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ENERGY EFFICIENCY IN THE DEVELOPMENT OF AN INNOVATIVE INDUSTRIAL PRESSURIZED SOLIDS FEEDER FOR PNEUMATIC CONVEYING SYSTEMS

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ABSTRACT

This paper presents the development of a pressurized ejector for particulate material handling by means of pneumatic transport, defined as a way to transport materials mainly in powder or granular form using a gas stream. Operating through high-pressure batches, the proposed equipment consists in an alternative to the conventional Pressure Vessel commonly used in pneumatic transport, having as advantages the reduction in complexity of operation; equipment dimensions; energy expenditure and production cost. The experimental part of this work took place in the Research and Development Center from *Zeppelin Systems Latin America* in a collaboration with the Industrial-Academic Doctorate program of the Federal University of ABC. The analysis of the obtained experimental results counted on statistical methods in the process of transport performance evaluation, controlling influence variables such as flow, pressure, time and mass transported. The purpose of this work was to elaborate an empirical model for the transport through the proposed equipment and its feasibility, aiming to establish points of maximum energy efficiency.

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INTRODUCTION

Industrial growth historically leads to an increase in energy demand. The growth of energy generation, in turn, requires high investments and inevitably entails environmental consequences. Investing in technologies that optimize energy performance can so be a solution for sustainable development (Viana, 2012). In this context, it is estimated that around 15% of electricity consumption is used for the production of compressed gas (Cecone, 2017). Part of this compressed gas is used in pneumatic transport, a highly diffused process for the handling of materials within an industrial production process, according to the 23rd edition of the Statistical Yearbook of the Metallurgical Sector, 2018).The definition of pneumatic conveying system depends on the properties of the product (particle size, sensitivity to abrasion); location of the system installation (transport distance, number of curves); equipment and peripheral systems (silos, counter explosion systems), in addition to installation and operational costs.

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These systems are used to handle solid particulate materials which, by means of a biphasic gas-solid mixture (usually using air), displaces the particulate material to its destination (Cremasco, 2012). Since the late 19th century, pneumatic transport has been used in Europe. This technique became popular and arrived in Brazil since the 60's. There are records of air grinding techniques used by the company *Mikropul-Ducon* and grain sucking installations of ships by *Johannes Möller do Brasil* (Gomes, 2011), current *Zeppelin System Latin America*. According to Mills, *et al*. (2004), pneumatic conveying systems are basically composed of a suitable source of gaseous fluid, a system for feeding material to be conveyed, a conveyor system for material displacement, a container for material packaging and a filtering system for gas separation after transport, as shown in Figure 1. According to Santos (2009), these systems are classified as operating in diluted or dense phase regime, according to the superficial velocity of the gas and the relation between mass flow of the gas and solid phases, besides considering other relevant information as load and transport speed. Pneumatic conveying system in the diluted regime is characterized by the high speed, generally higher than 10 m/s, and low concentration of product, defined according to the system demand and the characteristics of the product to be transported, but always having a high gas flow rate to transport small amounts of material as shown in Figure 2. These systems are considered flexible as the amount of product transported and transport distance can be varied (Prado, 2014).

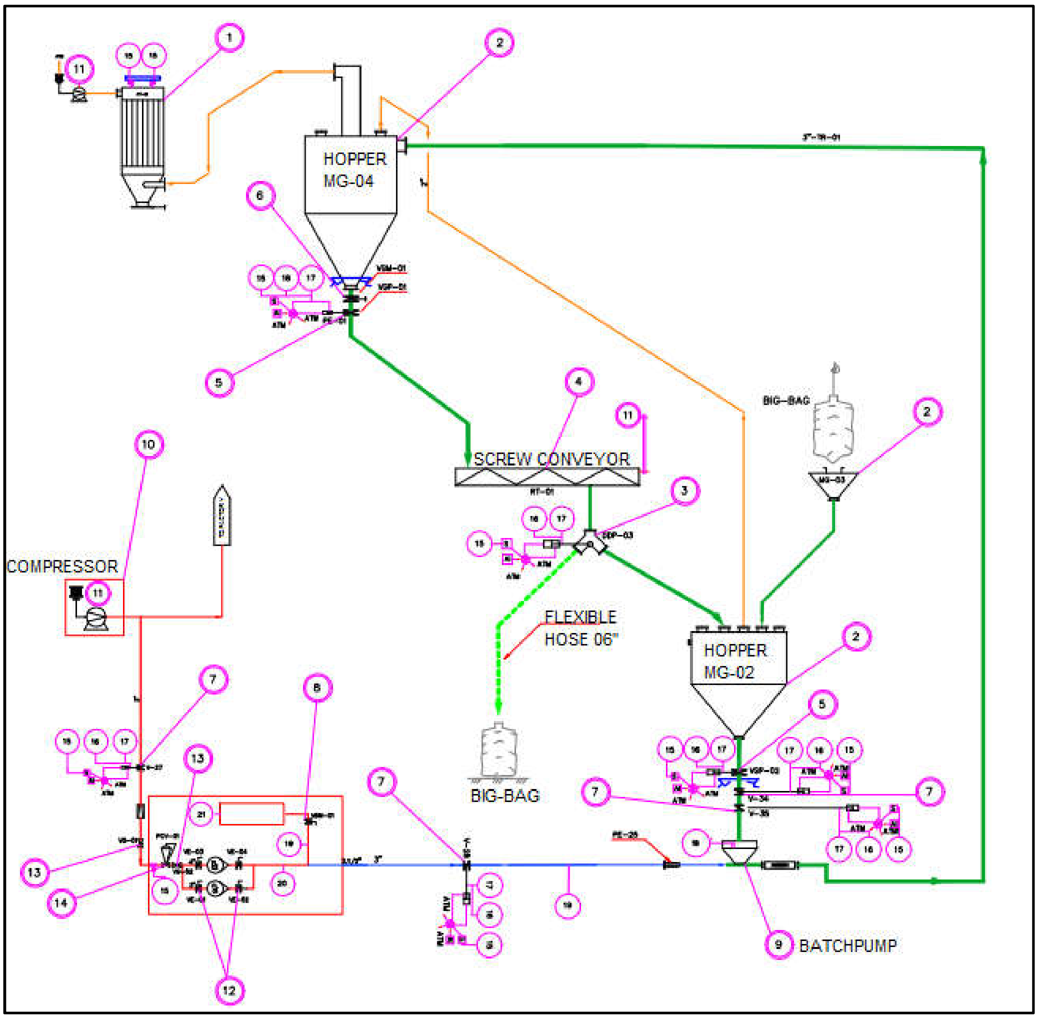

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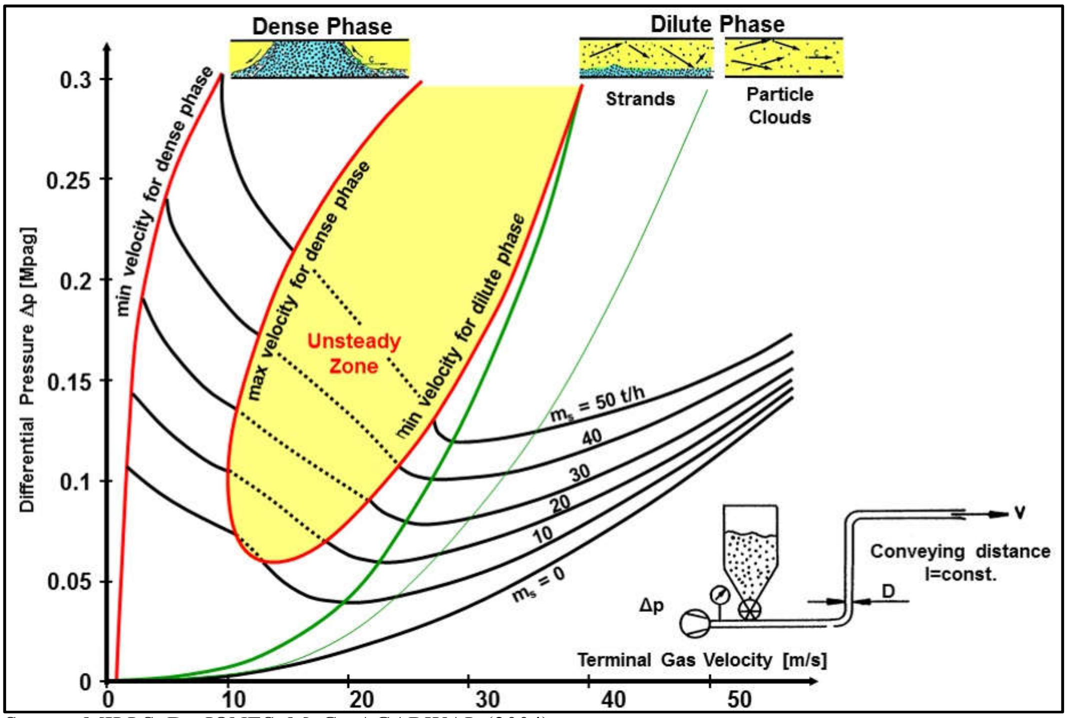
Fig. 1. Schematic illustration of the pneumatic cycle



Source: MILLS, D.; JONES, M. G.; AGARWAL (2004).

Fig. 2. Phase diagram of pneumatic transport

Dense pneumatic conveyor systems are designed for the transport of abrasion sensitive materials. They are characterized by high material concentration and low gas velocity, less than the minimum velocity of 10 m/s required to obtain a stable flow (Silva, 2005). In dense regime, particles settle on the lower part of the cross.It is worth noting that, in practical applications, there is an unstable flow region due to the reduction of gas velocity associated with the maintenance of material dosage. In this situation, the airflow is not sufficient to support particles of the suspended material, causing deposition and accumulation in the lower part of the pipeline. In this condition, a transition regime between diluted phase - transport of suspended material - and dense phase - transportation in dunes or bushings of the accumulated material in the lower part of the pipeline - is observed (Prado, 2014). Dilute phase, dense phase and unstable phase present in pneumatic conveying systems are plotted as a function of the linear pressure drop (Δp) and the gas surface velocity (U) in Figure 2.In pneumatic conveying, characteristics of the material transported and the gas used to this purpose must be considered since they will not only be defined by its own properties, but also by the equipment involved in the system, which dictates how the material will be transported and which consequences the conveyance will entail. This association determines, among other effects, the energy efficiency of the conveyance.In order to carry out efficient transport, attention must be paid to the amount of energy supplied to the system in the form of compressed air and the equivalent mass transported. The amount of pressurized air demanded reflects in the power required by the compressor system and, consequently, in the electrical consumption of a productive process.

MATERIALS AND METHODS

Hans-Dieter Zamburek Testing Facilities: The experimental procedure of this project disposed of an industrial scale solids feeder prototype, in an agreement between the university and the company *Zeppelin System Latin America*. The Research and Development Center of the company was founded in August 2004 and named Hans-Dieter Zamburek Test Center. Its objective is to determine parameters and the development of new technologies for projects of raw material handling systems. The equipment called *Batchpump*, available at the Test Center, allows the material to go through a 130m long transport pipeline, working cyclically as one can see in figure 1, betterdescribed in the next subsection. Measurements of flow characteristics were carried out and the obtained results were confronted to the current literature in order to build and model that seeks to optimize energy efficiency. In other words, this project is based on the measurement of various flow characteristics, such as transport pressure, flow rate, transport rate, compressed air volume used, etc., with the purpose of verifying points of lower consumption and maximum transport, seeking to identify the viability of the equipment under development.

System Layout: The conveyance 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 (V-34 and V-35); one butterfly valve for air control (V-28), the ejector vessel (VP 0100), a standard 3 " pipe of about 130m, having a 5m height difference between the hoppers, a flexible conveyor thread (RT-01) for interconnection; one flow meter (FL-01) and two pressure transmitters (PT-01 and PT-09) responsible for controlling the whole gas entrance in the system.The transport cycle starts with the opening of butterfly valves (V-34 and V-35), allowing the material to be transported to feed the vessel (since guillotine valves are open) by gravity. Then, V-28 valve and is subsequently open and closed so pressurized gas promotes material transport under batches. Due to the volume limitation and with the intention of simulating an intermittent system, the material is recirculated through the system. It was defined that at each determined mass value measured in the upper hopper, the system enters into the lower hopper feedback stage, preventing the opening of the air supply valve V-28, opening the pneumatic valve VGP-02 and connecting the thread RT-01 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 1, already mentioned.

Cycle Description and Data Acquisition: In order to control the transport cycle, it was developed an algorithm in Ladder using *MicroWIN* software to a *Siemens* Programmable Logic Controller (PLC). It should be noted that the transportation cycle is composed of two distinct categories of times. The so-called "dead" times refer to the duration of the pilot and actuation times of the valves, considered for safety. These times are not parameterizable. The so-called "useful" times are of effective material dosing and air flow in the transport pipeline. These times will be parameterizable and varied during the tests.All data will be collected using the *TwinCat* supervisory software, with its own programming primarily for data collection. Important information collected is gas flow through the pipeline, pressure near *Batchpump* inlet, mass transported and operating time.

Sample Characterization: As mentioned in the introduction, a previous characterization of the material to be transported is indispensable. In this project, the authors chose limestone powder, mostly due to its availability at the Test Center of the company. The material was submitted totests of granulometry, apparent density, and angle of repose. These properties are important when it comes to the design of silos, storage hopper, besides the comprehension of the dynamic behavior of the material along the transport cycle.However, in the process of sample characterization it was noted that although it is known that material properties does have an influence in the conveyance in this particular case It was noted that these differences were negligible due to the design of this particular system and thus they were not taken in consideration.

Pressurized Ejector: The Pressurized Ejector has the function of feeding solids into the gaseous. Before concerning about constructive aspects, it must be highlighted here an important characteristic that there is a period for compartment loading, by gravity, with dosing by the level switch, and thereafter the addition of pressurized air into the system that starts the movement of the resting material. This way, for a period of the transport cycle, there is no effective transport of material by pneumatic conveyance. One can claim that the cycle is not complete if the process of vessel loading is not considered, but it must be remembered that, in an industrial application, the process may not be a closed loop.In comparison to a common pressure vessel, the pressurized ejector works with pressure gradients considerably higher, up to 7 bars, while the first typically works with 2 bars.

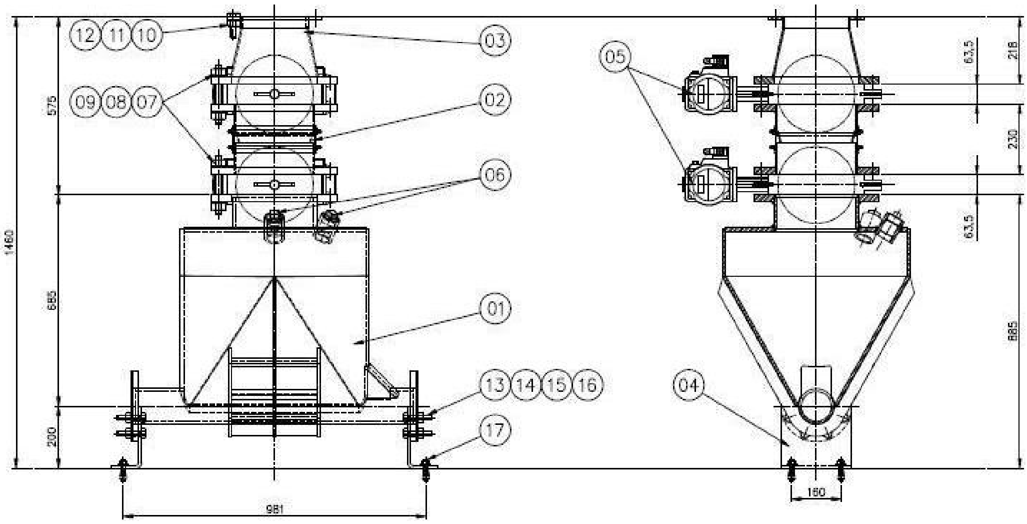


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Fig. 3. Pressurized ejector

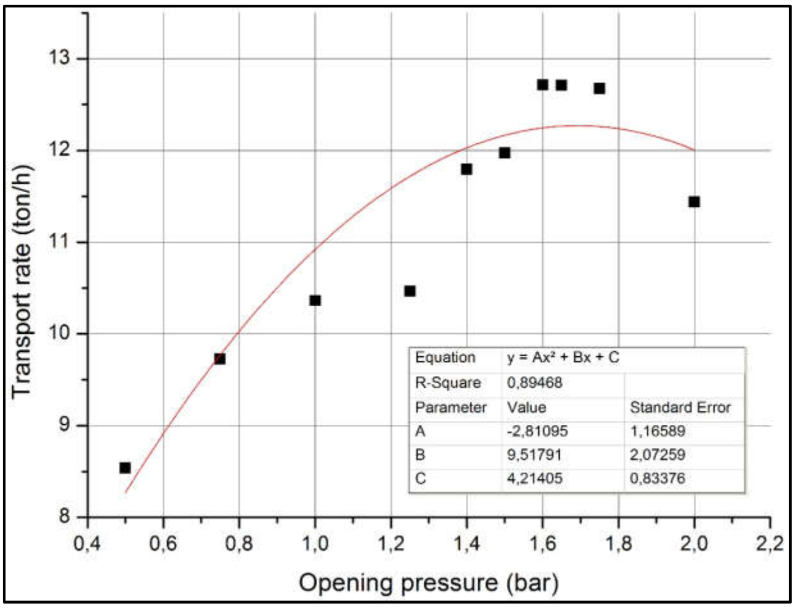

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Fig. 4. Transport rate as a function of the opening pressure

This difference implies that the dosage for traditional vessels must be more precisely controlled since the equipment is not able to convey if the pipeline is overloaded. On the other hand, the pressurized ejector used in this project must preferably work when the pipeline is completely full.Since the *batchpump* as a whole does require a very refined feeding control, it consists in a less complex version of a pressure vessel, presenting also greater simplicity in operation and installation, smaller size, greater ease of use in series, a greater number of transport cycles per hour, and lower cost of production. The ejector design is shown in Figure 3.

Experimental planning: In order to plan the experimental procedure and studying the energy efficiency of the considered system, input and output variables of the model were defined in a way that it is possible to parameterize and monitor the obtained results. The collected data received then treatment and statistical analysis, giving rise to the multivariable model of energy efficiency optimization objectified by the work proposed here (Cecone, 2017).

The input variables are parameters that, under diverse and associated conditions, characterize the energy consumption of the system. In this project, it is assumed that the most important input variables are: maximum and minimum operating pressure and gas flow through the pipeline (kept constant). The output variables are the parameters to be monitored in order to obtain a quantitative analysis of the obtained results from the dynamic simulations of the system with different system configuration and combinations of the input variables, characterizing the energy efficiency associated with each condition tested. For this purpose, it is proposed to consider as output variable the mass of material transported, transport rate and the resulting overall energy consumption of the system.

RESULTS

As mentioned in the previous section, the first tests were responsible to analyze the output variables behavior according to the maximum pressure applied in the pipeline. For practical reasons, the minimum value that could be set to this variable is

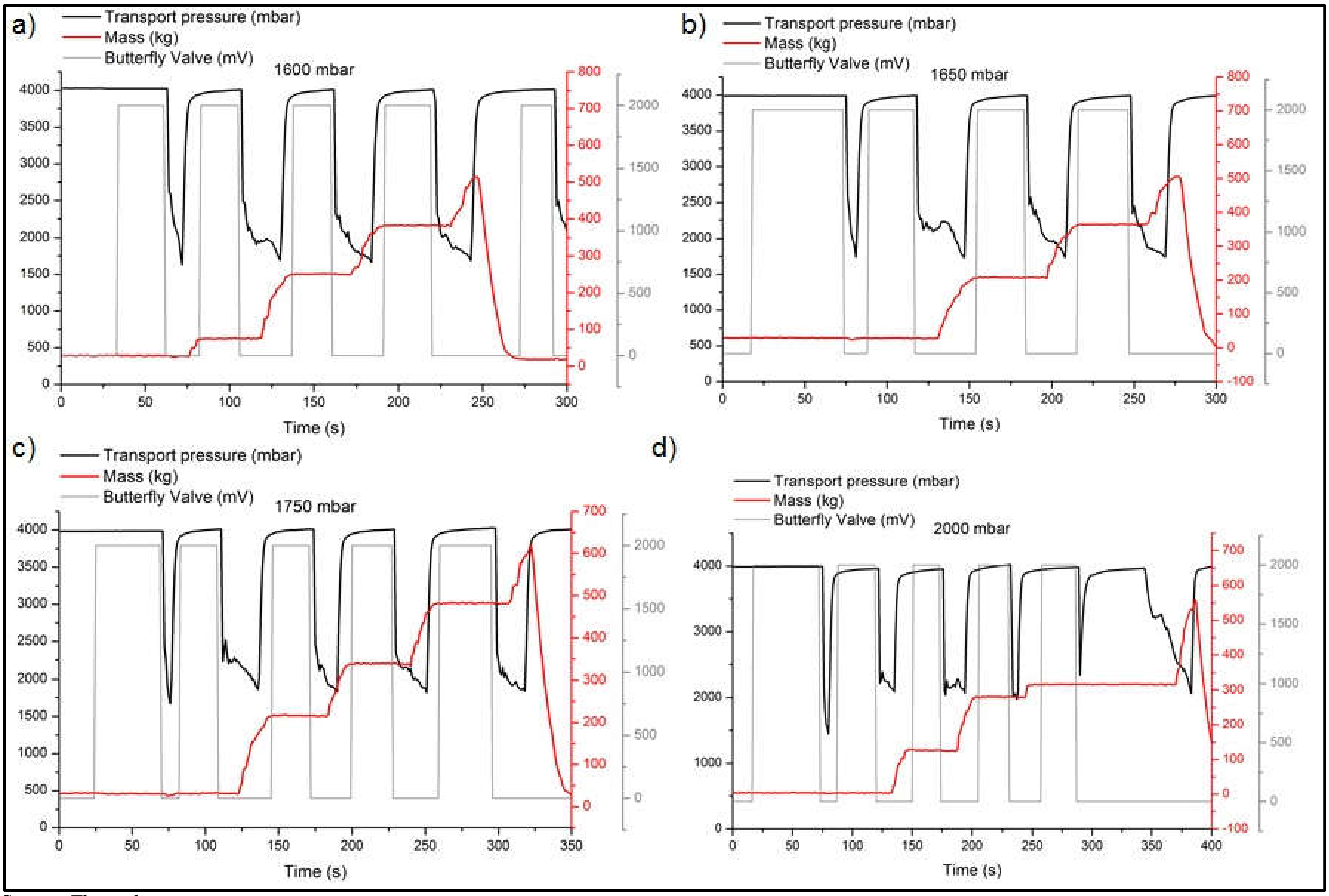

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Fig. 5. Time evolution for different opening pressures, more specifically: a) 1.60 bar b) 1.65 bard) 1.75 bar and d)2.00bar

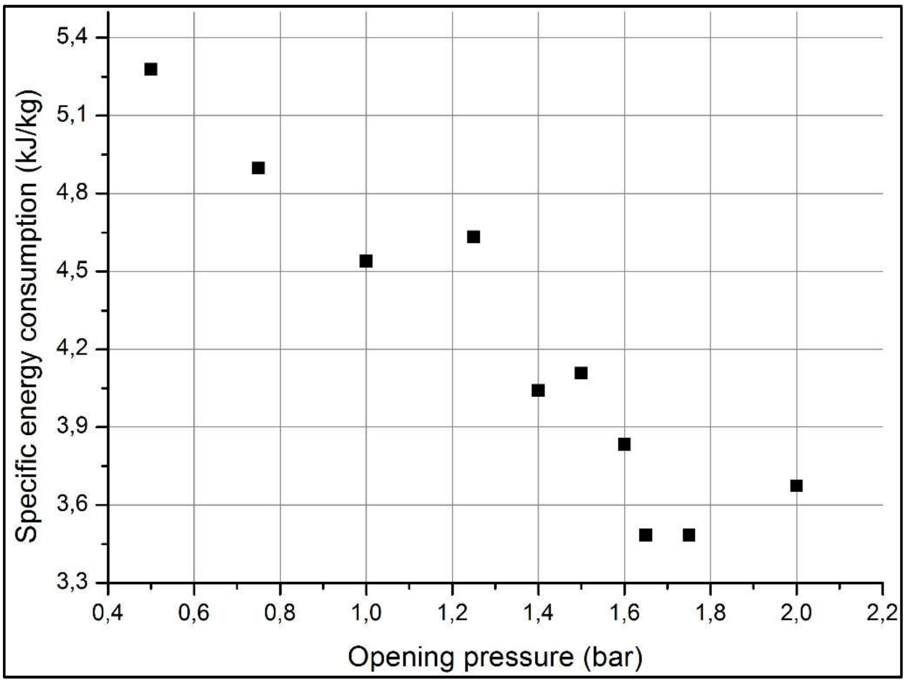

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Fig. 6. Specific energy consumption as a function of the opening pressure

This input variable was set to a limit of 4,5 bar. For higher pressures in the pipeline, the butterfly valves could not open. This procedure shows that the optimum value for the maximum pressure is around 4 bars. The maximum value of 4 bars was kept constant during the analysis of the transport performance submitted to the different minimum pressure that temporarily ceases the transport and enables the vessel feed. This variable is also referred to as “opening pressure”, since when it was reached, the butterfly valves open and deposit material in the vessel. By varying the opening pressure, different transport rates were obtained. The purpose of this stage was to determine which opening pressure could transport the greatest amount of material requiring for this the lowest amount of energy. Figure 4 illustrates the obtained results of the transport rate as a function of opening pressure and a polynomial fitting of the second order. The maximum of this function is reached at approximately 1.69 bar, providing a transport rate of 12.27 tons per hour. Figure 5 shows the time evolution of the system for different opening pressures around to one of the maximum transport rate.

DISCUSSION

This paper brings some conclusions about the use of a *Batchpump* in the pneumatic conveyance of powder and granular materials instead of a traditional pressure vessel. The possibility of working under high pressures make possible to transport a large number of materials per cycle, which result in dense phase conveyance, the material is not diluted in the gas. The consequence of this property is that, when conveying in the dense phase, the pipeline is less affected by the abrasiveness of the material in transport. In factories that produce minerals or use them as was material, to preserve the pipeline is a difficult task that can be facilitated by the use of *batchpump*. The quantitative analysis gauged in this project show that the *batchpump* can be easily controlled in order to provide an optimum point of operation in terms of transport rate and energy consumption, also do not require for this purpose a dynamic control. In other words, once the parameters are set, there is no need for keeping monitoring variables and adjusting the configuration of the inputs. Finally, it must be emphasized that the availability of butterfly valves that could overcome a pressure greater than 4.5 bars could make possible to develop the transport up to 7 bars, the maximum pressure supported by the vessel.

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