Performance Optimization of a New Solid Feeder

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Abstract

This research aims at obtaining the optimum point of operation for an industrial equipment that acts as a solids feeder in an industrial pneumatic conveying system, named Batchpump. The optimization method used is that of empirical measurements to a prototype that lead to increasing energy efficiency by manipulating end-of-cycle pressure. The laboratorial setup included, in addition to the 100 liter ejector (Batchpump) a conveying pipeline of 133m length 3 inch diameter, with a difference of height of 5 m. This experiment analyzed several measured variables regarding each cycle total time, cumulative mass conveyed as well as the pressure achieved. The results are presented in terms of the two calculated variables: transport rate (kg of conveyed solids per minute) and energy efficiency (kg of conveyed solids per Joule energy inserted in the system). The transport rate values show a direct relation between the operating pressure and the optimum working point at 1.6 bar. The tests showed that due to the higher flow restriction a decrease in the transport rate occurs. The energy efficiency showed a behavior directly proportional to the end-of-cycle pressure and the flow restriction.

Keywords
Pneumatic Conveying, Optimization, Energy Efficiency.

1. Introduction

Pneumatic conveying is one of the most important materials transportation techniques in the industry.The transport of dry bulk particulate materials: powder, granular, flakes by means of fluid (typically air) flow in a pipe. The working principle consists of imposing compressed air or inert gas flow down a pressure gradient in a pipeline conveying the solids. The solids come from a feeder device. At the destination, a silo with a filter or vent separates gas from particulate which will be stored for further use. In summary, conveying takes place by imposing a gas flow and suspending powdered or granulated material through a pipe (GOMES, 2011; TRIPATHI, 2018; FREITAS et al., 2019).

Pneumatic conveyor systems have been in Brazil since the 1960s. There are records of air grinding techniques used by Mikropul-Ducon and grain sucker installations by Johannes Möller do Brazil (GOMES, 2011). There are several advantages to using pneumatic conveyors in industries such as their high flexibility due to their ability to perform curves and follow complex paths, lower cost for high distances, negligible leakage of material into the environment, use with multiple sources and destinations, reduced size, ease of automation, etc. (GOMES, 2011; TRIPATHI, 2018; FREITAS et al. 2019).

In pneumatic conveying, different modes of transport are studied. This may be defined according to its density of particles in the pipeline, being a diluted phase, a way of conveying with low density of particles and material suspended in the airflow or dense phase, with high density of particles and materials being conveyed without being suspended. The dense phase is favored at the time of transportation of materials due to its lower air consumption and consequently energy to carry out transport and minor damages to both material and piping, being important for friable and abrasive materials. This transport may become unstable and cause clogging, and for this reason, it is necessary to study the boundaries for the transport of dense phase materials (MILLS, 2004; HU et al, 2014).

For industrial systems it is of great importance to obtain optimal points of operation of their processes. In a pneumatic conveying system, in general, it must be conveyed with the highest conveying rate possible, but with low airflow rates, due to both the high-energy consumption of the air generators and degradation due to high fluid velocities. The excessive reduction of this flow can cause clogging and therefore, there are limits that can be reached for optimal transportation.

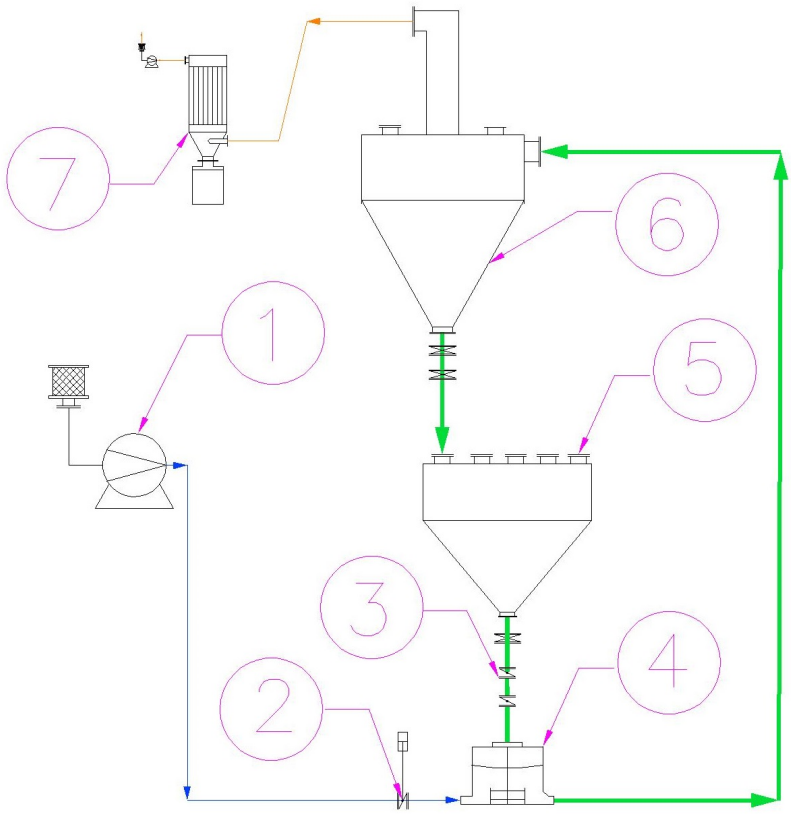
With this in mind, this study aims to determine the best performance efficiency points for a pneumatic test transport system, produced on an industrial scale. The tests were performed using limestone at agricultural grade and granulometric curve as the conveyed material.

2. Methodology

2.1 Testing facilities layout

The laboratory at the Research and Development Center of Zeppelin Systems Latin America was founded in 2004, under the name Hans-Dieter Zamburek Test Center. It is used, among other purposes, to run tests of solids conveying in different modes and using different subsystems and therewith determine parameters for raw material conveying and dosing system designs. It is also used for the development of new technologies in this field. Therefore, pneumatic conveying tests are carried out in dense phase and in dilute phase at industrial scale.

The goal of the research was to analyze and optimize the smaller design for the ejector feeder of a dense phase conveying system known as Batchpump, to replace the conventional blow tank, Fig. 1, compares the main features of the two designs.



Item	Description
1	Compressor
2	Air inlet butterfly valve
3	Batchpump
4	Dosing butterfly valves
5	Hopper
6	Receiveing Hopper on load cells
7	Filter

Figure 1. Layout of the system (FREITAS et al., 2021)

The system tested consists of two hoppers (item 5 and 6, Figure 1), two pneumatic guillotine valves, one manual guillotine valve, two butterfly valves for dosing (3) and a butterfly valve for air control, pressurized feeder (4) called Batchpump, a standard 3" pipe with 130m in length, having a 5m height difference between the hoppers, and flexible for interconnection. A flow meter and two pressure transmitters were used to obtain measurements and monitor the system.

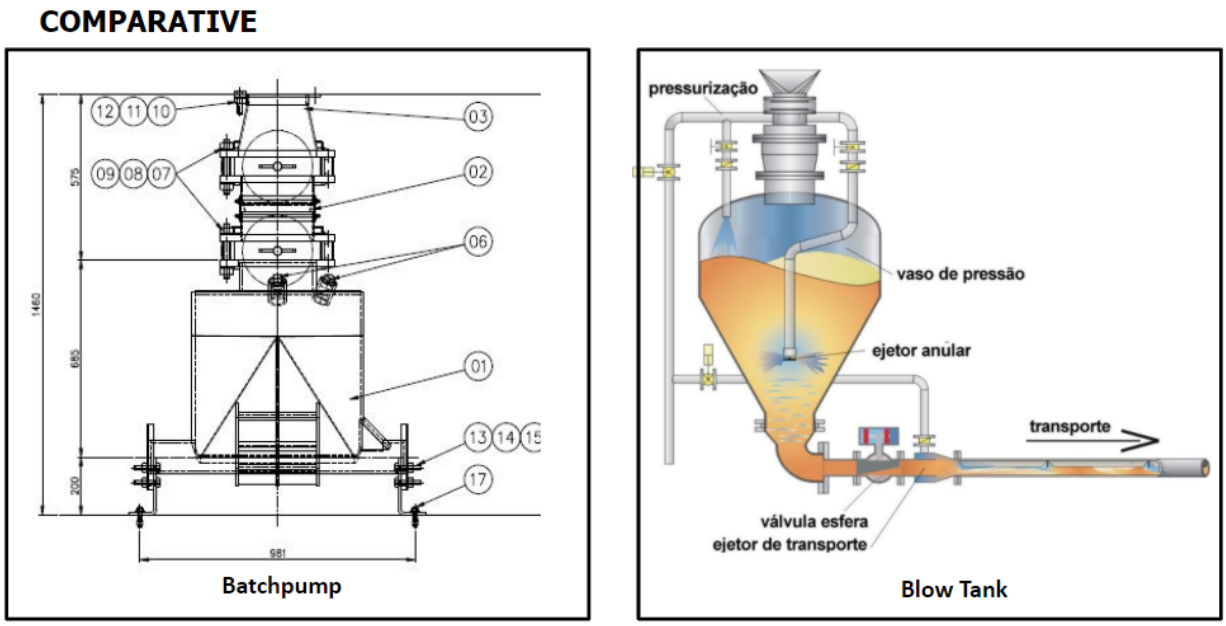


Figure 2. Batchpump on the left side with a total height of 1300 mm as opposed to the blow tank on the right with a total height of 3300 mm (FREITAS et al., 2020).

The cycle is composed by the dosage in the butterfly valves, by the opening of the air valve and its subsequent closing.

The conveying cycle begins with the dosing of material: both dosing valves (Item 3, Figure 1) are opened then there is a waiting time until filling of the ejector indicated by a level switch and then both valves are closed. Then the pneumatic conveying is initiated by the opening of the air valve, the conveying pressure is read by the pressure transmitter, and when the pressure is reduced below a limit defined by the end-of-cycle pressure there is the closing of the throttle air valve and the next transport cycle begins.

Due to the volume limitation and with the intention of simulating an intermittent system, the conveyed material has to return to the origin hopper. It has been defined that after transporting a certain amount of mass, the system feeds the lower hopper, opening the pneumatic valve until the system is returned to its initial operation.

2.2 Variable description

The variables of interest for the tests were divided into independent, fixed, non-manipulated, dependent variables and responses.

The independent variables are those that were manipulated, such as:

- **End-of-cycle pressure**: Pressure value in which, for values lower than the established, there is the closure of air valve and consequently finalization of a transport cycle and beginning of a new dosage;
- **Pressure at the feeder inlet, which was directly influenced by the flow restriction**, i.e. the number of turns in the globe valve (zero turns to fully open) which implies a decrease in the airflow measured by the flow meter.

The fixed variables were:

- **System Layout**: There were no changes in the system between the tests performed, i.e. the pipe diameter, curves, path traveled remained unchanged etc.;
- **Solid material conveyed**: For all tests, the same calcitic limestone was used as the conveyed powder.

- **Source pressure**: The pressure of the reservoir with compressed air used as an energy source was set at 4 bar by means of a pressure regulator.

The dependent variables were measured and included:

- **Conveying Pressure**: The pressure instantaneous instantaneous values were collected at every at every second from the pressure transmitter located upstream of the solids feeder;
- **Conveying air flow**: these values were measured with a volumetric flow meter before the feeder inlet. These values were corrected for free temperature and pressure discharge flow using pressure values obtained by the pressure transmitter. This correction is described in (1) where Patm is the atmospheric pressure relative to the locality in mbar and 1013.25 is the atmospheric pressure at sea level, also in mbar.

$$Q_t = Q_{FL02}(P_{atm} + P_{PT01})/P_{atm} \tag{1}$$

- **Dosing signal**: Signal referring to the status of the butterfly valve, located between the hopper and the solids feeder, describing whether it is open and therefore dosing the material;
- **Conveying signal**: Signal refers to the position of the butterfly air valve, describing whether it is open and therefore in the middle of a transport cycle;
- **Accumulated mass**: Total mass value measured by three load cells located in the hopper.

The response variables were:

- **Average conveying rate:** value in Kg/h obtained based on data collected from total mass measured in Kg and test duration measured in seconds. The calculation to obtain the transport rate is described in (2):

$$m = 3600M_{total}/t_{conveying} \tag{2}$$

- **Mass rate:** The mass rate was obtained based on data collected from total mass measured in Kg, total air volume measured in m³ and air density at 25ºC, 1.1839 kg/m³. The calculation to obtain the mass rate is described in (3):

$$\phi = M_{total}/(V_{total}\rho) \tag{3}$$

- **Specific consumption:** conveying efficiency in the form of energy consumption per unit mass of material (kJ/kg), given by the pressure differential in mbar multiplied by the free discharge flow rate in m³/h during the test duration interval divided by total mass measured in kg. The equation for the specific consumption is shown in equation (4):

$$e = (\sum_{i=0}^{t} \quad \Delta P_{c,i} Q_{ff,i})/(3{,}6M_{total}10^9) \tag{4}$$

- **Average conveying airflow:** average between values of conveying airflow recorded every second by flow meter. For this purpose, the valve signal air valve, defined as 1 open and closed to 0, was used to calculate the mean while there was air consumption. This can be seen in equation (5):

$$\underline{Q_t} = (\sum_{i=0}^{t} \quad Q_{ff,i}\alpha_i)/\sum_{i=0}^{t} \quad \alpha_i \tag{5}$$

- **Mean conveying pressure:** The mean conveying pressure is the average of the transport pressures recorded every second by the pressure gauge. Analogous to the mean transport flow, this can be seen in mathematical terms in equation (6):

$$\underline{P_t} = \sum_{i=0}^{t} \quad (P_{t,i}\alpha_i)/\sum_{i=0}^{t} \quad (\alpha_i \tag{6}$$

3. Results

The results of the tests were collected in terms of the measured variables described in section 2 of the methodology where the percentual loss of pressure in the feeding device, measured and triggered by the pressure switch was kept at 90% of source pressure. The data recorded the independent variables at the end-of-cycle was: time for the transfer, total accumulated mass, conveying pressure along time for each flow restriction. The response variables for this test were: Conveying rate, mean air flow and mean transport pressure, mass rate and specific consumption. The results were plotted as a function of the independent end-of-cycle pressure variables, controlled by PLC, and flow restriction, given by the number of closing loops of the globe valve. The curves were plotted with the Y-axis for the responses, X-axis for the end-of-cycle pressure and the flow restriction was given by the difference between curves. The transport rate results in kg/h are described in Fig. 2.

Conveying rate

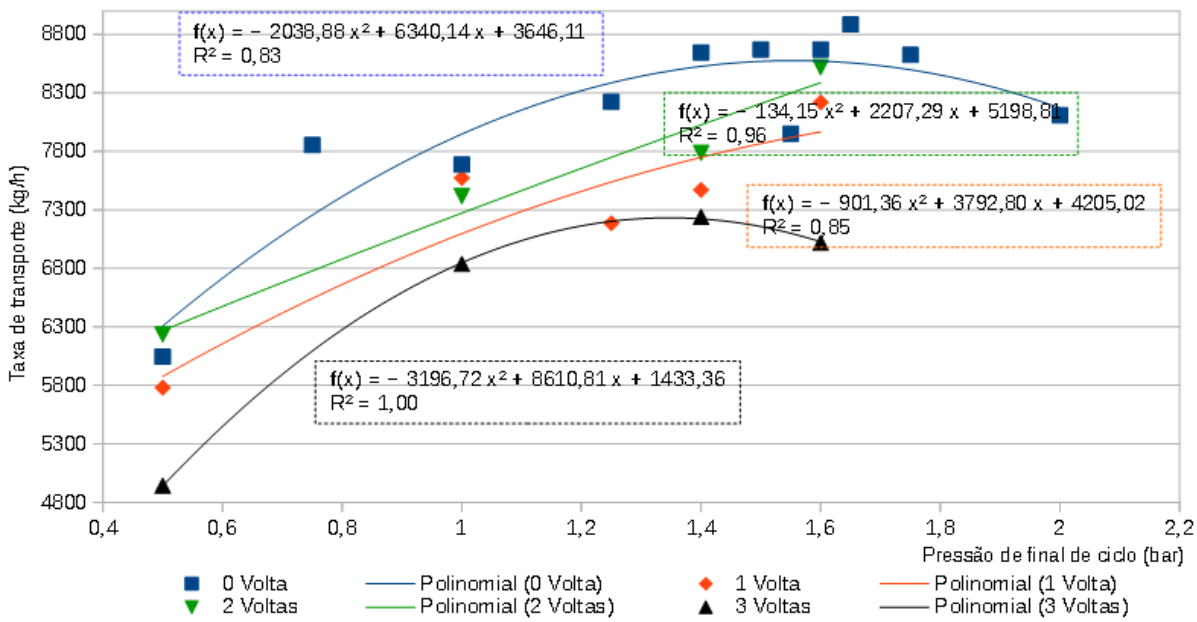


Figure 3. Conveying rate as a function of the end-of-cycle pressure and flow restriction

Observing Figure 3, it can be seen that there is a behavior of increase of conveying rate up to a certain point with sequential drop in both curves, without flow restrictor, in blue, and with 3 turns in the balloon valve. This increase is due to the reduction of transport duration, which consequently there is a smaller region of line cleaning, however due to this amount of material remaining in the line there is also an increase in difficulty for transportation, approaching areas of clogging. For the curves of 1 and 2 turns it is noticed that there is no such behavior, it is believed that this occurs because it did not arrive in the region of inflection of the curve.

The mass rate results in Kg_{mat}/Kg_{air}, are shown in Fig. 4.

Mass rate

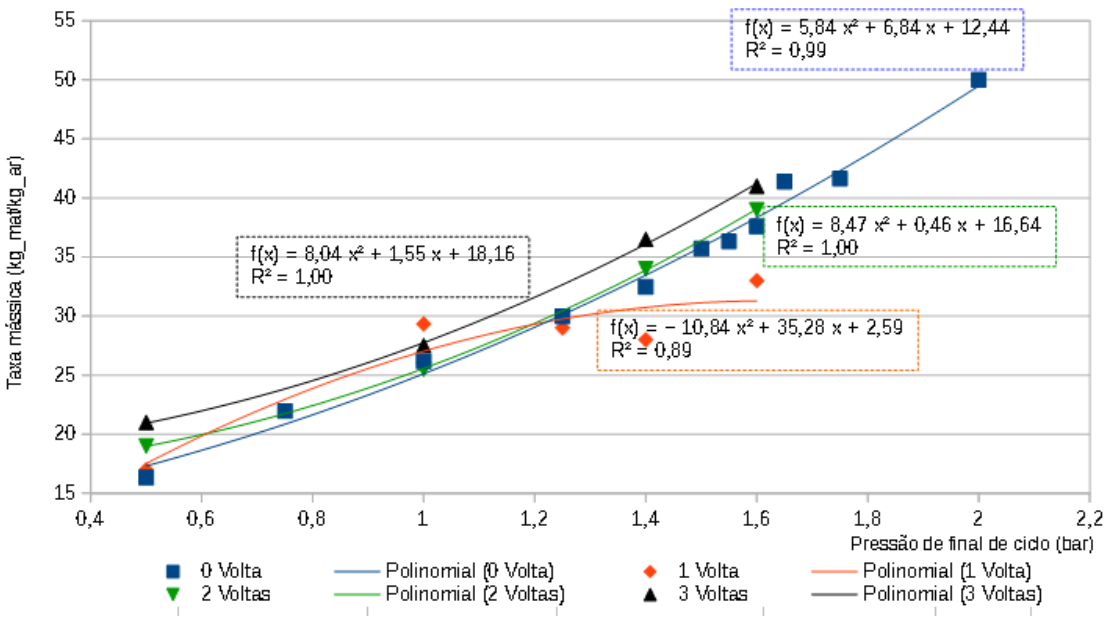


Figure 4. Mass of solid to mass of air rate as a function of the end-of-cycle pressure and flow restriction

It is observed from Fig. 4 that there is increasing behavior according to both the end-of-cycle pressure and the flow restriction. This can be attributed to the increase in material deposited in the pipeline due to the early completion of a cycle or the addition of less air, and consequently less energy.

The results of specific consumption in KJ/Kg, are described in Fig. 5.

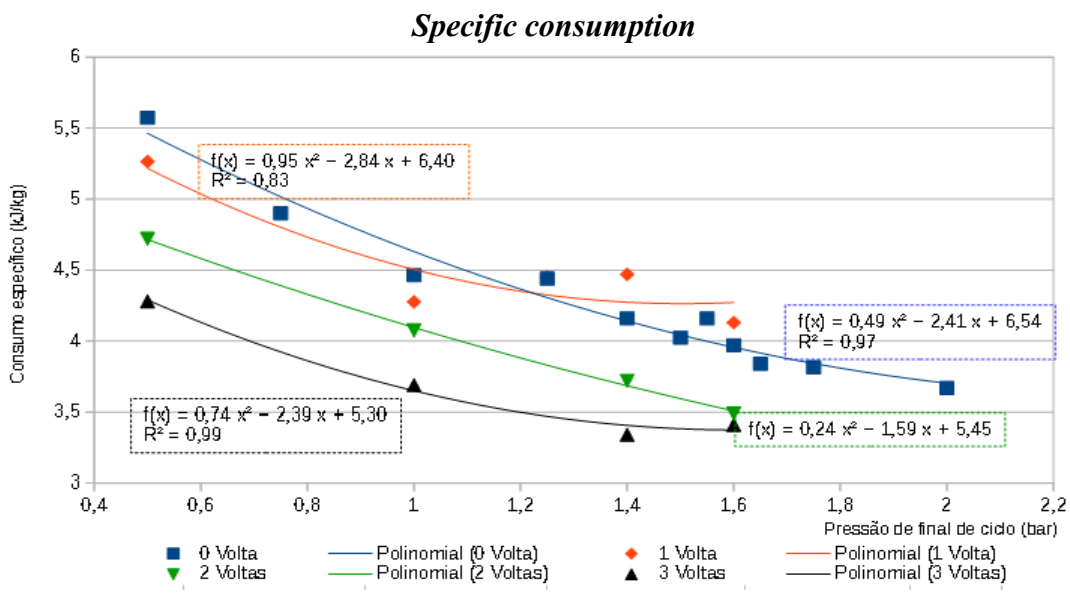


Figure 5. Specific consumption as a function of the end-of-cycle pressure and flow restriction

The specific energy consumption versus end-of-cycle pressure is shown Fig. 5 as calculated from the measured variables according to the previous section. This graph shows a decreasing operation at higher pressure, thus more efficiency at higher pressures.

4. Conclusions

The empirical research described, aiming at optimizing the small volume feeder "Batchpump" showed that, albeit using more cycles per hour, it can operate at comparable mass flow and comparable efficiency. From the measured data, it can be inferred that the cumulative mass flow at the end of each cycle was directly correlated to the mean pressure which in turn was also directly related to the end-of-cycle pressure. With the increase in the solids mass flow induced by higher end-of-cycle pressure, there was an increase in energy efficiency. This increase reached a maximum point at 1.6 bar with subsequent decrease in conveying rate. The transport rate values shows a direct relation between the operating pressure and the optimum working point at 1.6 bar. The tests showed that due to the higher flow restriction a decrease in the transport rate occurs. The energy efficiency showed a behavior directly proportional to the end-of-cycle pressure and the flow restriction. The main limitation is that the new feeder will be subjected to a larger number of cycles, whereas the valves and actuators may be under a higher wear and tear. We understand that this effect can only be optimized on field installations, with help from valve sealings and gasket suppliers. A further limitation is that the pressure source used for testing, specially at higher pressure levels, may not have been appropriate to be considered as a "constant pressure source". A larger source air pressure tank could be used to keep the input pressure more stable at higher energy levels.

Acknowledgements

The authors would like to thank the National Council for Scientific and Technological Development (CNPq) under Grants 140368/2018-3, 163815/2018-6 and 200716/2020-4. The Federal University of ABC and Zeppelin Systems Latin America for their support that made this project possible.

References

Freitas, Adriano Gomes, Yuri Oliveira Lima, Vitor Furlan de Oliveira, Ricardo Borges dos Santos, and Luis Alberto Martinez Riascos. "BATCHPUMP: AN ALTERNATIVE TO CONVENTIONAL BLOW TANKS." *Latin American Applied Research*. 51, (2),107-112, 2021.

Freitas, Adriano Gomes, Yuri Oliveira Lima, Vitor Furlan de Oliveira, Ricardo Borges dos Santos, and Luis Alberto Martinez Riascos. "Energy efficiency in pneumatic conveying: performance analysis of an alternative blow tank." *Particulate Science and Technology*, 1-8, 2020.

Freitas, Adriano Gomes de; Santos, Ricardo Borges dos; Oliveira, Vitor Furlan de; Lima, Yuri Oliveira; Riascos, Luis Alberto Martinez. University-Industry Interaction for the Development of Innovations**,** *International Journal of Development Research*, 09, (05), 27847-27852, 2019.

Freitas, Adriano Gomes de; Santos, Ricardo Borges dos; Oliveira, Vitor Furlan de; Lima, Yuri Oliveira; Riascos, Luis Alberto Martinez. Energy efficiency in the development of an innovative industrial pressurized solids feeder for pneumatic conveying systems**,** *International Journal of Development Research*, 09, (04), 27147-27152, 2019.

Freitas, Adriano Gomes de; Santos, Ricardo Borges dos; Oliveira, Vitor Furlan de; Lima, Yuri Oliveira; Riascos, Luis Alberto Martinez. Energy Efficiency of an Industrial Pressurized Solids Feeder for Pneumatic Transport, p. 101-112. In: *40° Seminário de Balanços Energéticos Globais e Utilidades*, São Paulo. ISSN: 2594-3626, DOI 10.5151/2594-3626-33719, 2019.

Freitas, Adriano Gomes De; Lima, Y. O.; Oliveira, V. F.; Riascos, Luis Alberto; Santos, R. B. Otimização de sistema de transporte pneumático em fase densa com vaso de pressão não convencional. In: *XXVII Jornadas de Jóvenes Investigadores*, 2019, São Carlos, 2019.

Gomes, Luiz Moreira. *Contribuição à análise do transporte pneumático em fase diluída***.** 2011. 169 f. Tese (Doutorado) - Curso de Engenharia de Recursos Naturais, UFPA, Belém, 2011.

Hu, Shengyong et al. Investigation on blockage boundary condition of dense-phase pneumatic conveying in bending slits. *Powder Technology*, [s.l.], v. 266, p.96-105, nov. 2014.

Mills, David. *Pneumatic Conveying Design Guide***.** 2. ed. Oxford: Elsevier, 650 p., 2004.

Tripathi, Naveen Mani et al. Experimental analysis of particle velocity and acceleration in vertical dilute phase pneumatic conveying. *Powder Technology*, [s.l.], v. 330, p.239-251, 2018.

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