm, in accordance with the ABNT NBR ISO 4701:2020 standard [6].

Two acrylic towers were employed to simulate the rainwater drainage process within the railcar bodies (Figure 3a). The internal dimensions of the towers are 80 mm x 80 mm x 500 mm. Incorporated in the bottom and size are interchangeable drains, providing versatility to be tested with various configurations (Figure 3b). The drain with slit open of 0.6 mm was tested, produced using a 3D printer with ABS polymer material. The geometry of drain contains 45 slit openings in an area of 6400 mm2 and a thickness of 6 mm (Figure 3).

Vibration induction in the apparatus (Figure 3c) is achieved through vertical impacts, using an eccentric motor containing a striker pin controlled by a frequency inverter attached to the bottom of the table. To quantify the vibration, an accelerometer sensor (Lynx SNS-ABS05 ±8g in ADS500 LYNX controller) was employed. More information about the apparatus can be found in [3].

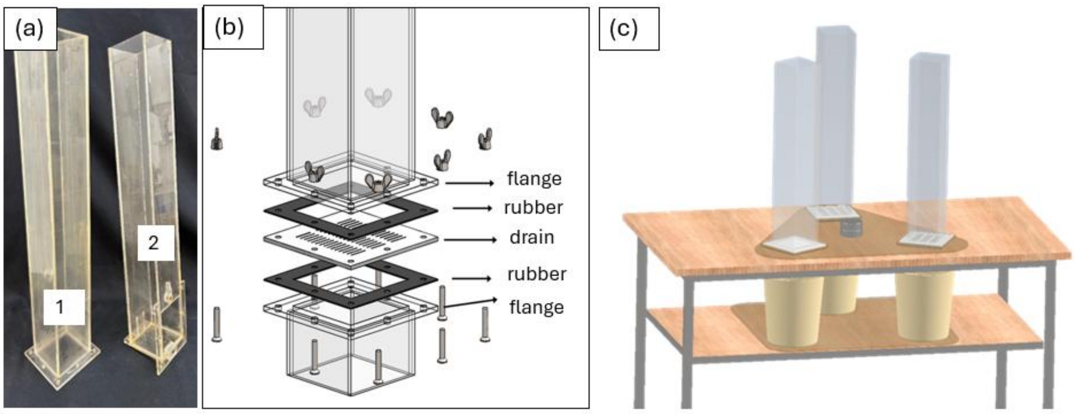

Figure 3: (a) Acrylic towers, (b) interchangeable drains and (c) disposition of towers on experimental apparatus.

2.2 Experimental procedures

In the initial stage, a 1500 g sample of pellet feed was subjected to drying in a kiln oven at 110 °C for 24 hours to ensure the complete removal of environmentally absorbed moisture. Subsequently, 145g of deionized water (~9.69%) was added to achieve moisture content corresponding to 100% saturation. The resulting saturated ore was then carefully introduced into the acrylic tower, ensuring a uniform distribution across its cross-sectional area.

From the columns filled with saturated ore, a mass of 1000 g of deionized water was added from the top using a dropper, in order to avoid the formation of channelling within the packing. After the water was added over the ore volume, the experimental apparatus began to vibrate through activation of the eccentric motor. The experiments were conducted until complete drainage, when no free water could be observed on the ore surface. The water drained together with the ore passing through the drain is collected to measure the mass of ore lost. The arrangement of the ore volume over the bottom drain can be observed in Figure 4a, and for the lateral drain, in Figure 4b.

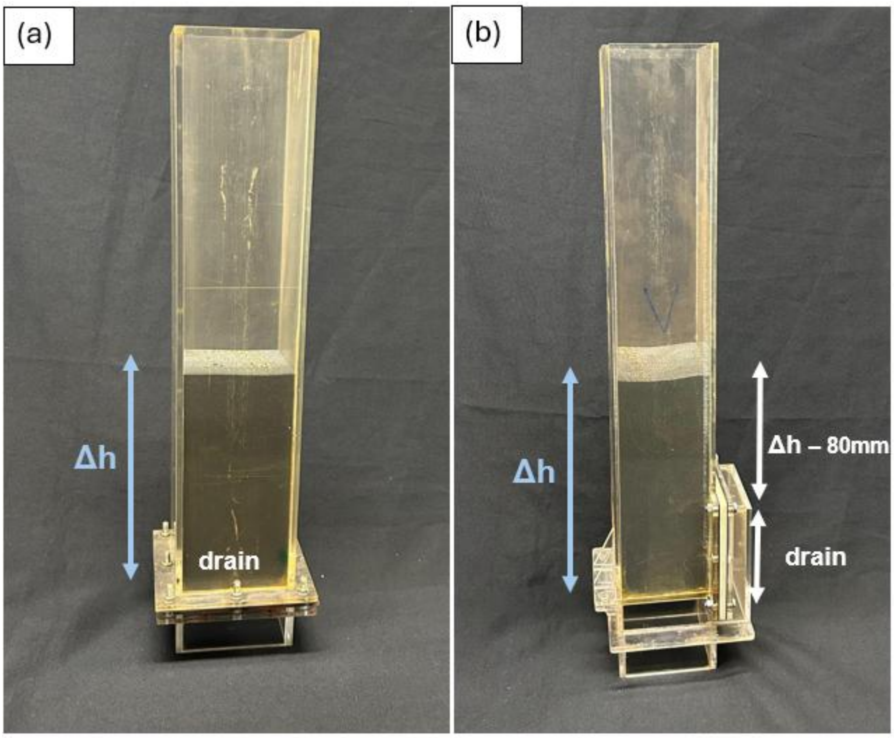

Figure 4: Pellet feed ore placed over the bottom (a) and lateral (b) drains, indicating the Δh distance above the drain prior to the onset of vibration.

3 Results

The particle size distribution of the pellet feed is shown in Figure 5. It can be observed that most of the particles retained in the sieves of the granulometric test have an average particle diameter smaller than 1 mm, representing a fine fraction resulting from metallurgical processing.

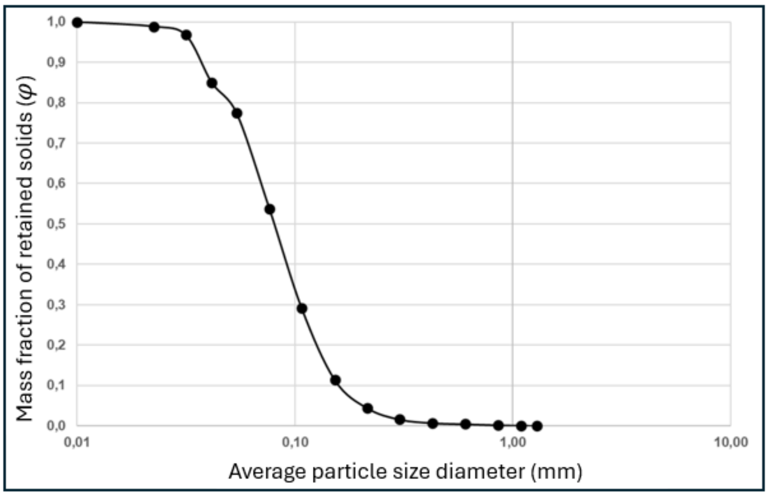

Figure 5: Pellet feed average particle size diameter.

For understanding the decay graphs of the water column height, Figure 6 schematically illustrates the path of water under the two drainage conditions: bottom and lateral. During the experimental procedure, water tends to percolate in a downward vertical direction toward the bottom drain. For the lateral drain, the lower part of the test column is initially isolated, leading to water accumulation at the bottom, followed by lateral percolation for drainage. Since the ore is initially fully saturated, with 100% moisture at the start of the experiment, water retention and accumulation between particles is negligible. As the test rig is vibrated, the ore column height at the end of the drainage period is always lower than the initial height due to the induced compaction. All tests were performed in triplicate, and the results presented correspond to the average values.

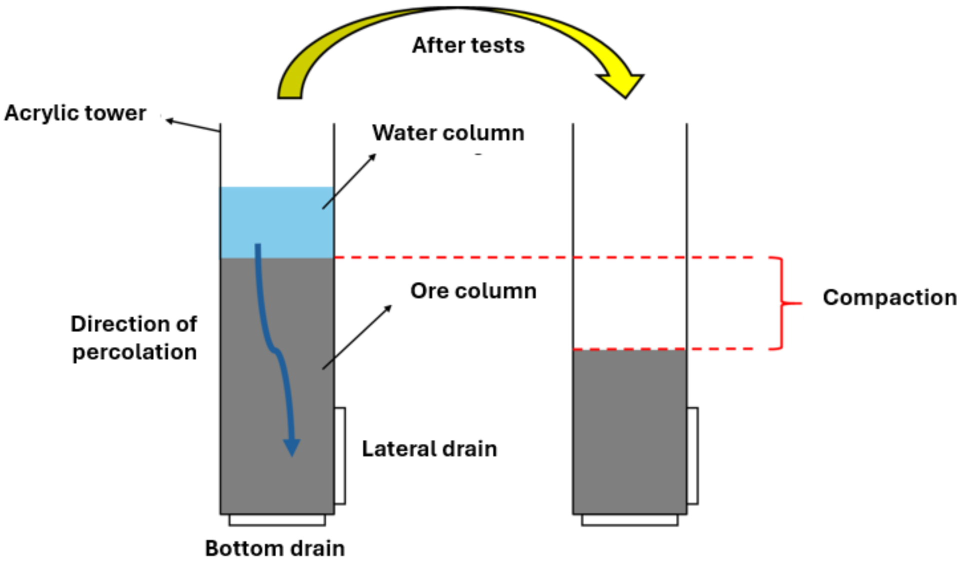

Figure 6: Illustration of water percolation and drainage in the test columns.

Figure 7 shows the frequency and amplitude of the vibration induced in the columns over a 3-second time interval. No parameter in the literature specifies the vibration of an instrumented wagon for comparison purposes, maybe due to installation difficulties and operational costs. In this study, vibration is treated as a parameter accompanying the proposed analyses, aimed at contributing to comparative literature.

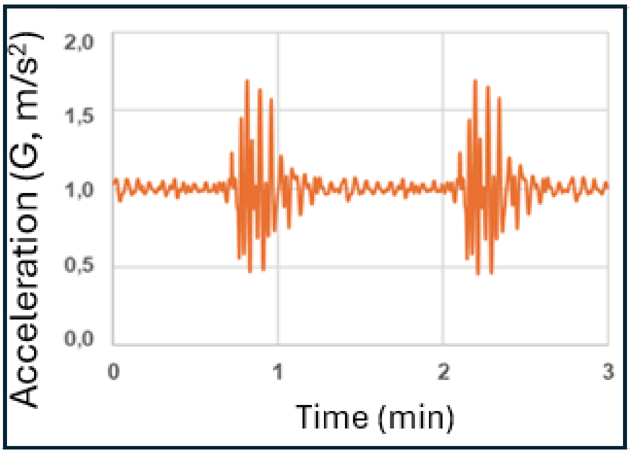

Figure 7: (a) Amplitude and frequency of the towers in the vibrated apparatus.

Following the drainage tests with induced vibration, the acrylic columns with bottom drains containing compacted ore are shown in Figure 8. In all cases, a reduction in the ore pile above the drain was observed. No channelling was observed for all cases.

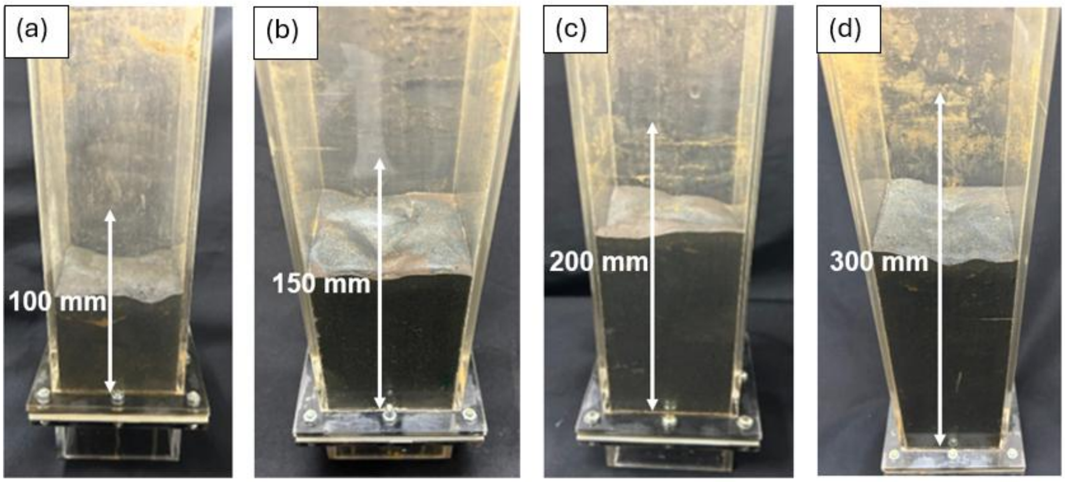

Figure 8: Arrangement of ore after total drainage test with induced vibration and subsequent compaction for the initial ore heights: (a) 100 mm, (b) 150 mm, (c) 200 mm, and (d) 300 mm.

For the columns with lateral drains, the drainage behaviour remained similar to that observed for the bottom drains, except for the ore column with 100 mm above the drain. In this case, Figure 9 highlights the formation of channelling, where water more intensely wastes the ore particles. When this phenomenon occurs, a significant amount of material is transported due to erosion generated by the agitation of the flow.

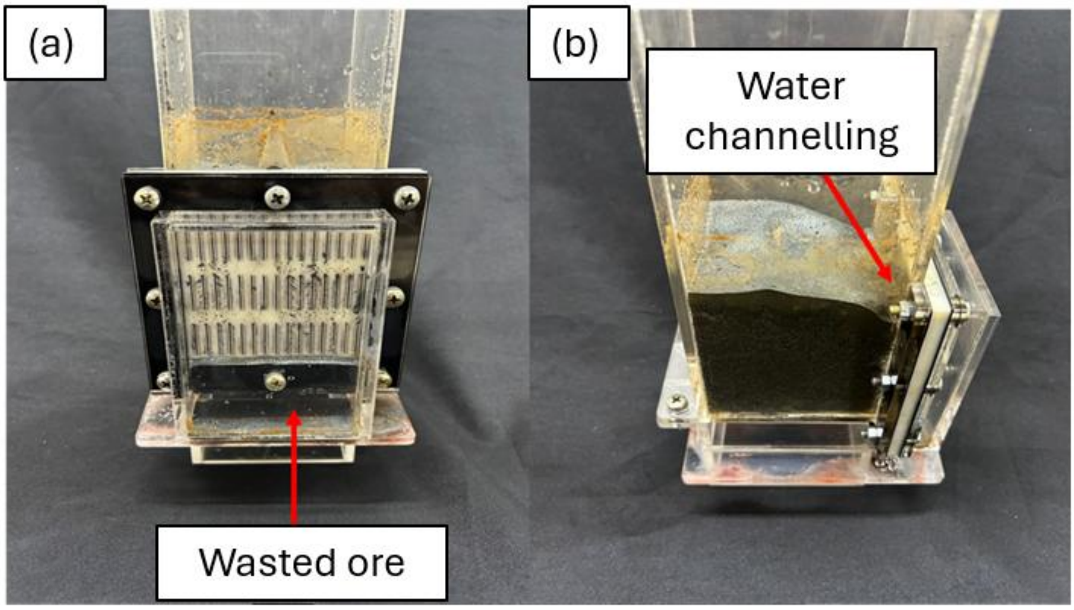

Figure 9: (a) Wasted ore and (b) formation of channelling in the test with a 100 mm pellet feed loading height above the lateral drain.

Figure 10 shows the variation in water column height above the ore for loading heights of 100 mm, 150 mm, 200 mm, and 300 mm. The average time required for complete water removal was 160 min, while the ore column exhibited an average compaction of approximately 24%. Figure 11 presents the decay profiles of the water column height for the same loading heights, except for the 100 mm case, where instantaneous water loss occurred due to the formation of channelling. The average drainage time for the lateral drain was around 150 min, significantly shorter than that observed for the bottom drains, as the lateral configuration facilitates water removal due to its closer proximity to the top of the column. Compaction remained consistent at approximately 24% across all cases, For the 100 mm loading height, the ore allowed the drain to remain exposed to free water throughout the experiment, which had a height of 80 mm and promoted channelling.

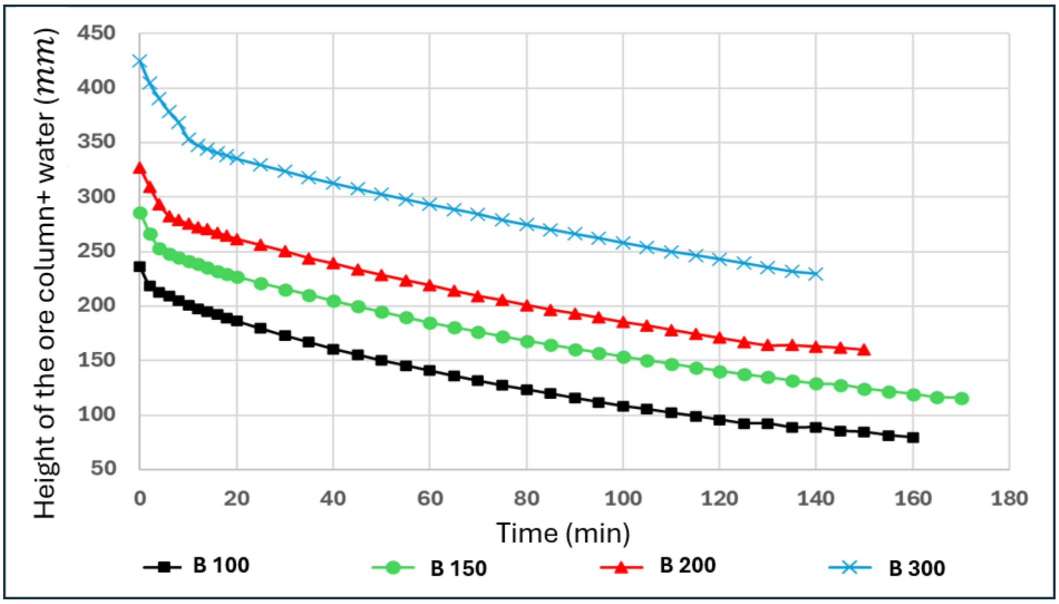

Figure 10: Decay profile of water level over the ore column for different loading heights above the bottom drain

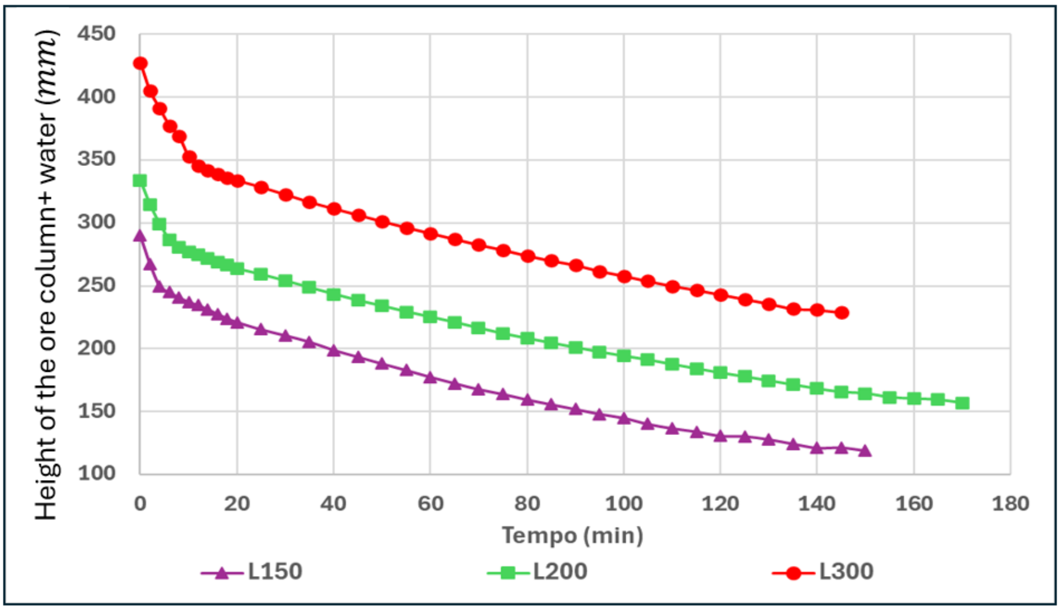

Figure 11: Decay profile of water level over the ore column for different loading heights above the lateral drain

It was observed in Figure 12 that as the loading volume, and consequently the ore height increases, less ore waste occurs. The most significant waste was observed for the lateral drain, where exposure of the drain occurred at a loading height of 100 mm. In this case, a waste percentage of 11% was recorded.

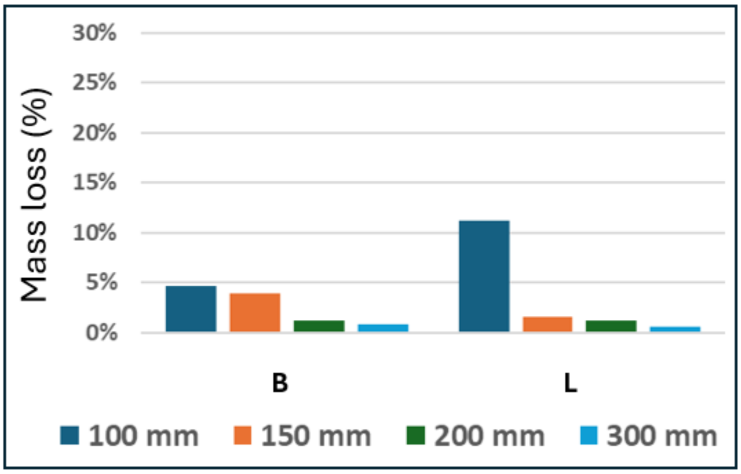

Figure 12: Pellet feed waste to bottom (B) and lateral (L) drains for different ore loading heights.

The analysis of these results represents a relatively small volume when compared to the size of a full-scale wagon. Therefore, the percentages reported here do not directly reflect the values that would be observed in practical field conditions, as the percentages are calculated over a very small ore volume. However, the main contribution of this data lies in informing loading logistics. Whenever ore is loaded in such a way that accumulated rainwater can reach an exposed drain above the load, channelling form, causing significant losses near the drain. This occurs because pellet feed ore consists of very fine particles that can easily be carried into drain slots.

Recent studies have indicated that drain slot openings larger than 0.6 mm for pellet feed can lead to significant losses. This factor cannot be entirely avoided in railway or transport, as the commodities transported are often mixed [5]. Other ores, such as sinter feed, exhibit completely different behaviours from pellet feed and require larger slot openings. Since the same wagons are used for ores with differing morphological and granulometric characteristics, alternative solutions to current slotted drains should be considered to minimize losses along the track.

The consequences of these losses extend beyond ore volume. For instance, ballast contamination is another undesired outcome in this transport mode, as ore accumulation over time can become significant. Additionally, water accumulated on the load can be quantified in terms of fuel consumption. For long compositions exceeding 200–300 wagons, the effect becomes considerable. For example, assuming a surface area of approximately 30 m² per gondola-type wagon, each 50 mm of accumulated water corresponds to an additional mass of 1.5 tons per wagon.

This study is part of a larger project in which commercial drains are being tested on a large-scale bench to more accurately validate mass losses associated with drains used in gondola-type wagons under real field conditions.

4 Conclusions and Contributions

This work established a direct correlation between mass loss and loading volume during drainage of pellet feed iron ore through laboratory-scale experiments. Low loading heights allow lateral drains to become exposed after a certain degree of compaction, forming channelling that carry ore particles through the drain openings. This phenomenon highlights a critical consideration for loading gondola-type wagons in real cases, which may be exposed to rainwater during transport. Free water accumulated on the surface tends to be drained toward the wagon head, and a significant mass of ore can be lost through channelling, even when drain openings are as small as 0.6 mm.

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