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INDUSTRY-UNIVERSITY INTERACTION FOR THE DEVELOPMENT OF INNOVATIONS

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ABSTRACT

This technical report exemplifies a collaborative work between an academic research center and a company and highlights the importance of incentives for innovation. Pneumatic conveying is a highly diffused industrial process for material displacement, commonly disposing of pressure vessels of high design complexity, making its installation expensive. This work describes preliminary results of an industrial prototype designed to act as a feeder of particulate solids, having as the hypothesis that, with low complexity in comparison to a traditional pressure vessel, it is possible to dictate the transport rate and energy efficiency just controlling the opening time of dosing valves. This equipment was employed in a pneumatic conveyor system which has been submitted to a dense phase transport. The tests were implemented using as the transported material alumina in state of powder and, by fixing the time of dosage, it is possible to impose a transport cycle duration. The maximum value of transport rate obtained in the test parameters was 2.25ton /h for the transport cycle of 45s in a transport line with 130m of extension, and 3" of diameter. The experimental model validation proved to be a valuable opportunity for innovation research and development for both university and company.

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INTRODUCTION

Pneumatic conveying is one of the most important industrial techniques for materials transport. It occurs due to the gas flow injection in a pipeline filled with powdered or granulated material. The process can be carried out in different ways, either in dense or dilute phase, where the differences are associated with the particle behavior in the gas flow. These modes of operation determine important conveyance characteristics that can affect the final product, being determined mainly by the pressure and velocity of the gas stream.Conventionally for dilute phase transport, rotary valves are used as solids feeders. For dense phase transport, pressure vessels are usually applied. The seconds are pressurized vessels ofseveral sizes, with main and supplementary air injection in a controlled way by automation, besides a depressurizing and unlatching system. This equipment is designed to convey materials using low velocity and high operating pressure, characteristics that imply in lower consumption of air and, consequently, of energy.

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Besides that, it also reduces degradation of pipelines due to the friction of the material transported. Compared with dilute phase systems, a dense phase system has a much more complex fluid dynamics and hence a high complexity to be designed.Seeking for alternatives to overcome current challenges of pneumatic conveying systems, a pressurized vessel prototype was produced by Zeppelin Systems Latin America, which has dimensions, cost, the complexity of installation and operation lower than alternative ones already available. This pressurized ejector was also designed under the hypothesis that the system has transport capacity similar to a conventional pressure vessel, by dictating the rate of transport from the time control of the opening of the dosing valves. The objective of this project consisted so in to perform tests for validation of the presented hypothesis by conveying alumina powdered due to its good flowability.

Theoretical References

Batchpump is how the equipment was named by the company, being characterized as a pressurized ejector, with the function of feeding solids in a gaseous stream, aiming to be an alternative for rotary valves or traditional pressure vessels. A rotary valve continuously adds material on a developed airflow. For a pressure vessel, there is a period of loading, by gravity, with dosing controlled by level switches, and subsequent addition of air into the system in order to start the movement of the previously resting material. For the equipment described in this paper, Batchpump, the process of feeding is analog to that of traditional pressure vessels: due to gravitational effect the material leaves a storage hopper and the dosing occurs at each transport cycle controlled by the opening time of butterfly valves, followed by the insertion of air for solids conveyance. The equipment drawing is shown in Figure 1:

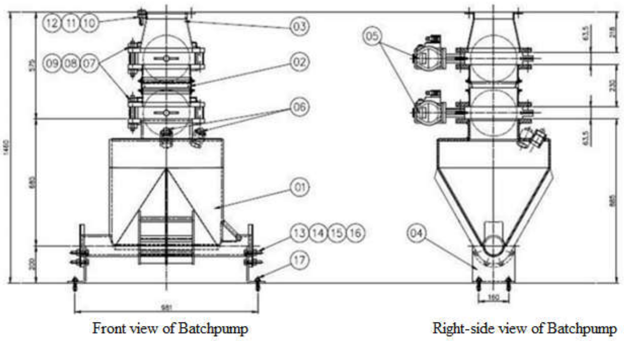

Figure 1. Batchpump prototype drawing

The major differences in the operation mode of Batchpump and pressure vessels are associated with the material volume and the control of air insertion in the system. The pneumatic system already implemented using the new pressurized ejector at the Test Center proved that both installation and operation are simpler for Batchpump than for a conventional pressure vessel. The equipment assembled at the Test Center is shown in Figure 2:

Figure 2. Batchpump prototype

MATERIALS AND METHODS

Tests were carried out at the Test Center were used at the Brazilian branch of Zeppelin Systems Latin America, in the city of São Bernardo do Campo, São Paulo/ Brazil. The studied system consists of two hoppers (MG-02 and MG-04), two pneumatic guillotine valves (VGP-01 and VGP-02), one manual guillotine valve (VGM-01), two butterfly valves for dosing (G35) and a butterfly valve for air control (V-28), the ejector vessel (VP0100), a standard 3" pipe of 130m, having a 5m height difference between the hoppers, (RT-01) conveyor and flexible for interconnection. This system is controlled by a flow meter (FL-01) and two pressure transmitters (PT-01 and PT-09). The transport cycle consists of dosing by means of butterfly valves, opening, and subsequent closing (V-28 valve). Due to the limited availability of material, it was necessary to recirculate it in batches through the system. It was defined that at a certain set mass value measured in the upper hopper the system would enter into the lower hopper feedback stage, preventing the opening of the air supply valve (V-28), opening the pneumatic valve (VGP-02 and RT-01) thread until a certain set value was reached, thus returning the system to its initial operation. Each feedback loop was defined as "mass cycle". The system is shown in Figure 3 and the equipment at the Test Center is described spatially in Figure 4

Tests Planning

The pneumatic system available at Zeppelin Systems Test Center consists of a 130 m length pipeline with the difference in height between the ejector outlet and the receiving hopper entrance of 5 m, with two butterfly valves, one for containment of the material and one for sealing the transport air. The maximum system pressure was set by the pressure regulator, the imposed transport cycle time was firstly set by the time which the (V-28) valve remained open and the dosing time was relative to the time at which both valves (V- 34 and V-35) remained open.A second technique was proposed to control the opening and closing of butterfly valves. At this stage, tests were performed considering the pressure transmitter (PT-09) reading instead of time as the determinant condition to temporarily suspend the conveyance by closing the valve (V-28). These tests would be performed from low pressure up to 80% of the maximum system availability.

RESULTS

The "Time Imposed Tests"results were obtained from conveyances with adjusted transportation time of 300s, 240s, 180s, 120s, 90s, 70s, 65s, 60s, 55s, 50s, 45s, and 40s. This time, controlled by PLC, is exactly the air injection duration that promotes material displacement along the system. Time-evolution curves were obtained from the collected data, presenting graphically the pneumatic transport behavior. A representative curve can be seen in Figure 5. On the left vertical axis is the transport pressure in the system and on the right one, the transported mass. On the axis of the horizontal axis, the time from 0 to 450 seconds, which was the required time to transport about 600 kg throughout the system.The output variables collected are named as follow: maximum system pressure, filling time, imposed transport cycle time, number of cycles, total test time, total mass, transport time andfeeding time. The transport time is related to the time in which material is effectively being conveyed.

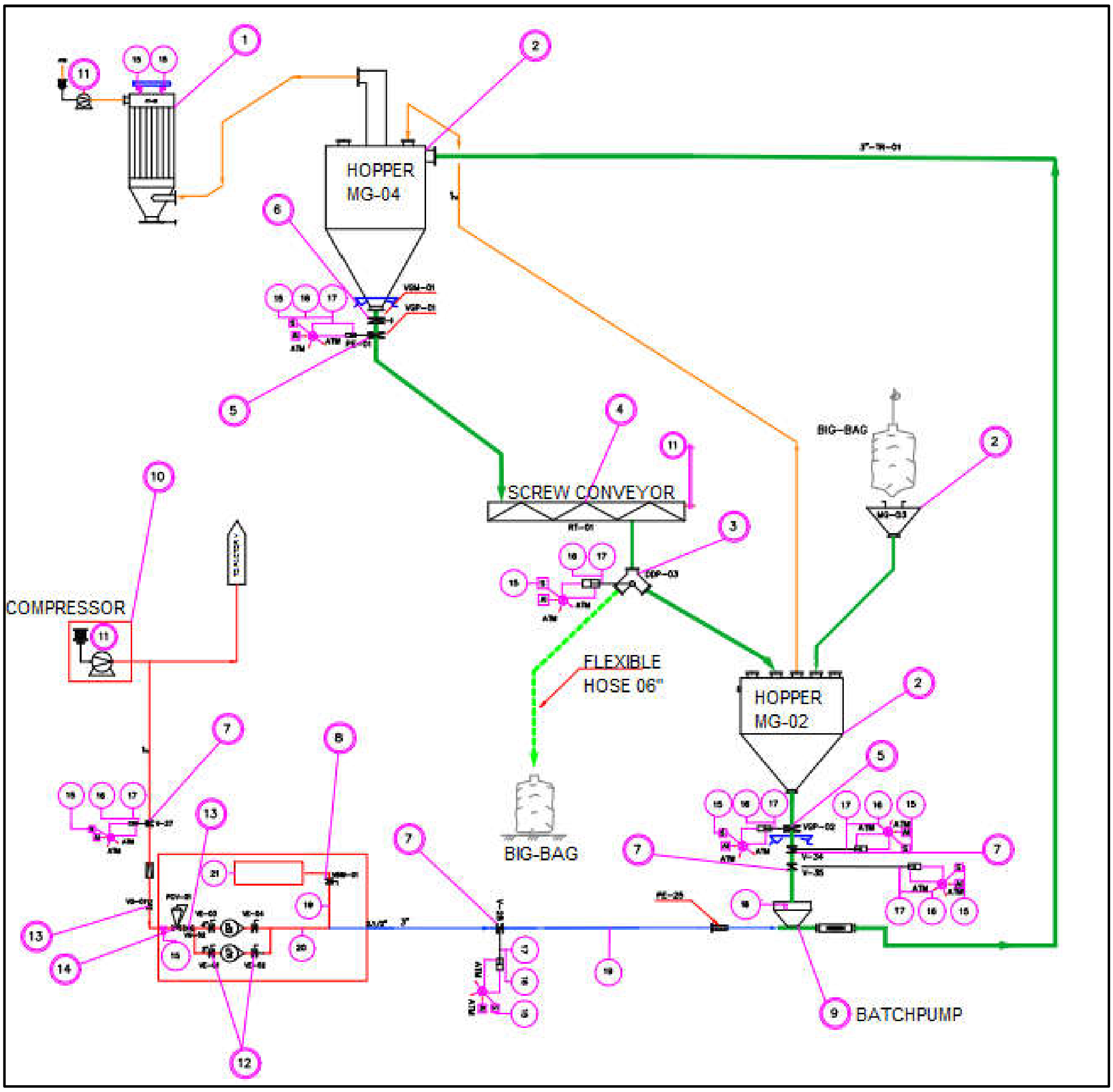

Figure 3.System Layout (Freitas, A. G. et al. 2019)

The feeding time is associated with the time taken by the material to descent from MG-04 to MG-02. The dependent variables were calculated based on the independent variables.

The "transport rate" was calculated by the ratio between the sum of all mass differences at each "mass cycle" by the correspondent cycle time:

$$\dot{M} = \frac{\sum_{k=1}^{n}(m_{fk} - m_{ik})}{t_{total}} \quad (1)$$

The variable "number of cycles per hour" was defined as the ratio between the "total number of cycles" by "conveying time" and multiplying by the time contained in 1 hour:

$$N = \frac{n_t}{t_{transport}} \frac{3600s}{1h}$$

(2)

By dividing the "total mass" transported by the number of transport cycles, it is possible to obtain the "mass per transport cycle"

$$M_c = \frac{M_t}{n_t} \quad (3)$$

The "mechanical energy consumed" was evaluated by multiplying the sum of the product between "transport pressure" in Pa (pressure differential between the measurement point near the Batchpump input and the system output, assuming output pressure as atmospheric) and the "free discharge flow" in m³ / s:

$$E = \sum_{k=1}^{n}(P_{Tk}Q_{DLk}) \quad (4)$$

“Specific consumption" was defined as the "mechanical energy consumed" per "total mass":

$$\dot{E} = \frac{E}{M_t} \quad (5)$$

The variable "volume of air used" was calculated by the sum of each "flow in free discharge":

$$V = \sum_{k=1}^{t} Q_k \quad (6)$$

"Conveyed mass pervolume of airused" was calculated by dividing the "total mass" by the "volume of air used":

$$M_v = \frac{M_T}{V} \quad (7)$$

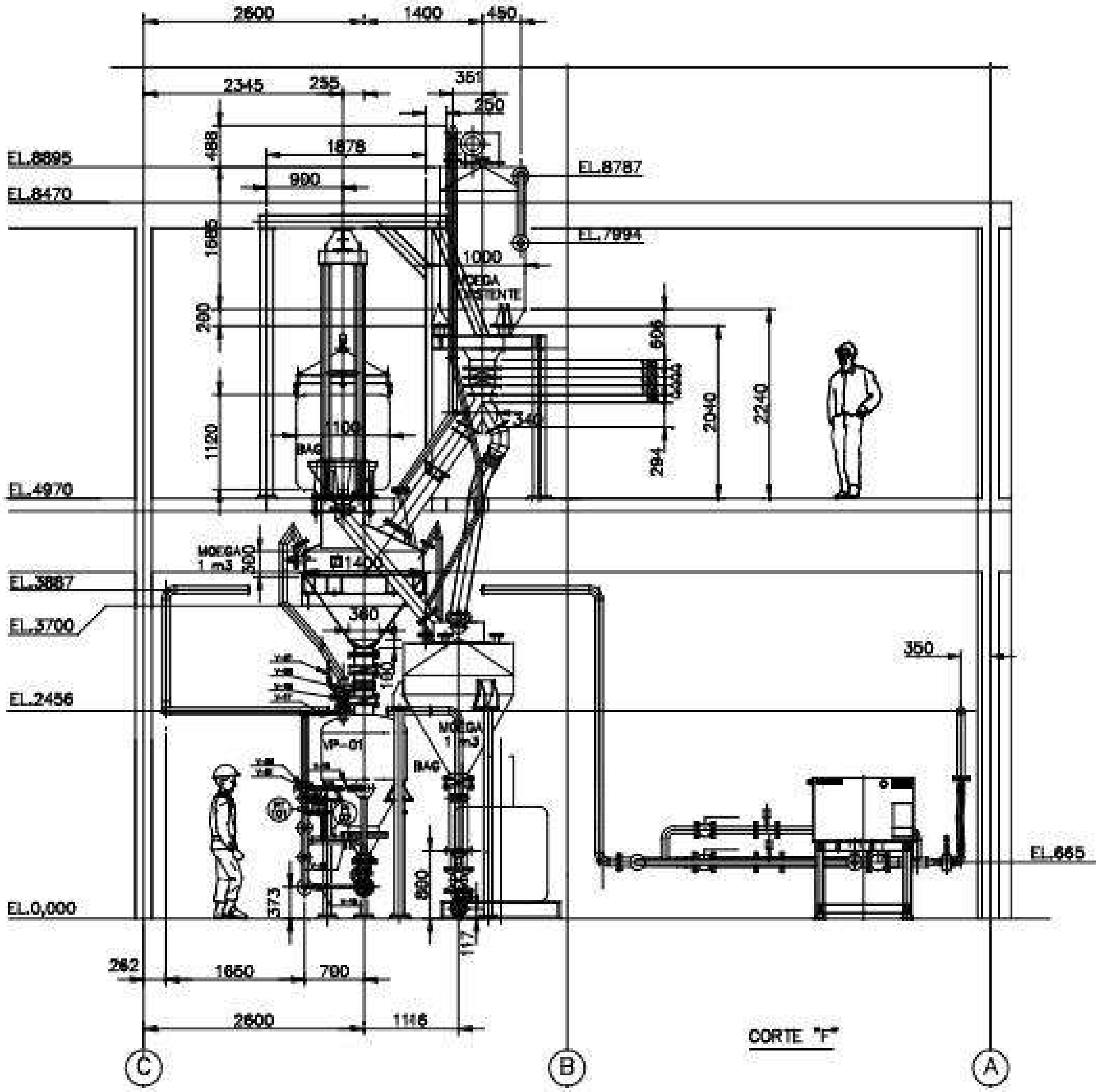

Figure 4. Tests Facilities layout

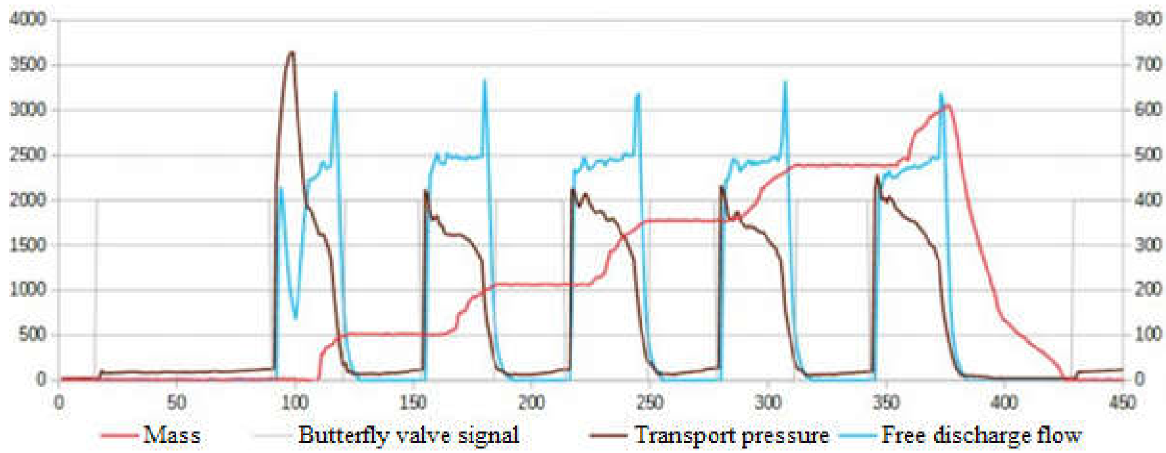

Figure 5. Standard Chart of Results

The time-imposed tests were performed according to the initial hypothesis that, even before removing all the material from the pipeline, it is possible to open the dosing butterfly valves, implying in time-saving and therefore a higher transport rate and lower transportation and energy costs.The obtained results for dependent variables evaluation are presented in table 1, which correlates the adjusted transport time with its respective transport rate, mass per m³ of air, specific consumption and number of cycles.

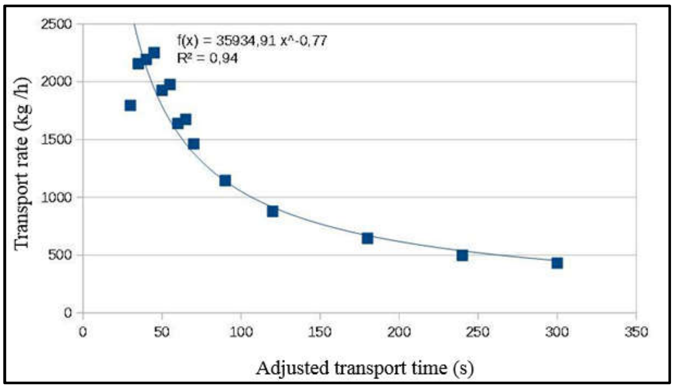

Figure 6. Points obtained from transport rate as a function of imposed transport cycle time

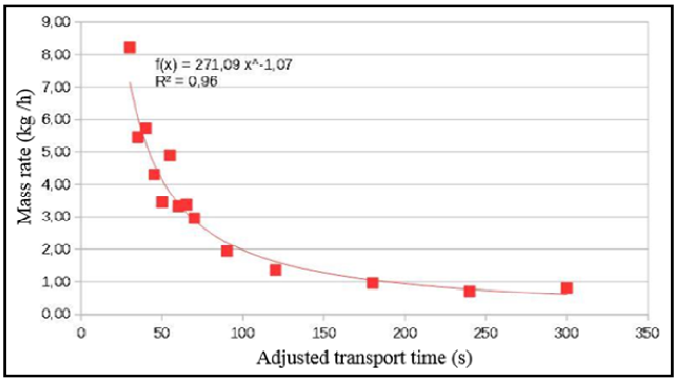

Figure 7. Points obtained from mass rate as a function of imposed transport cycle time

Figures 6 and 7 present the "transport rate" and "mass rate" as functions of the adjusted transport time. It can be seen observing these curves that the transport rate behavior exponentially decreases as the transport time increases. The asymptotic region of those graphs can be understood as following: for a constant mass of material into the pipeline, an optimal time is required to transport it. If this time is overestimated, the system injects gas in the pipeline but no material is actually conveyed. The result is a constant amount of material being transported in a fixed time and the remaining period is only used for inserting unused air into the system, so the same mass is transported in growing times, what reduces mass rate.It must also be highlighted that, even with the transport rate reduction, i.e., for high values of transport time, the system presents a greater reduction of consumption as one can see in Table 1.

Table 1. Test results

Adjusted transport time	Transport rate	Mass rate	Specific consumption	Cycles per hour
s	kg/h	(kg_{mat}/kg_{air})	(kJ/kg)	
30	1795.02	8.21	23.85	13
25	2155.87	5.46	34.07	16
20	2194.02	5.74	26.49	19
15	2251.45	4.31	20.66	27
10	1926.45	3.45	19.73	36
55	1976.15	4.89	16.9	45
60	1638.27	3.33	15.34	47
65	1675.23	3.37	16.48	50
70	1462.22	2.96	13.28	53
90	1146.04	1.94	11.09	58
120	878.74	1.36	11.3	63
180	645.09	0.96	12.25	74
240	497.89	0.7	13.34	67
300	431.15	0.8	13.21	68

The region with low adjusted transport time also shows a decreasing in transport rates. It can be affirmed that this decreaseis not directly related to the number of transport cycles but both variables present a decrease due to the increase in transport difficulty in considerably low transport times.

Table 2. Comparative the values of transport rate from the highest transport rate to the lowest

Adjustedtransport time	Mass rate
s	(kg_{mat}/kg_{air})
15	2251.45
20	2194.02
25	2155.87
55	1976.15
10	1926.45
30	1795.02
65	1675.23
60	1638.27
70	1462.22
90	1146.04
120	878.74
180	645.09
240	497.89
300	431.15

Table 3. Comparative the values of the mass rate from highest to lowest

Adjusted transport time	Mass rate
s	(kg_{mat}/kg_{air})
30	8.21
20	5.74
25	5.46
55	4.89
15	4.31
10	3.45
65	3.37
60	3.33
70	2.96
90	1.94
120	1.36
180	0.96
300	0.8
240	0.7

DISCUSSIONS

Tables 2 and 3 present a comparison of the obtained mass and transport rates for the imposed transport time tests. It can be seen that the mass rate show a considerable increase inthe lowest values of aperture time and this region can be further studied in order to seek optimal values. It is also noticed that the point of greatest mass rate is not the same as the point of highest transport rate. The initial hypothesis that the feeding valves should be opened even before the pipeline is totally empty was verified and is a viable technique. The transport rate has increased to some extent with the decrease in the duration of cycles by the imposition of time. From a certain point, the difficulty of transportation became considerable, implying in the reduction of transport rate.For several transport cycles, there was no mass displacement along the pipeline, the whole mass was trapped at the beginning of the line or even before entering the line. These events resulted in a strong release of air in the backward direction. This violent air releasing had a tendency to unclog the line so that the subsequent cycle promoted material transport.Due to the explosive release of air, several leakages were observed along the system, in the butterfly valve firstly and when it was fixed, another one occurred in the MG-03 material hopper. In order to avoid material and air pouring, there was initially positioned a lid of about 200 kg, which was not heavy enough. Subsequently, another counterweight of about 200 kg was added, totaling 400 kg. The leakage occurrence subsided but still occurred. When the total counterweight of 600 kg was not enough to control the backward pressure when the system reached its maximum pressure of 4 bar across the line, causing backflow in the pipeline, the authors optedforterminate the control experiments by time.

Conclusions

Considering the presented execution and results for the experiment carried out in the Test Center of the company, by conveying alumina in state of powder, it is possible to conclude that the optimal point of operation in terms of efficiencyobtained at 45s of transport time due to their higher transport rate, lower transport difficulties and mass rate in comparison to a conventional pressure vessel.

Future Developments

Conventional pneumatic transports are performed by continuously gaugethe pressure in the entrance of the system. The pressure differential along a pipeline is directly correlated to the amount of material into the line at a given moment so that observing this variable it is possible to infer the amount of material present along the pipeline. A better analysis of the Batchpump prototype performance requires the development of tests observing the pressure differential between the equipment and the end of the line.

Analogously to the hypothesis discussed above,an optimal pressure for an aperture of butterfly valves can be associated with the higher possible transport rate, the same for energy consumption. The authors aim to conduct tests by changing the pressure value at which the system stops conveyance and feeds material into the pipeline.The results of future tests can be compared with the ones presented in this paper and also must include a more complete analysis of the Batchpump operation, correlating, for example,the opening pressure with its respective transport rate, mass per m^3 of air, specific consumption and number of cycles, seeking for energy efficiency technologies.

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