BATCHPUMP: AN ALTERNATIVE TO CONVENTIONAL BLOW TANKS

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***Abstract*— The pursuit of energy efficiency solutions is fundamental for sustainability. In an industrial setting, one of the energy-intensive processes is the generation of compressed air, which can be used for the transportation of particulate materials. This process is called pneumatic conveying. One equipment that can be used to pneumatically convey materials is the blow tank, a highly complex and costly feeding device. Those issues inspired the development of alternative industrial equipment; here we study a novel compact blow tank for conveying bulk solids, the Batchpump device with lower dimensions; simpler installation, and also, lower manufacturing cost. Tests were conducted with limestone powder for both equipment in a pilot testing facility with pipeline measuring 133m of length, 3'' diameter, and the air inlet pressure of 4bar at steady state. The data collected showed that Batchpump had a conveying rate of 32% lower while consuming 32% less air per kg of material than the conventional blow tank, with the advent of its portability, which implies that it is possible to replace this conventional blow tank with smaller equipment.**

***Keywords*— Pneumatic Conveying, System Optimization, Energy Efficiency, Innovation.**

I. INTRODUCTION

One of the most important bulk material handling techniques in the industry, pneumatic conveying, consists of the displacement of particulate solid within a pipe as a result of air movement through an induced pressure gradient. Material concentration and behavior in airflow can be used to classify general conveying systems between dense or dilute phases. This type of transportation is well widespread and is expected to grow by about $30 billion by 2025 (Klinzing, 2018).

The first uses of pneumatic conveying in the mid-nineteenth century occurred in a dilute phase, and dense phase applications began in the mid-1970s (Martinussen, 1996). However, studies had already been carried out to predict the behavior of this type of system, such as the diagram developed by Zenz decades before (Zenz, 1949).

The dense phase regime has as its main objective a displacement of particulate matter with lower energy expenditure, reduction in system abrasiveness, and decrease in air filtration equipment (Lavrinec *et al*., 2019). This type of transport is characterized by high pressure and low airflow, being subdivided into other transport characterizations such as flow in plugs and slugs (Mills *et al*., 2004).

The characteristics of the material correspond to the main factor in choosing the conveying phase that will be used and, once determined, establishes requirements for the system design, especially regarding the piping (size, diameter, and the path to be conveyed) and to the blow tank to be used (Freitas *et al*., 2020).

Blow tanks are intermediate equipment on a conveying line made to feed material into the pneumatic conveying line. This deposition of material in the line occurs intermittently, that is, over a certain time interval through which a valve opens at the outlet of the blow tank equipment, the material is inserted in the pipeline. At the next interval, the vessel outlet is closed, the blow tank is fed again and the line material is transported. When two blow tanks are associated in the same line, it is possible to make the system operate in a continuous transport regime, although each equipment continues to operate intermittently (Kus *et al*., 2016).

Blow tanks are used for pneumatic conveying for applications that require certain aspects that would otherwise be inviable for mechanical carriers, such as transportations with great lengths or transportation of toxic materials. Irregularly shaped materials can cause these blow tanks to lock up, in addition to the use of several reliability mechanisms that increase the complexity of the equipment (Kumar, 2015).

These equipment are rather costly, because of their sizer, and necessity of a great amount of control valves, but the main issue is its size, mainly for retrofitting older plants, the addition of a blow tank might make the whole project unfeasible due to the need to change the piping routes or having to place the blow tank underground, which leads to other problems with water infiltration. By identifying on the market, the possibility of placing a new type of blow tank that would reduce the cost and complexity to build a new conveyor line in a pneumatic system, Zeppelin Systems Latin America Company has developed a prototype of a compact blow tank named Batchpump™ (Freitas *et al*., 2019). Designed to convey particulate solids mainly in the dense phase mode, this device has the main goal to be available with lower capital expenditure (CAPEX) and also optimizing energy efficiency to its convey rate when compared with conventional blow tanks. This work focuses on validating the hypotheses under which the new equipment was designed and built and promoting the comparison between Batchpump and conventional blow tanks.

II. METHODS

The experimental procedures of this work were performed at the Hans-Dieter Zamburek Test Center from the company Zeppelin Systems Latin America.

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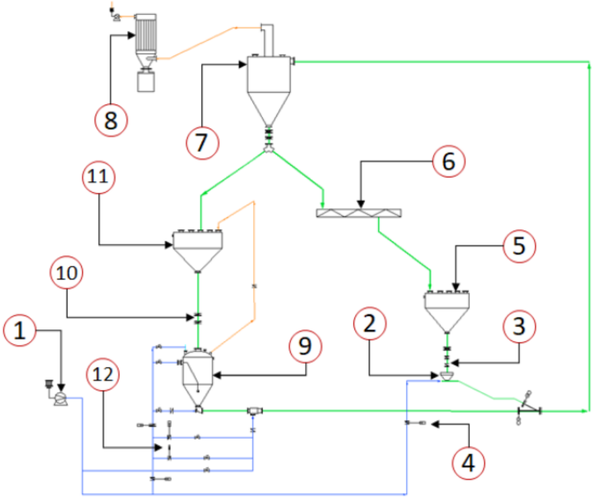

Item	Description	Item	Description
1	Compressor	7	Receiving hopper
2	Batchpump™	8	Filter
3	Batchpump dosing valve set	9	Conventional Blow tank
4	Batchpump air inlet valve	10	Blow tank dosing valve set
5	Batchpump lung hopper	11	Blow tank lung hopper
6	Screw conveyor	12	Blow tank air control valve set

Figure 1. Pneumatic conveying test system layout. The blue pipeline is the injection of compressed air. The green pipeline is the material transport line.

Figure 1 presents a representation of the conveying system. It is composed of a conveying line with diameter of 3’’ and length of 133m and two material inlets, one for the conventional blow tank transport (Item 9) and the other for the Batchpump (Item 2).

A. Mass conveying cycle: Batchpump

The material starts in the lung hopper above the Batchpump (Item 5, Fig. 1). It is fed into the Batchpump (Item 2) by two dosing valves (Item 3), the upper one for material retention and the lower to be airtight. After the dosing process finishes, the conveying cycle begins with compressed air (Item 1) insertion into the system at pressure set to 4 bar by the air inlet valve (Item 4). As the material is conveyed through the gas stream, the pressure in the system decreases. When the pressure is below an adjustable value PSLL (threshold pressure) the air inlet valve closes (Item 4). The conveying air is released after having the solids removed by a filter (Item 8). This conveying cycle is repeated until there is reached a predefined mass of material in the receiving hopper (Item 7) and so the process is restarted by returning this material from the receiving hopper to the lung hopper (Item 5). This complete cycle was called a mass conveying cycle of the Batchpump. The Batchpump is shown together with his dosing valves in Fig. 2. Its total volume is 100L, and it has 885mm of height, from the ground to its top (excluding the dosing valves), and 95 mm width, made with carbon steel.

B. Mass conveying cycle: Conventional blow tank

The material present in the hopper lung (Item 11, Fig. 1) is inserted into the blow tank (Item 9) opening the dosing valve set (Item 10). After this mass transfer, the conveying cycle begins with the opening of respectively: air supply valve, which lets air enter, with pressure set at 4 bar, pressurization valve, and constant supplementary air valve (Item 12). Then, begins the transport of material through the pipeline. There are some variables to be set to decide when each auxiliary valve will be opened. If the pressure exceeds a PSL2 (auxiliary air pressure) value, the supplementary air valve opens, if the pressure continues to rise exceeding the PSH2 (shutoff) value, the pressurization valve is closed, if the pressure exceeds the PSHH (clogging pressure) value, all air valves are closed. If the pressure drops to PSH1 (transport air pressures) value, the booster valve opens, if the pressure continues to drop to PSL1 (auxiliary air pressure), the supplementary air valve closes. If the pressure drops from PSLL (threshold pressure), the conveying comes to an end.

Figure 2. Batchpump device (Freitas *et al*., 2020).

After reaching the minimum pressure value, successful transport is considered, completing the conveying cycle. This material is returned to the lung hopper (Item 11) from the receiving hopper (Item 7) and the process is restarted again. This complete cycle is the conveying mass cycle of the conventional blow tank.

Observing items 10 and 12 in Figure 1, one can note the larger number of valves and pipelines associated with the conventional blow tank (Item 9) in comparison to the Batchpump (Item 2), which implies a complexity of the first compared to the second in terms of operation and parameterization. In terms of parametrization, when the Batchpump is used, the only process parameter that need to be adjusted is the PSLL. Considering that the maximum pressure and airflow restriction are fixed, it can be considered a single-input multiple-output system, that is, the optimal value of PSLL in terms of outcome parameters such as conveying rate and energy efficiency can be easily set with the procedure described in Freitas *al*., (2020). When it comes to the conventional blow tank, six parameters need to be adjusted for the system operation, which make the system a multiple-input multiple-output type. The combined effect of these input variables in the process outcome parameters increase the complexity of operation and parametrization of the system.

C. Variable definition

The input variables that govern the dynamics of the pneumatic conveying system were programmed in the blow tank control software, as follows (PSHH, PSH1, PSH2, PSL1, PSL2, and PSLL):

- Clogging pressure (PSHH): Adjustable pressure value corresponding to what is considered a clogged line and terminates transport. This value was imposed up to 4 bar, the same value used as maximum source pressure;
- Transport Air Pressures: Pressures (PSH1) and shutoff (PSH2) of the transport air supply valve;
- Auxiliary air pressures (PSL1 and PSL2): Pressures for which auxiliary air valve opens (PSL2) and closes (PSL1);
- Threshold pressure (PSLL): Pressure to which the auxiliary air valves are closed. End of the transport cycle. Note: for Batchpump tests, only the threshold pressure was varied.

The output variables used as the basis for performance evaluation were: Conveying pressure; Airflow (subsequently corrected for free discharge flow); Mass transported. All these variables were mapped each second and through them, it was possible to define the performance indicators of the system. They are:

Conveying Rate ($\dot{m}$): Total amount of mass (M_T) carried by the system during the evaluated time interval (Δt). In mathematical terms, it is given by

$$\dot{m} = M_T \, \Delta t \tag{1}$$

Solids-to-gas ratio (ϕ): The solids-to-gas ratio was obtained based on data collected from the mass (kg) of material conveyed during a time interval, the volume of air in m³ consumed during the same time interval, and air density at 25ºC, 1.1839 kg/m³. The calculation to obtain the solids-to-gas ratio is described is

$$\phi = M_T/(V_{air} \cdot \rho) \tag{2}$$

D. Experimental procedure

During this experiment, multiple conveying cycles were performed with both equipment. The material chosen for the tests was calcific limestone as it is widely used in the world market by the agricultural sector for pH control and soil stabilization; civil construction; mining; etc. Calcific limestone is composed of ores that imply high abrasiveness, greater uniqueness of components making it difficult to form clusters, but due to electrostatic charges can be shown with high cohesiveness (Lumay *et al.*, 2012). These characteristics of the material tested are some of the reasons for selecting the comparison between equipment that can operate in a dense phase, such as a conventional blow tank or Batchpump.

E. Test definition

The tests were performed by varying the PSLL (Threshold Pressure) input variable for both different conveying cycles. For the Batchpump, there is only the need to change this variable, but for the conventional blow tank, there were also several variables to be set up (PSHH, PSH1, PSH2, PSL1, PSL2). To simplify the testing, all those variables were increased in the same intervals as the PSLL, except the clogging pressure (PSHH). For the nomenclature of each test, only the threshold pressure (PSLL) will be considered in both cases to optimize in terms of energy efficiency, described by the solids-to-gas ratio, as a quantity of material transported per unit of energy used, in the form of compressed air. For the tests, the source pressure was set at 4 bar, the same material was used and the conveying system was not changed.

Table 1. Parameters used in Batchpump.

Test	PSLL (bar)
1	0.5
2	0.75
3	1
4	1.25
5	1.4
6	1.5
7	1.6
8	1.65
9	1.75
10	2

Table 2. Parameters used in conventional blow tank.

Test	HH	H1	H2	L1	L2	LL
1	4	2	1.8	1.5	1.2	0.5
2	4	2.5	2.3	2	1.7	1
3	4	3	2.8	2.5	2.2	1.5

The parameters used in Batchpump are described in Table 1.

The parameters for the tests used in the conventional blow tank are described in Table 2. The abbreviation “PS" defined for each pressure parameter presented in subsection II: “B. Mass conveying cycle: Conventional blow tank” has been suppressed in the label of the columns in Table II. The pressure parameters are presented in bar.

Using the conventional blow tank, in addition to the pneumatic valve set, there are manual valves for airflow restriction for blow tank pressurization, material fluidization, conveying, and auxiliary air (Item 12, Fig. 1). To increase the upper limit of data collection, all manual valves have been opened 100% to obtain the results as easy as possible.

III. RESULTS

The results obtained with the Batchpump conveying cycle tests are described in Table 3. The results for the conventional blow tank are presented in Table 4.

A more extensive collection of Batchpump compared to the conventional blow tank was used, since this equipment is unusual. Due to the experience of the company in parametrizing and operating conventional blow tanks, its best region of operation was previously known, thus a small number of points of operation in this region were collected. Tabulated values were plotted in curves in Fig. 3 and Fig. 4.

It is noticed that both distinct conveying cycles have similar behavioral characteristics for both observed output variables. The conveying rate shows a quadratic behavior with an optimal point of operation, while the solids-to-gas ratio presents a linear behavior for both cases.

Table 3. Conveying test results with the Batchpump.

PSLL (bar)	Conveying Rate (t/h)	Solids-to-gas Ratio (kgmat/kgair)
0.5	6.045	16
0.75	7.853	22
1	7.686	26
1.25	8.224	30
1.4	8.645	32
1.5	8.669	36
1.6	8.670	38
1.65	8.885	41
1.75	8.624	42
2	8.108	50

Table 4. Conveying test results with the Blow Tank.

PSLL (bar)	Conveying Rate (t/h)	Solids to Gas Ratio (kgmat/kgair)
0.5	11.625	26
1	13.104	31
1.5	9.695	38

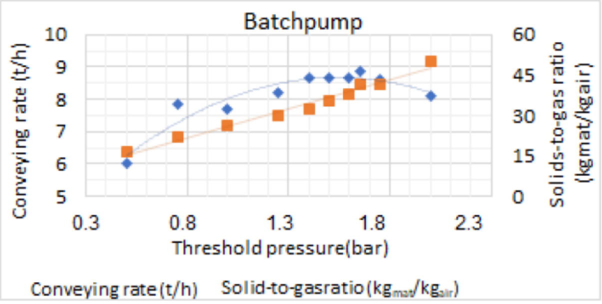

Figure 3: Conveying Rate and Solids-to-gas ratio.

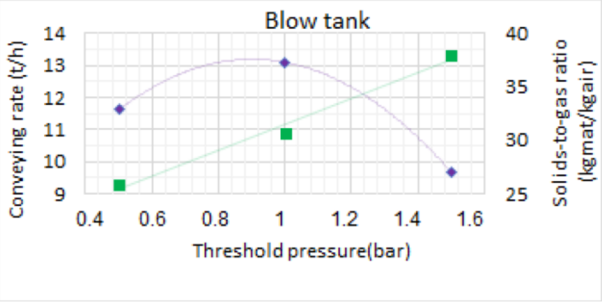

Figure 4: Conveying rate and solid- to-gas ratio curves for the 0.6m³ conventional blow tank.

A. Conveying Limits

It is noticed that both distinct transport cycles have similar behavioral characteristics for both observed output variables, with the blow tank having a higher conveying rate at all points. The conveying rate shows a quadratic behavior with an optimal point of operation, in terms of conveying rate with PSLL = 1,65bar with the Batchpump and with PSLL = 1bar with the blow tank, while the solids-to-gas ratio, or energy efficiency, presents a linear behavior for both cases, with the Batchpump presenting higher material transported per kg of consumed air, with the optimal point of PSLL = 2bar to the Batchpump and PSLL = 1,5 bar to the blow tank

It is possible to see in Fig. 4 the behavior of an example of the graphic result of the curves of conveying pressure, in the left axis, and the total mass and free airflow in the right axis.

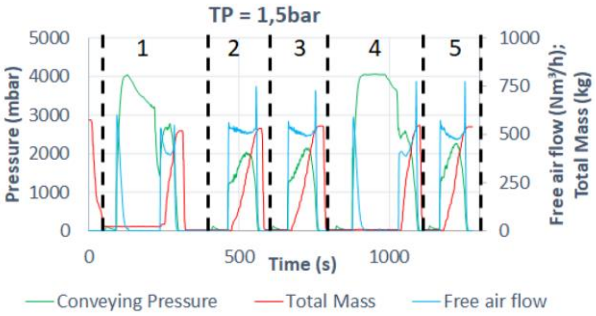

Figure 5: Curves of conveying pressure (left axis) and total mass and free airflow (right axis).

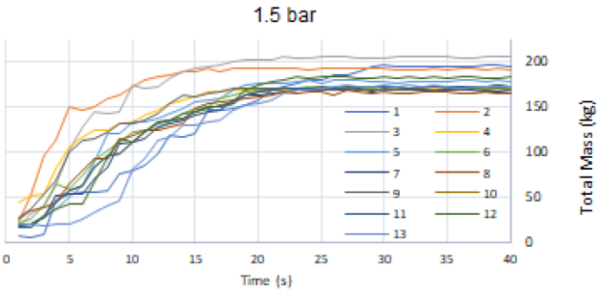

Figure 6: Batchpump initial time mass curves.

Looking at the 5 conveying cycles in Fig. 5, it can be noted that there is a similarity between the behavior of cycles 2, 3, and 5, as seen comparing the airflow (blue lines), mass (red lines), and green lines in the graph, but it is clear that cycles 1 and 4 have a high discrepancy (longer, higher conveying pressure, airflow goes to zero before the end of the cycle, conveyed mass does not change) in comparison to the others. This difference is defined as conveying instability, which negatively impacts the average conveying rate. The fact that the airflow unexpectedly goes to zero and, at the same moment, the conveying pressure suddenly increase to an uncommon level can indicate a temporary clogging (in the subsequent cycles, the behavior is not observed). If this type of behavior persists, in addition to impairing the repeatability of the system, increasing the degree of uncertainty of the output variables, it can lead the system to a permanent clogging.

B. Conveying cycles curves

A clear distinction is made between the mass curves affected by the conventional blow tank and the Batchpump. To make this comparison, one may see the need to confirm that there is repeatability in the behavior of each conveying cycle. For this assessment of this source of uncertainty, the beginnings of the conveying cycle curves were brought to the same instant of time and recorded an expanded uncertainty of the corresponding conveying rates. This can be seen in Fig. 6.

Satisfactory repeatability error (5.93%) indicates consistency between Batchpump conveying cycles. The difference associated with recent cycles in comparison to factors arising from the fact that at the beginning of the conveying cycles there is not the same conveying resistance observed in subsequent cycles due to the increase in mass in the pipe. Therefore, when the system

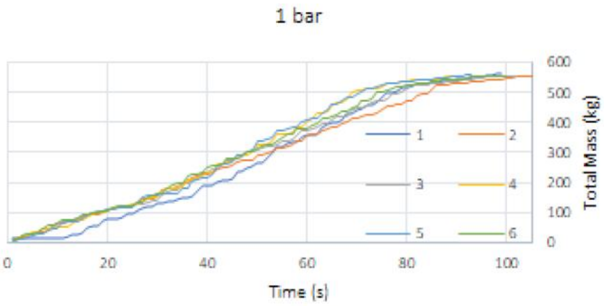

Figure 7: Batchpump initial time mass curves.

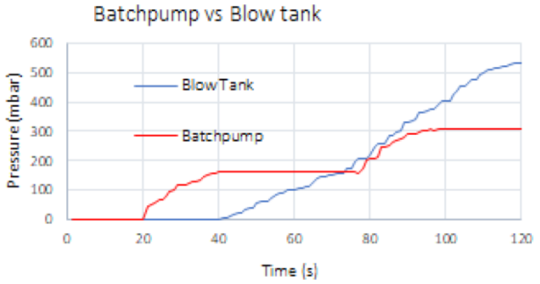

Figure 8. Mass curves between the conventional blow tank and the Batchpump.

reaches the steady-state, it is possible to choose a single representative cycle to describe the conveying of each test defined by the threshold pressure. For the conveyance with the conventional blow tank, the same methodology was used and the repeatability error value was 12.73%. It can be seen as curves used for repetition evaluation in Fig. 7.

Moreover, in each Batchpump discharge, it is noticed that there is an exponential-like behavior for mass transfer, this is not observed in the conventional blow tank due to its larger volume and its complexity by the actuation of several auxiliary valves. With increasing resistance, there is a greater addition of conveying air that may imply greater linearity of the transported mass.

C. Comparative analysis

Comparisons between the characteristic curves of each equipment and the respective conveying rates were performed using representative cycles of each test, choosing sections of the cycles so that it was possible to consider steady state. Since the system has no level switches, the filling time was estimated experimentally at 20s for the Batchpump and 40s for the conventional blow tank. Considering these values and the initially empty equipment, it was possible to estimate the time that each equipment takes to convey a fixed amount of mass, 400 kg. Fig. 8 illustrates these comparisons.

It is noticed that even with the longest dosing time of the conventional blow tank, this equipment is capable of achieving a higher predetermined value of conveyed mass, which makes it have a higher conveying rate compared to Batchpump. Although this difference is not significant to justify the choice of equipment with such complexity, size, and cost that is the blow tank.

IV. CONCLUSIONS

From both device comparisons, the Batchpump had in its highest conveying rate, 8.88 t/h, at PSLL = 1.65bar with 41kg of material transported per kg of compressed air needed, while the blow tank had his highest conveying rate, 13.10 t/h at PSLL = 1bar with 31kg of material transported per kg of air. In other terms, the Batchpump consumes about 32% less air for each kg of material transported while having a conveying rate of 32% lower as well, both in their highest conveying capabilities (PSLL = 1.65 bar for the Batchpump and PSLL = 1bar for the blow tank). The difference in volume, however, is 6 times lower, which implies that it is indeed possible to replace this conventional blow tank with smaller equipment exchanging conveying rate for air consumption.

A. Future Work

The main contribution of this work can best be appreciated by industrial application in pneumatic conveying systems. The reduction in equipment dimensions brings new application alternatives, allowing usage in more restricted boundary conditions and simplification of installation. In order to better understand this interaction between materials and conveyance operational variables, it is necessary to use more powerful tools, possibly computational fluid dynamics (CFD) frameworks to analyze the more fundamental relationships in particle-particle-wall-gas interactions. Then, this compact Batchpump device will have a good chance of emerging as a successful commercial offering for some applications.

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