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FLUID-DYNAMICAL PARAMETERS CONTROL FOR ATOMIZED SLIP PNEUMATIC CONVEYING

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ABSTRACT

One of the most important problems in ceramic industrial processes is the atomized slip conveying.
Currently conveyor belts pick up the material from the bottom of spray dryer and they rise up it to stocking silos.
By conveyor belts, the atomized slip crosses the working environment, so fine particles spread out causing dust pollution and generating dangers for workers' health (silicosis).
The paper describes an innovative atomized slip pneumatic conveying to solve this problem.
The software simulator "TPSimWin" is able to foresee thermo-hygrometric and fluid-dynamical parameters that give the characteristics request by the specific working process.
The attention of this paper will be focused on fluid-dynamical characteristics of the pneumatic conveying: both solid maximum conveying speed and speed gradient (i.e. the variation of solid's speed, in m/s, for unit length of pipe), need to be limited to guarantee wholeness of product.
So the TPSimWin Software gives the necessary solid dynamic information to design correctly the pneumatic conveying plant. The outputs it gives are diagrams that show, step by step along the pipeline, the behaviour of air speed, solid speed, solid speed gradient and air pressure.
The main goal of this paper is to introduce an innovative solution for the transport of atomized slip, taking in consideration the critical problem of material degradation and showing a solution to solve it.
A method to ensure and to monitor thermo-hygrometric characteristics will be described in a second following paper.

INTRODUCTION

Figure 1 shows a traditional process flow chart of a ceramics plant.

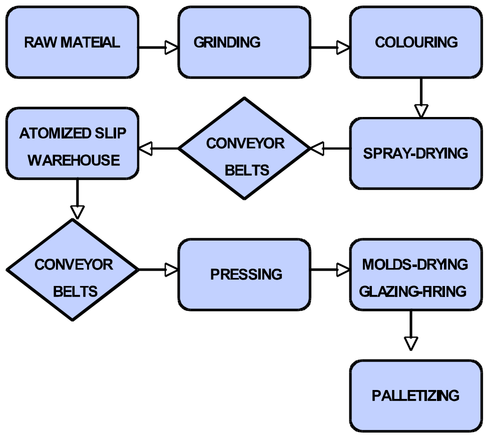


Figure 1: Process flow chart in a ceramics plant.

This paper will show how it is possible to design a pneumatic conveying plant that is able to convey atomized slip, without any problem in granulometry preservation and, as we will read in a following paper, with humidity control, avoiding localized atomized slip drying.
The main idea is to substitute conveyor belts before and after the atomized slip warehouse (as shown in figure 1) with a pneumatic conveyor pipeline.

In the ceramics industry, more than 95% of atomized slip conveying is currently carried out by conveyor belts because of their technological simplicity and the fact that they avoid product damage. At the same time, the product on the conveyor belt is not fluidised by air and thus the humidity parameter does not change its value significantly, but remains almost constant during its run.

Figure 2: Conveyor belt.

On the other hand, there are also some significant negative characteristics.
First, the conveyor belt is open to the atmosphere and this allows fine powder dispersion in the working environment. Everywhere the working environment is more or less covered by a thin film of powder and air suction plants are usually not enough to suck in all dispersed powder.
It is not only a problem of general cleanliness, but predominantly a healthiness problem: workers breath this fine powder every day.This power is atomized slip.The inhalation of atomized slip is dangerous because it consists of silica dust. Silica dust can be the cause of respiratory disease such as silicosis. Silicosis is a potentially fatal, irreversible, fibrotic pulmonary disease. The rate of disease progression appears to depend upon the rate of silica deposition in the lungs, as well as the total amount of crystalline silica that is retained in the lung.
Conveyor belt speed is designed on the basis of atomized slip mass flow rate. This speed represents the saltation velocity for particles small enough. In other words, for an incoherent material (like atomized slip) of a defined granulometry, it is possible to find a speed value (saltation velocity) over which particles could be transported into the atmosphere (working environment). This phenomenon of dustiness is therefore directly related to conveyor belt speed.
Another two problems, albeit of lower importance, are connected with conveyor belt use. The first is the relatively greater dimension of the plant, as will be shown in this paper, and the second is the possibility of product contamination by the environment.
Some relevant advantages introduced by pneumatic conveying are: reduction of maintenance work, the possibility to perform complex paths, the simplicity of installation, smaller overall dimensions and the cleanliness of the plant and, that is more important, of the work environment.

MANUFACTURING CYCLE MAIN PHASES

In this paragraph, the main phases of the manufacturing cycle will be introduced, with particular attention to atomized slip conveying.

Raw material warehouse

The raw materials are mainly clay and feldspar. They come from several parts of the world; in the last decade or so, around 50% came from, respectively, Turkey and Ukraine.
The medium sizes of clay are between 10 and 20 cm, while for feldspar they are between 2 and 5 cm. There are several kinds of clay and many more of feldspar, which are mixed together to form the secret blend for every product.

Grinding

In this phase a mix of raw materials and water are poured into mills to obtain a slip with a specific granulometry according to the final product characteristics. It is possible to perform dry grinding, but in a blend including more than four components, the use of water is recommended in order to reach higher product homogeneity. There are continuous and non-continuous mills: the selection is an equilibrium between performances and costs.
Slip is stored in special tanks with a blender in order to maintain product homogeneity and solid suspension, while waiting to be used in a spray dryer.

Spray-drying

By means of a plunger pumps, slip is fed into a spray dryer. Slip particles are dried by a hot air flow inlet at constant speed: a uniform-density flow finely balanced in the two phases (air and solid) is conveyed around the central axis of the spray dryer, whose output is atomized slip between 100 and 600 μm in size. The particles are very fragile and empty. Figure 3 shows a macro photo of atomized slip.

Figure 3: Enlargement of atomized slip.

Conveyor belts, atomized slip warehouse and pressing

Atomized slip conveying between the spray dryer and the warehouse and between the warehouse and the presses represents the most problematic phase of the manufacturing cycle. As shown in figures 4 and 5, the use of conveyor belts necessarily implies the introduction of fine powder into the atmosphere.

Figure 4: Spray dryer outlet and conveyor belt inlet.

Figure 5: Conveyor belt outlet and warehouse inlet.

The great advantages of conveyor belts utilization are the low speed and absence of relative solid speed and product fluidization. These aspects make it possible to avoid, respectively, product damage and drying.

Similar problems are encountered in the second atomized slip conveying between the warehouse and the presses. This last process is mainly carried out by hydraulic presses that guarantee reliability, agility and are easy to use.

Molds – drying – glazing – firing – palletizing

All these phases are developed on the same line and they contribute in differentiating the final product by mechanical characteristics, dimensions and artistic details.

ATOMIZED SLIP CIRCUIT ANALYSIS

Atomized slip pneumatic conveying design is based on the analysis of a real plant, selected in the Imola-Faenza ceramics district.

Three spray dryers (called ATM) are installed at this plant. ATM1 and ATM2 have a mass flow rate around 8 t/h each and ATM3 around 30 t/h.

Each spray dryers unload atomized slip on conveyor belts whereby it gets at each silos.

Each conveyor belt circuit was measured (length, slope and mass flow rate) in order to identify the most difficult situation, to produce a design that could be used for each single conveying section.

Figure below shows the conveyor belt lay-out from ATM 3 (in which s_{xx} are silos of storage of atomized slip).

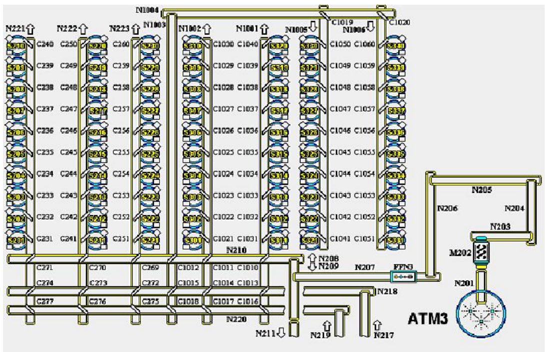


Figure 6: Conveyor belt lay-out for ATM3.

It is possible to automatically manage the feeding of each individual silo by a PLC.

After this analysis, a first attempt configuration of pneumatic conveying was designed as shown in figure 7.

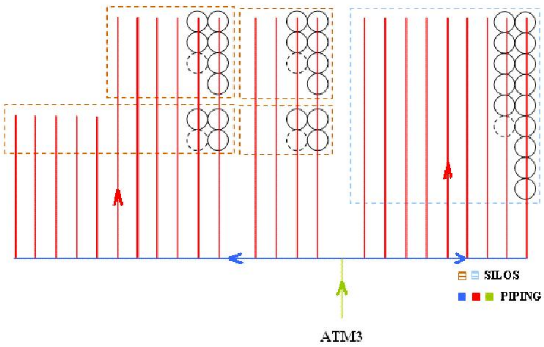


Figure 7: Pneumatic conveying plant lay-out for ATM3.

The green, blue and red pipeline connect the spry dryer ATM3 to each silos.

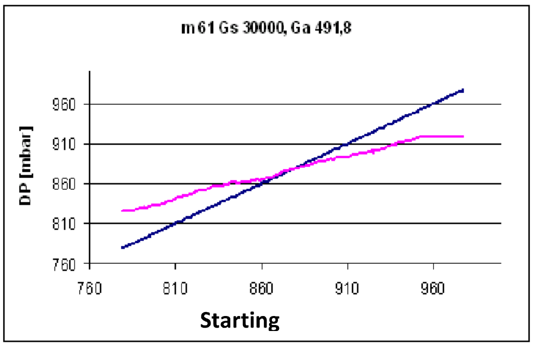
PNEUMATIC CONVEYING PLANT DESIGN

Pneumatic conveying plant design was performed with the use of TPSimWin software [1,2,3,4,5].
TPSimWin software is able to foresee the whole two-phase flow fluid dynamic characteristics. It calculates in detail both the solid and the air speed and the pressure drop along the pipeline.
Analyzing these data it is possible to predict where the speed and the speed gradient of atomized slip becomes inappropriate to preserve the integrity of atomized slip particles.

TPSimWin inputs are: bend and straight friction factor and product hydraulic diameter and density.
The first three values can be evaluated by using a pneumatic conveying facility for bulk solid characterization [6], such as the one located in Bologna, in the laboratory of the Department of Mechanical Engineering (DIEM) actually in use.
Atomized slip characteristic values were:

bend friction factor: 0.4
straight friction factor: 0.00004
solid hydraulic average diameter: 0.093 mm

The first output of the TPSimWin software is the stability diagram (figures 8a and 8b) [5], in which we see, looking at the slope of the DP vs. starting pressure curve, drawn in magenta, that the transport is a dense phase one (loading ratio m=61, where m is kg of solid per kg of air) and it is relatively stable.



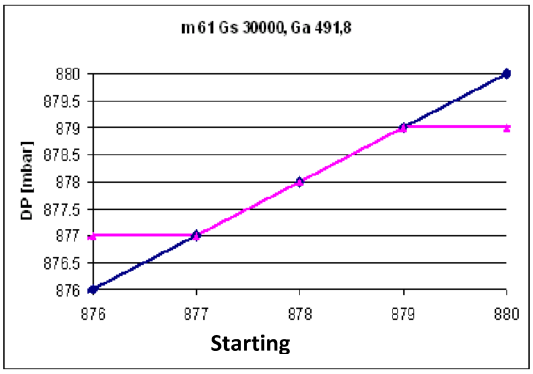


Figure 8a_8b: Stability diagram for spray dryer ATM3
The intersection between the magenta line that characterizes the plant pressure drops and blue line, corresponding to the equilibrium between starting pressure and DP, defines the point(s) of " U " diagram that describes drop pressure as a function of m [5].
The TPSimWin second output is a diagram (fig. 9) whose abscissa is a linear development of full length pneumatic conveying pipe (the bends are highlighted with a little mark on the abscissa) and on the ordinate, step by step along the pipe, air speed, solid speed and air pressure drop.
The limits that were fixed for solid conveying, based on previous experience, are on maximum solid speed and speed gradient (i.e. the variation of solid speed for unit of pipe length). In particular, the maximum solid speed is fixed around 7 m/s, while the maximum speed gradient is 8 s^{-1}.
The diagram gives information about speed, acceleration and slow down of atomized slip all along the pipeline. In particular it shows where speed exceeds the maximum admissible value, that is where we should have problems of fragmentation of atomized slip consequent to collision against the pipe wall and between particle and particle.
Figure 9 shows an attempt in which atomized slip reaches silos 120 m away, but solid speed rises over the limit of 7 m/s.
Introducing two steps of pipe enlargements, highlighted by black circles in figure 10, the possibility of designing atomized slip pneumatic conveying in a dense phase (m=61) for a distance of 120 m was verified.
The section enlargements, showed in figure 10 inside the two circles, were opportunely introduced at the exit of two bends where the difference between air and product speed is maximum, to avoid an air speed decrease to a value lower than the solid speed, with the risk of transport blockage.
Keeping an upper limit of solid speed is not enough to avoid product degradation: from this point of view, to have a real effectiveness, the maximum value of product velocity must be connected to a speed gradient threshold.
It is important to underline that solid speed gradient may rise up to very high values along pneumatic conveying particularly when calculation step is very short (as shown in fig 11): when this high values are localized in a very few steps, it means that a very low quantity of material is involved in a strong slow down.

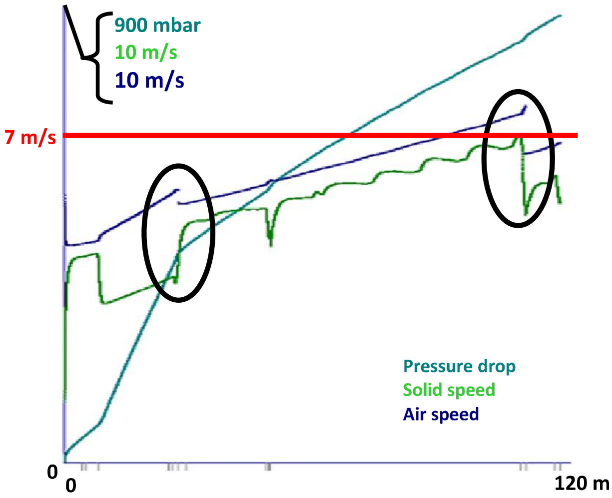


Figure 9: TPSimWin output diagram in which solid speed exceeds limit of 7 m/s (red horizontal line)

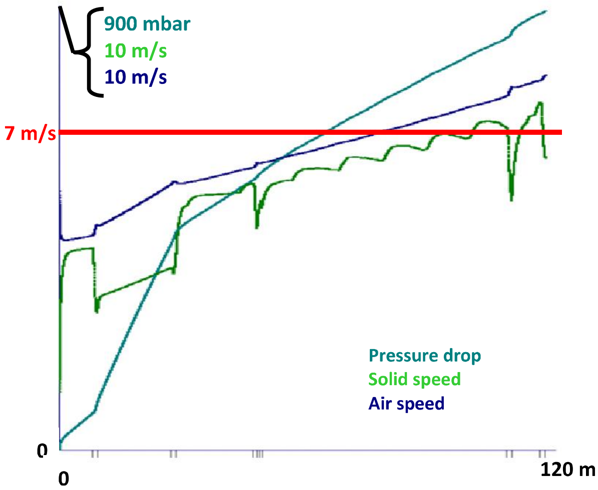


Figure 10: TPSimWin output diagram with variation of section highlighted by black circles.

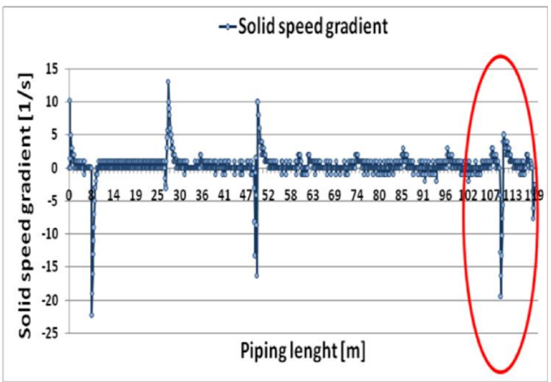


Figure 11: Solid speed gradient (5 mm step) along all pneumatic conveying. The area, highlighted by red circle, will be zoomed in next figure 12

Analyzing the transport by a calculation step of 25 cm, a better idea about what it is really happening to the most part of the conveyed solid is given.
Figure 12 shows that, by a calculation step of 25 cm, the solid speed gradient is, on the average, lower than 8 s^{-1}. It means that we can neglect local phenomena, when they are not too much frequent, as they involve only a small quantity of product.

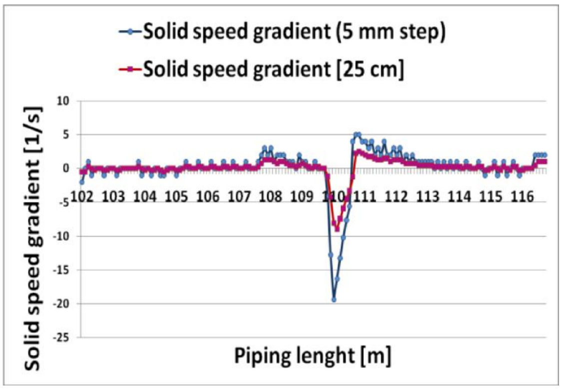


Figure 12: solid speed gradient zoom. Comparison between 5 mm step and 25 cm step that is more representative of real condition.

So the control of solid speed gradient is particularly important to guarantee solid integrity along conveying. In fact kinetic energy variation (ΔE) is related to speed gradient ($\Delta E \propto \Delta v^2$). Energy losses are connected to product damage: there is a relation of proportionality between the volume of eroded solid and the energy consumed to wear away it.

Let's show an example where we consider the section highlighted by a black circle in the following figure 13. The average atomized slip speed decreases from v_i = 5,7 m/s at bend inlet to v_o = 4,7m/s at bend outlet (bend length = 1,2 m). Kinetic energy losses are proportional to:

$$\Delta E_1 \propto v_i^2 - v_o^2 = 5{,}7^2 - 4{,}7^2 = 10{,}4 \ m^2/s^2$$

If, for example, atomized slip particles speed at inlet bend were 15 m/s, under the same value of acceptable kinetic energy losses (ΔE_1), the value of solid speed at bend outlet should be:

$$\Delta E_2 = \Delta E_1 \propto 10{,}4 = v_i^2 - v_o^2 = 15^2 - v_o^2$$
$$\Rightarrow v_o = 14{,}7 \ m/s$$

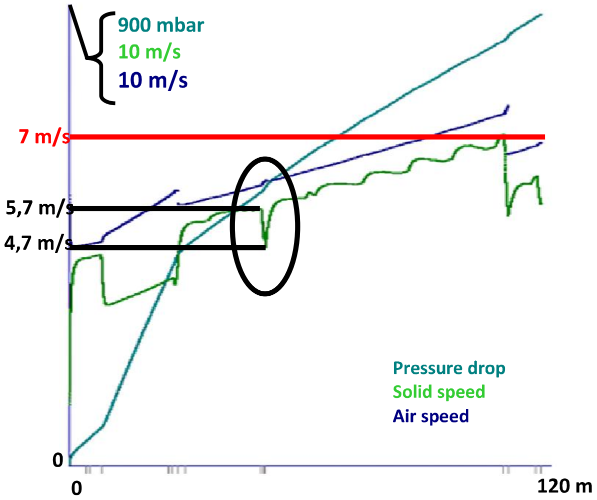


Figure 13: TPSimWin output diagram, in which a speed gradient on a bend has been highlighted by a black circle

So, for the same value of kinetic energy losses, while under the first condition (5,7 m/s) the allowable speed gradient (SG) along the bend is:

$$SG_1 = (v_i - v_o)/L = (5{,}7\ m/s - 4{,}7\ m/s)/1{,}2\ m = 0{,}83\ s^{-1}$$

under the second condition (15 m/s) the allowable speed gradient, that cause the same kinetic energy losses and then the same product degradation, should be:

$$SG_2 = (v_i - v_o)/L = (15\ m/s - 14{,}7\ m/s)/1{,}2\ m = 0{,}25\ s^{-1}$$

From these results spring (as shown in figure 14) that if the solid speed is lower (green line), the allowable gradient speed (blue line) is higher and then the solid speed can come down (red line) to a lower value according to acceptable kinetic energy losses, while in case of higher value of speed (green line), in order to keep constant kinetic energy losses, we are obliged to reduce speed gradient (blue line).

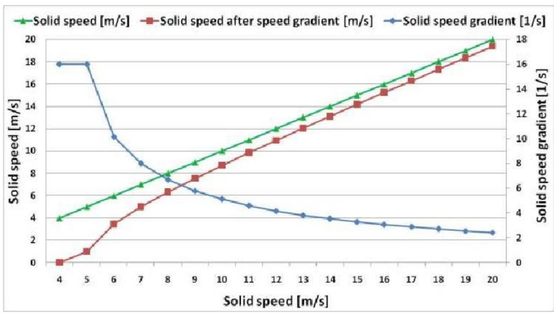


Figure 14: Relation between solid speed and solid speed gradient for pipe length of 25 cm with the hypothesis of constant kinetic energy losses

It means that, to have the same amount of kinetic energy lost by solid for friction phenomena, in the first case it is necessary to limit the slow down under 1 m/s in 1.2 m of bend development, while, in the second case, the maximum admissible slow down value is 0.3 m/s from bend inlet to its outlet.

CONCLUSION

The main goal of this paper was to verify the possibility to convey atomized slip on pneumatic conveyors while avoiding critical problems of solid physical degradation.

By means of atomized slip characterization in a pneumatic conveying facility and the use of TPSimWin simulation software, it was possible to verify the transportability of atomized slip in a pneumatic conveying plant.

By solid speed and solid speed gradient control along the pipeline, it is possible to guarantee solid particle integrity, that represents one of the most important characteristic required to atomized slip for next processing. Another important characteristic is relative solid humidity, which is already introduced in a previous paper [7] and that will be discussed in a next work.

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