PNEUMATIC CONVEYING OF DENSE-PHASE SPRAY-DRIED POWDER AN ENVIRONMENTAL ALTERNATIVE TO CONVENTIONAL TRANSPORT

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ABSTRACT

The transport of spray-dried powder between the companies in the Castellón ceramic sector, as well as the transfer that occurs inside the ceramic companies themselves up to the press feed, constitutes, with the methods used at present, a significant source of spray-dried powder spills, product losses, and dust emission into the atmosphere.

The present work provides and justifies the use of an alternative spray-dried powder transport system: pneumatic conveying. This system always handles and conveys the product in completely closed containers and airtight pipes. Thus, it avoids any type of dust emission and/or spills into the environment, and provides a response to one of the most stringent, legally binding demands of the Integrated Environmental Authorisation [1].

In this study it has been experimentally verified in an industrial facility that this type of transport causes no breakage of the granules that make up the spray-dried powder, or drying of the powder. By keeping the moisture content and size distribution of the granules constant, the system allows the physical properties of the spray-dried powder to be held steady, assuring optimum development of the pressing operation. The study is rounded off with a comparative analysis of electric power consumption by pneumatic conveying and by traditional spray-dried powder transport systems.

1. INTRODUCTION

In the ceramic tile manufacturing process it is necessary to conduct a great number of spray-dried powder transport operations, spray-dried powder being one of the most important raw materials in this industry. These transfer operations take place in the transport systems at the spray-drying facilities during the charging, transport, and discharge operations of the dump trucks that supply the tile production plants, and in the own manufacturing installations, involving transport from the storage silos to the press feed. In the course of such operations, spray-dried powder is spilled and dust emissions occur into the atmosphere, which cause product losses and contaminate the environment [2][3]. This situation is aggravated in Castellón province by the high concentration of ceramic tile manufacturing companies.

At present, spray-dried powder is generally transported inside the facilities by means of conveyor belts and bucket elevators, which are equipped with powerful extraction systems to minimise the powder spills. Despite the use of these extraction systems, it is very difficult to keeping material from escaping and, for this reason, it is necessary to seek an alternative to these transport systems. Such an alternative is the use of dense-phase pneumatic conveying, which is suitable for this application. In effect, dense-phase pneumatic conveying allows the spray-dried powder to be transported in a fully airtight form through a pipe in a gaseous phase consisting of air. This type of transport displays the peculiarity of taking place at a low rate of advance, which allows maximum separation of the gas stream from the semi-processed raw material, favouring impelling rather then dragging the spray-dried powder [4][5].

Using this system, transport from the spray drying facilities to the tile production plants would take place in hermetically closed tank tracks, which would be discharged through closed pipes directly into the storage (silos) or consumption points. Similarly, inside the tile manufacturing companies, the spray-dried powder would be conveyed using impellers and fully airtight pipes, with the ensuing advantages of safety, cleanness, and substantial benefits for the environment.

The machinery manufacturing company Talleres Jois, in its constant development of pneumatic conveying-based technology for the Spanish ceramic cluster, has currently installed these systems, with different configurations, at several companies in Castellón.

2. OBJECTIVE

With a view to verifying the technical feasibility of dense-phase pneumatic transport of the spray-dried powder, a study has been conducted, first, of the integrity of the spray-dried powder granules and the evolution of powder moisture content throughout the entire pneumatic conveying system installed by Talleres Jois. The electric consumption associated with the generation of the compressed air required to drive the different charging systems present in the same installation has then been analysed.

3. EXPERIMENTAL PROCEDURE

To study the effect of dense-phase pneumatic conveying on the properties of the spray-dried powder, sampling was done at different points of the installation in order to compare the sample properties and determine whether the material underwent any type of degradation during transport. The following sampling points were selected: at the supply truck delivering the spray-dried powder to the plant, storage silo inlet, silo outlet, and at the press feed system.

The characterisation tests were carried out on a red stoneware tile composition and on a red earthenware tile composition. Transport of the earthenware tile composition from the supply trucks to the storage silos was performed by means of a multiple-delivery system driven by a 1000 l impeller; in contrast, transport of the stoneware composition took place by a system with a single delivery of 27 Tm. In regard to transport from the storage silos to the press feed, both compositions were conveyed by a multiple-delivery system with 1000 l impellers.

The collected samples were characterised by the tests described below [6].

3.1. DETERMINATION OF SPRAY-DRIED POWDER MOISTURE CONTENT

In order to determine the moisture content of the different samples taken, a part of the sample was dried in a laboratory oven at 110ºC to constant weight. The mass loss corresponded to the moisture content. The test was performed in triplicate and the average was calculated.

3.2. DETERMINATION OF THE GRANULE SIZE DISTRIBUTION OF THE SPRAY-DRIED POWDER

In order to determine the granule size distribution of the collected spray-dried powder samples, an array of 750, 500, 300, 200 and 125 μm sieves was used with receptacle to collect the sieved fraction. The empty sieves were weighed and arranged from small to large mesh aperture, the top sieve having the largest aperture. A sample consisting of 50 g material was placed on the top sieve with moderate vibration for seven minutes. The fractions retained by the different sieves were then weighed, as well as the smaller size fraction collected under the sieve. The test was conducted at least twice and the average was calculated.

The results obtained were plotted for ranges of granule size equally spaced every 100 μm, for which it was necessary to construct the cumulative grain size distribution and interpolate the results for the desired granule size values.

3.3. OBSERVATION AND PHOTOGRAPHY WITH THE STEREOSCOPIC MICROSCOPE

In order to determine whether the spray-dried powder agglomerates that constituted the different samples degraded during transport through the installation, these samples were deposited on a glass sample holder and were observed with a stereoscopic microscope fitted with a camera.

3.4. DETERMINATION OF THE SPRAY-DRIED POWDER FLOW RATE

The flow rate of a particulate material is defined as the speed at which the material flows through an orifice located at the bottom of a receptacle containing the material, expressed in volumetric flow (cm3/s) or mass flow (g/s) units [7].

A flowmeter, consisting of two metallic funnels arranged one above the other, shown in Figure 1, was used to determine the flow rate. The top funnel was fitted with a mechanism that allowed the bottom funnel to be filled without any action by the operator, while the bottom funnel was equipped with a rapid release trap that allowed the material discharge to be initiated at the desired moment. The experimental procedure consisted of depositing the test material in the top funnel and then activating the device that allowed the material to fall into the bottom funnel. When all the material had been emptied, the trap in the bottom funnel was opened and the time it took for all the material to be discharged was determined. The flowability or mass flow rate was determined as the quotient between test material mass and the emptying time of the bottom funnel. The test was conducted at least twice for each sample and the average was calculated.

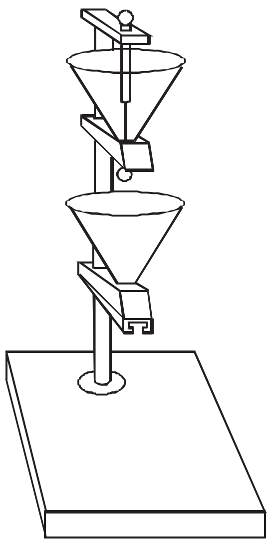


Figure 1. Experimental assembly for the measurement of the flow rate of a particulate material.

3.5. MEASUREMENT OF GRANULE MECHANICAL STRENGTH

Granule hardness was indirectly determined in a universal testing machine at a displacement rate of 2 mm/min. The test consisted of forming a test piece by pressing, recording the pairs of values applied load–powder bed height. These values then yielded a graph similar to the one shown in Figure 2.

The intersection point of both stretches of the plot defines the yield point or yield pressure (P_f). This value is directly related to the hardness or mechanical strength of the granules.

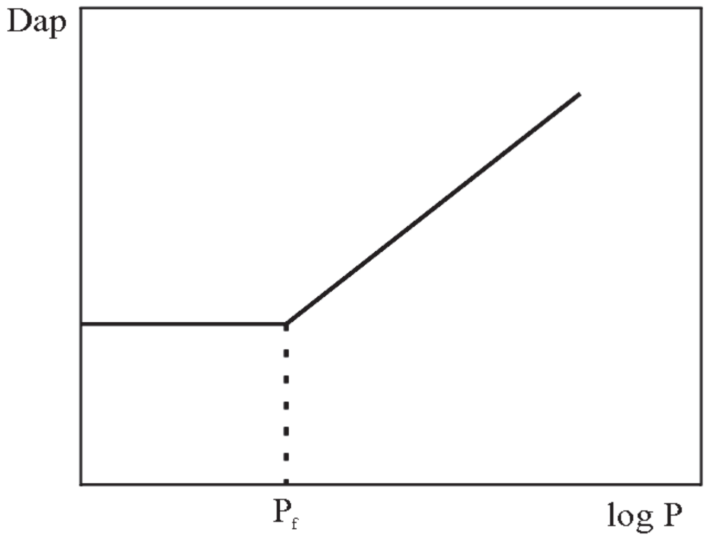


Figure 2. Model of the compaction diagram of a granulated powder.

3.6. RESISTANCE TO WEAR BY ATTRITION OF THE SPRAY-DRIED POWDER GRANULES

In order to determine the resistance to wear by attrition of the granules of the spray-dried powder compositions, tests were conducted to determine the quantity of material that degraded when a sample of spray-dried powder, contained in a plastic cylindrical receptacle, was rotated on a frame.

During rotation, inter-granule friction and the friction between the granules and the walls of the receptacle lead to the progressive break-up of the spray-dried powder agglomerates and the comminution of the particles that make up the material. The smaller the wear resistance of the spray-dried powder granules tested, the larger is the quantity of degraded material.

These tests were performed using 30 g spray-dried powder with a particle size distribution between 400 and 500 μm, obtained by previously sieving the initial sample. After putting the spray-dried powder into the plastic container, this was rotated on the frame for two minutes. The sample was then sieved and the percentage of degraded material was determined as the quotient between the quantity of material that passed through the 400 μm sieve and the quantity collected on this sieve. The material collected on the sieve, with a particle size larger than 400 μm, was put into the container again and rotated for another 4 minutes, after which the sample was sieved again to determine the quantity of material that had degraded during this time. The test continued like this for a total rotation time of 15 minutes.

3.7. ANALYSIS OF ELECTRIC POWER CONSUMPTION BY THE PNEUMATIC CONVEYING FACILITY

The study of electric power consumption by pneumatic conveying was conducted on the spray-dried powder charging process from the charging of the reception hopper by the dump trucks to the silo inlet, using both the multiple-delivery impeller system (red earthenware tile composition) and the single-delivery impeller system (red stoneware tile composition). The power consumption analysis was performed using an electric grid analyser. Prior to each test, the average compressor consumption associated with the generation of the compressed air needed to meet the demands of the plant was determined, halting the pneumatic conveying facility. This average consumption was then used to determine the electric power consumption associated with the pneumatic conveying facility during the charging phases of the storage silos, calculated as the difference with respect to the overall consumption (plants + transport system).

4. RESULTS AND DISCUSSION

4.1. EFFECT OF PNEUMATIC CONVEYING ON SPRAY-DRIED POWDER MOISTURE CONTENT

Table 1 gives the average spray-dried powder moisture content at the different sampling points. Analysis of these data reveals that the variation observed in spray-dried powder moisture content, for the different sampling points and compositions, is very small. The existing differences could be due to the error in the methodology used (sampling, airtightness of the sample storage containers, time elapsing between sampling and measurement, etc.) in sample collection.

Composition	Sampling point			
	Truck	Silo inlet	Silo outlet	Press
Red stoneware tile	6,0	5,9	5,9	6,1
Red earthenware tile	6,2	5,8	5,6	5,7

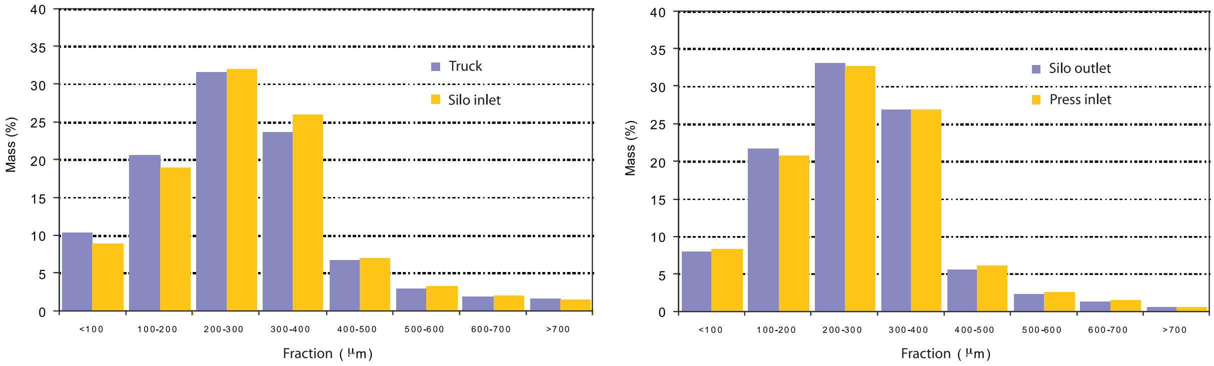
Table 1. Average moisture content of the spray-dried powder samples collected in the pneumatic conveying facility.

4.2. EFFECT OF PNEUMATIC CONVEYING ON GRANULE SIZE DISTRIBUTION OF THE SPRAY-DRIED POWDER

Figures 3 and 4 present the average granule size distribution of the different collected samples. It may be observed that there are only significant differences in the particle size distributions of the red earthenware tile composition between the silo outlet and the press feed system (Figure 4).

Parallel to these results, with a view to determining the error made in the determination of the granule size distribution of the different collected samples, it was decided to study the reproducibility of the measurement method used. For this, a quantity of spray-dried porcelain tile powder was taken and dried beforehand in an oven to eliminate the effect of humidity on the test, from which 10 samples of 50 g each were obtained. These samples were tested with the same sieve array used previously to determine the granule size distribution of the samples, following the procedure described.

The reproducibility is observed graphically in Figure 5 by a plot of the average particle size distribution together with the error bars corresponding to the calculated



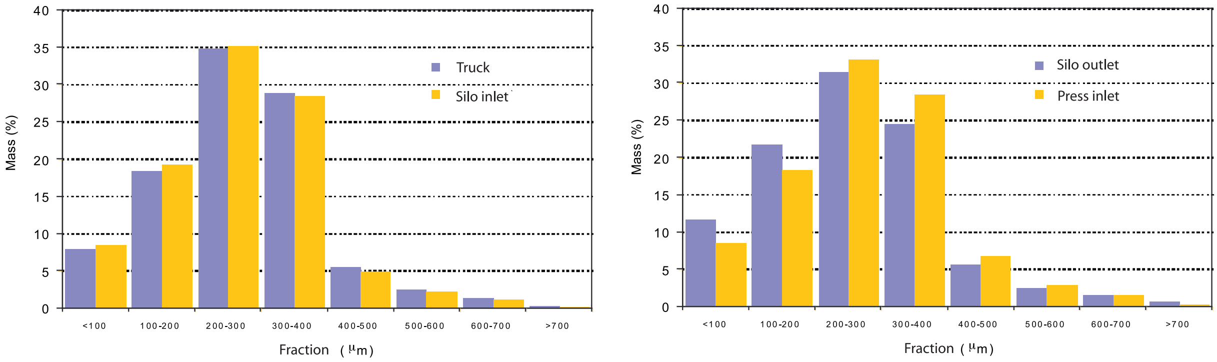


Figure 4. Granule size distributions of the red earthenware tile composition: truck and silo inlet (left), silo outlet and press inlet (right).

average values. It may be observed that in no case did the relative error exceed 1%. The same test was then conducted with the same composition but at a moisture content of 6%. The results obtained were similar to those presented here and the relative error did not exceed 1% in any case.

Fraction (µm)	Average (%)	Deviation (%)	Error (%)
<100	10,7	1,5	± 1.0
100-200	20,1	1,2	± 0,8
200-300	30,5	0,5	± 0,3
300-400	21,7	0,7	± 0,5
400-500	7,8	0,7	± 0,5
500-600	3,7	0,5	± 0,3
600-700	2,4	0,3	± 0,2
>700	3,1	0,6	± 0,4

Figure 3. Granule size distributions of the red stoneware tile composition: truck and silo inlet (left), silo outlet and press inlet (right).

The results obtained with the red stoneware tile composition (Figure 3) indicate that the differences found in the particle size distributions measured at the different sampling points are similar to the error of the method (Figure 5). Therefore, the pneumatic conveying system used does not modify the granule size distribution of the spray-dried red stoneware powder.

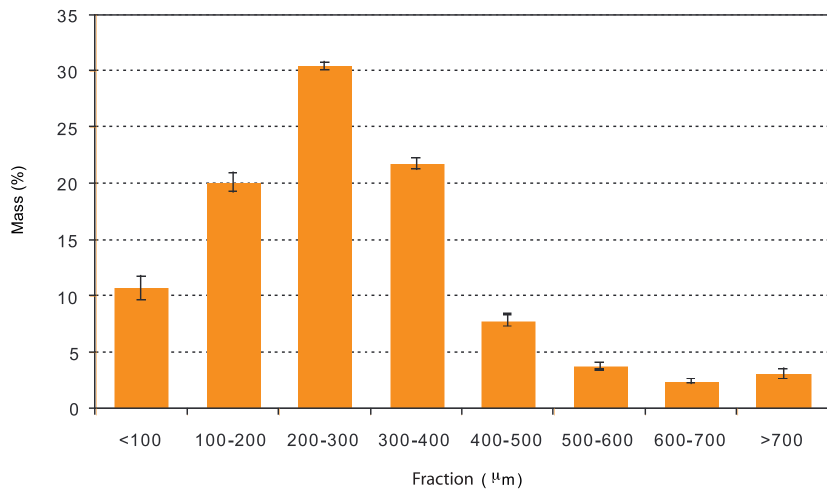


Figure 5. Granule size distribution obtained in the study of the reproducibility of the measurement method used.

With regard to the red earthenware tile composition, significant differences were found between the particle size distributions at the silo outlet and the press inlet (Figure 4 right). However, the finest particle size distribution corresponds to the sample collected at the silo outlet, whereas it might have been expected (if there was a degradation of the spray-dried powder granules from pneumatic conveying) that the finest distribution would be found in the sample collected in the press feed system and not at the storage silo outlet. For this reason, it may be inferred that the differences noted are certain to be due to errors made in sampling.

Therefore, analysis and comparison of the particle size distributions show that the granules of both the red stoneware tile composition and of the red earthenware tile composition undergo no significant degradation during conveying at any point in the installation.

4.3. OBSERVATION AND PHOTOGRAPHY WITH THE STEREOSCOPIC MICROSCOPE

Observation in the stereoscopic microscope of the red stoneware tile and earthenware tile compositions (see Figures 6 and 7) shows that both compositions conserve the sphericity of their particle agglomerates throughout the entire transport, confirming that these compositions undergo no significant degradation during conveying, as also inferred from the analysis of their granule size distributions. Examination of the photographs only allows noting a slight reduction in size of the agglomerates, which occurs in both compositions, during transport from the silo outlet to the press feed system.

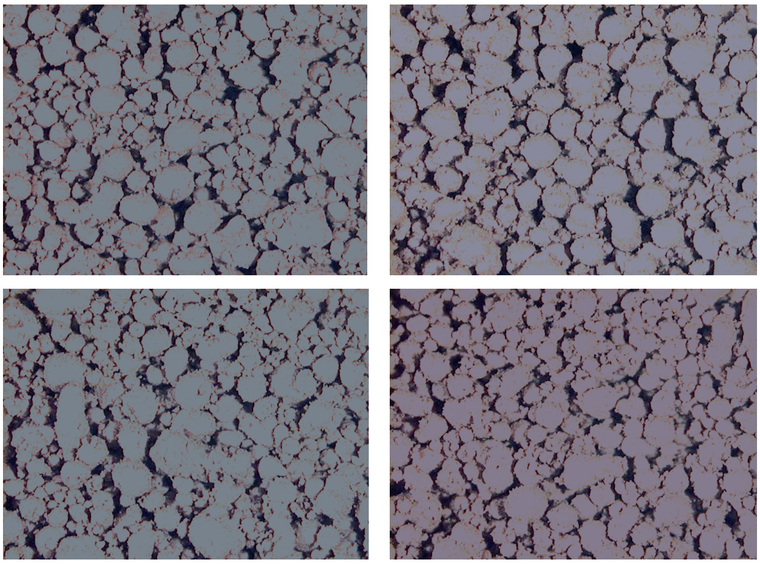


Figure 6. Photograph taken with the stereoscopic microscope of samples of the red stoneware tile composition. From left to right and from top to bottom: truck, silo inlet, silo outlet, and press feed.

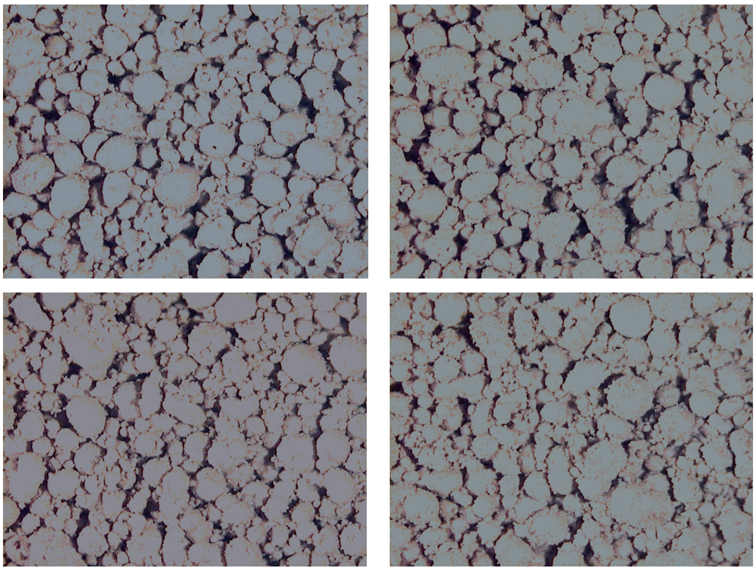


Figure 7. Photograph taken with the stereoscopic microscope of samples of the red earthenware tile composition. From left to right and from top to bottom: truck, silo inlet, silo outlet, and press feed.

4.4 DETERMINATION OF THE SPRAY-DRIED POWDER FLOW RATE

The results of the flow rate tests on the red stoneware and red earthenware tile compositions, presented in Table 2, indicate that the slight reduction in size of the agglomerates, which occurs between the silo outlet and the press feed, and which may be observed in the photographs taken with the stereoscopic microscope, do not involve a change in the rheological behaviour of the compositions, since the flow rate values remain practically constant for all the collected samples.

These results match the conclusion drawn from the analysis of the particle size distributions, since the consistency in the flowability of the material throughout the entire facility is indicative of the low degree of degradation that these compositions undergo during conveying.

Sample	Red stoneware tile		Red earthenware tile	
	Flow rate(g/s)	Moisture (%)	Flow rate(g/s)	Moisture (%)
Truck	15,9	6,1	15,4	6,2
Silo inlet	15,8	6,1	15,7	5,8
Silo outlet	15,6	6,1	15,3	5,7
Press	15,4	6,2	15,3	5,6

Table 2. Results of the flow rate tests corresponding to the different red stoneware and red earthenware tile samples collected.

4.5. DETERMINATION OF GRANULE MECHANICAL STRENGTH

Table 3 presents the results of the mechanical strength tests of the granules of the two studied spray-dried powder compositions. It may be observed that both compositions display a very similar yield stress and, therefore, similar mechanical strength. This fact corroborates the similarity of their behaviour in the different tests conducted.

Sample	Moisture (%)	Yield pressure (kg/cm^2)
Earthenware truck	5,6	$4{,}9 \pm 0{,}2$
Stoneware truck	5,3	$4{,}5 \pm 0{,}2$

Table 3. Yield pressure of both test spray-dried powders.

4.6. RESISTANCE TO WEAR BY ATTRITION OF THE SPRAY-DRIED POWDER GRANULES

Figure 8 displays the evolution of the percentage of degraded material throughout the tests conducted for the two compositions. It may be observed that the values of degraded material are very similar for both spray-dried powder compositions for any rotation time. These results are consistent with those obtained in the granule mechanical strength measurements and confirm that the behaviour of both compositions during pneumatic conveying is similar.

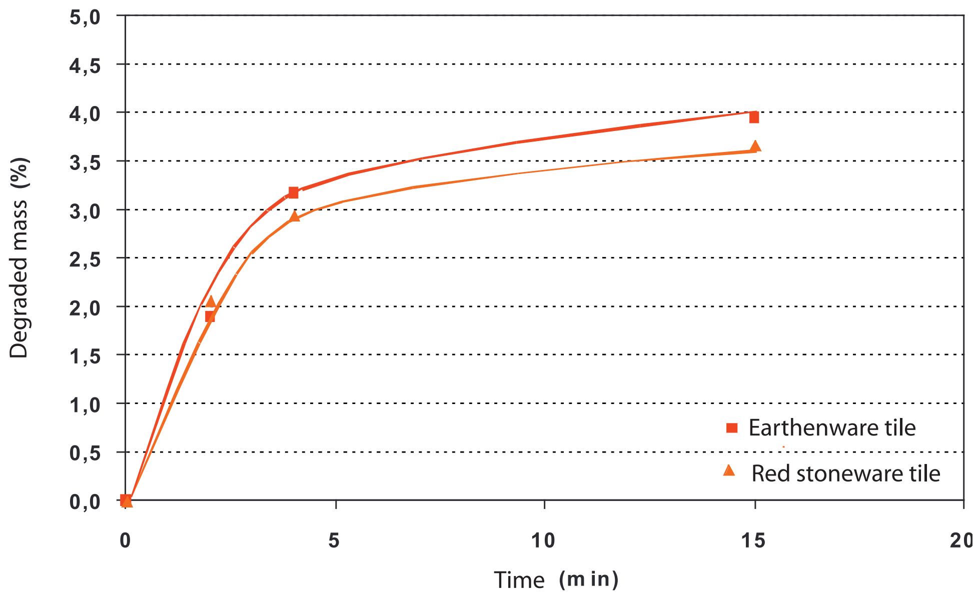


Figure 8. Variation in the quantity of material degraded by friction as a function of rotation time.

4.7. ELECTRIC POWER CONSUMPTION FOR COMPRESSED AIR PRODUCTION REQUIRED IN THE STORAGE SILO CHARGING PROCESS

Table 4 presents the electric power consumption data corresponding to the two charging systems in the facility, together with the charging time and the quantity of spray-dried powder supplied. The specific electricity cost has been calculated considering an average cost of 0,078 €/kWh. For comparative purposes, the consumption associated with a conventional spray-dried powder transport facility with belts and bucket elevators is also given.

System	Charging time (min)	Total charge (kg)	Consumed power (kW h)	Specific consumption (kW h/Tm)	Specific cost (€/Tm)
1 Tm impeller Red earthenware tile	97,6	27 960	32,27	1,15	0,090
30 Tm impeller Red stoneware tile	30,5	27 940	12,61	0,45	0,035
Belts and elevators	60	28 000	17,00	0,61	0,047

Table 4. Analysis of electric power consumption and costs associated with pneumatic conveying of spray-dried powder.

The consumption analysis indicates that there are certain differences between the electric power consumption corresponding to the facility charging the red earthenware tile composition and the system charging the red stoneware tile composition, due to their different configuration.

The table also shows that the electric power consumption associated with the system with the smallest impeller (red earthenware tile) is much higher than that using a larger impeller (red stoneware tile), owing to the existing differences between both systems, described in the introduction of this paper.

5. CONCLUSIONS

The analysis of the pneumatic conveying systems studied allows the following conclusions to be drawn:

- The moisture content of the granules of the different studied compositions is not significantly modified during pneumatic conveying.
- The spray-dried powder granules of the red stoneware and red earthenware tile compositions undergo no significant variation in their size distribution during handling by pneumatic conveying.
- The comparative tests determining the flow rate and mechanical strength of the spray-dried powder confirm the results obtained after samplings conducted during pneumatic conveying by the industrial facility.
- The electric power cost associated with pneumatic conveying using a 1 Tm impeller, is practically twice that corresponding to transport with belts and bucket elevators. However, if an impeller is designed like the one used in this study to transport the red stoneware tile composition (30 Tm), the transport cost is approximately 25% less than that of traditional belt and bucket elevator systems.
- The operating principle itself of dense-phase pneumatic conveying constitutes an important step in the abatement of atmospheric emissions in the ceramic cluster and must be taken into account as a reference point in the very near future, since it embodies an alternative to existing conventional transport, as has already occurred in related sectors like the glaze and frit branch in which reception and handling of most of the raw materials take place by pneumatic conveying.

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