Countercurrent Compressed Air Cleaning Systems for Dust Filters

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1. Importance of the Product Code

1.1 The Product Code

The product code is important in industrial applications for identifying the chemical and physical characteristics of products and allowing appropriate measures to be taken during handling.

As stated in [1], information of primary importance for handling solids in the form of dust and granules, otherwise known as "bulk solids," is obtained from the description and codification of the products to be handled. In particular, the formation of the "cake," a stable layer of product which forms on the filter, of significant thickness, which effectively contributes to the separation process, is covered.

The accumulation of product transported in the flow of air, as it expands from the polluted area to the clean area, causes an initial blockage, due to the mesh of the filter element. Here we can observe a dual phenomenon: the smaller granules are lodged in the mesh of the filter and form a compound, or composites, which during the initial phases of filter life leads to more efficient separation, due to the occupation of gaps in the fabric. It also determines an increase of localized pressure drops, due to the presence of the filter. In the long run, the abrasive elements in the compound damage the fabric.

Any form of cleaning process will have an impact on the fabric fibres of the filter element, resulting in a whirlash action, as shown by tests carried out on a number of cleaning systems by different researchers [11]. The relative motion damages the fibres by friction on hard abrasive surfaces. This process has been observed through the microscope; after several thousand cleaning cycles, the filter fabric is frayed, and individual fibres are torn. A similar phenomenon occurs with the ropes used for rock-climbing: after several months of constant use, the ropes start to fray, even without having received sudden jolts from falls. This is due to the penetration of very fine dust between the individual fibres, and the constant stretching and bending movements of the rope.

Secondly, the compaction of an external layer of varying thickness, according to the characteristics of the product, is of major importance in establishing a working balance between pollution and cleanliness levels. The balance is certainly dynamic; there is an increase in pressure drops in the filter due to the progressive build-up of cake, but the external layer improves efficiency in the separation process by providing an extra filter mesh. The cleaning process will tend to destroy most of this layer, with a view to containing pressure drops.

Several observations have been made:
- the infiltration of dust into the innermost fibres of the fabric depends on the granulometric distribution of the transported product and the inertia of the particles
- the speed of accumulation, adhesion, compactness, permeability and resistance to cleaning of the external layer depends on product characteristics
- pressure-drops depend on the layer formed by the pollutant
- efficiency of the separation process is based largely on the dynamic balance regulating the formation of "cake"
- the cleaning cycles must be adjusted to maintain the correct balance between the formation of the "cake" and the containment of pressure-drops.

The importance of product characteristics has therefore been reiterated.

The most important characteristics are listed below:
- apparent specific weight, i.e. during transportation
- granulometry (ISO examined)
- flowability
- abrasiveness
- degradability
- hygroscopicity
- tendency to form lumps, agglomerates, and filaments
- presence of oils and fats
- tendency to compact
- moisture.

The most favorable cleaning system parameters can thus be selected, once the product characteristics are known, taking the arrangement of the filtering elements into account.

1.2 Product Code

On the basis of the aforementioned characteristics, an index can be calculated for the product, with which to classify classes of pollutants.

This is a purely qualitative classification: its validity and accuracy can only be established by thorough case-studies. From experience, the following subdivision can be made:
- specific weight
- granulometry
- flowability
- important characteristics
- moisture.

The latter three characteristics can be connected to the product's ability to form resistant and stable layers, i.e. the tendency of the product to strataly.
1.2.1 Class 1
Solids with high values for specific weight and granulometry (\( > A_{0.45} \)) and a low tendency to stratch; very low flowability, humidity percentages below unity and lack of important characteristics, such as the tendency to compact, etc. This class of products has the lowest air consumption rate during cleaning.

1.2.2 Class 2
Solids with medium specific weight, medium to low granulometry (\( > A_{0.15} \)) and medium tendency to stratch; medium to low flowability, humidity under 5% and absence of important characteristics, such as tendency to compact, etc. This class requires a greater expenditure of air for cleaning compared to the previous class.

1.2.3 Class 3
Solids with medium to low specific weight, low granulometry (\( > A_{0.07} \)) and medium to high tendency to stratch; medium to high flowability, humidity under 10% and presence of important characteristics, such as tendency to compact, etc. This class requires a greater expenditure of air for cleaning compared to the previous class.

1.2.4 Class 4
Solids with a low specific weight and granulometry (\( > A_{0.07} \)) and a high tendency to stratch; high flowability, humidity higher than 10% and a heavy influence of significant characteristics such as tendency to compact, etc. This class of solids requires a greater expenditure of air for cleaning compared to the previous class.

1.3 Air Consumption in Relation to Filter Element Configuration and Material Used to Construct the Filters

The consumption rate of compressed air during the cleaning of the filter element depends mainly on the following:

- pollutant type, which determines the quantity of air required in liters and the programming of cleaning operation times
- configuration of the filter element, which determines the quantity in liters of compressed air required. The greater the surface area, the greater the loss of the highly effective cylindrical shape, with consequent increase in consumption rates. Because of its irregular surface, the pleated filter cartridge definitely has the highest consumption rates
- materials used in the construction of the filter elements.

2. Influence of Cleaning Time and Interval Scheduling

The cleaning cycle is made up of two different phases:
- cleaning circuit running time: includes intervals and active running time during the cleaning process
- blasting: the partial net active period corresponding to the opening of one blast valve

The pollutant type and the inertia levels at which the product comes into contact with the separating layer determine the selection of cleaning times and compressed air cleaning conduits opening times.

### 2.1 Precoating

Precoating is the first running stage before the cleaning cycles are initiated. It serves as a running-in period for the fabric, allowing the formation of the first separating layer and of a stable external layer.

The length of the precoating period is determined by product characteristics and inertia levels: class 1 products, therefore, require only a few hours, class two products more, and so on, according to the increasing presence of critical characteristics.

### 2.2 Influence of Pollutant Type

Table 4 shows the influences of pollutant type on cleaning times.

### 2.3 Influence of Filtration Speed

The filtration speed has a negative effect on the filter system:
- during the precoating period high filtration speed can lead to rapid wearing of the fabric
- filtration speed should therefore be maintained within the limits of the values indicated in [1] during both the precoating and the wearing phases, thus reducing the risk of emissions due to the wearing by impact of the fabric, known as the "bullet effect".

Operations which require high filtration speeds must have short blasting times, to contain the demaging effects of sudden impacts on the filter element; the overall active running time must, however, be increased in min/h, because of the rapid formation of cake on the surface.
3. Effects Derived for the Geometry of the Membrane Valve

The overall performance of the system is influenced by the dimensions of the throughfeed duct and running pressure level: in order to select the correct valve and duct dimensions, the valve performance curve must be seen as a function of the operating pressure. The selection must, therefore, take into account filter element requirements.

Increasing throughfeed duct dimensions, whilst keeping running times and pressure the same, improves cleaning efficiency: pneumatic or electric membrane valves are usually used. Laboratory tests have pointed to significant differences between valves with the same nominal dimensions, but with variations, albeit slight, in the internal geometry. These differences are due to various factors:

- size of the tank at the infeed end of the membrane: the larger the volume in this area, the faster the flow expulsion rate, due to the accumulation of energy
- diameter and length of the outlet duct: increasing the length will cause unwanted pressure drops
- internal geometry: the absence of sudden changes in direction of the flow, turbulence and pressure drops, guarantees greater valve efficiency
- duct surface finishing: an increase in surface roughness leads to an increase in pressure drops with subsequent energy dispersal.

The following measures have been designed to improve the efficiency of the cleaning circuit parts in question:

- composition of modular valves, which can be connected to each other to form a supplementary volume to enhance system efficiency
- outlet duct made on the same principles as the Venturi, to exploit fluid acceleration for increasing kinetic energy, with subsequent improvement of cleaning efficiency.

Fig. 1 illustrates a cross-section of a membrane valve.

4. Comparison Between Principles for the Construction of Compressed Air Distribution Ducts

The installation of distribution ducts starts with the valves, which control the passage of compressed air from the pressurized tank, containing the operating fluid.

The ducts are connected to the filters to be cleaned by means of outlets. The geometry of the outlets largely determines system cleaning efficiency, in so far as it sets the direction flow.

There are several different configurations for such outlets.

The geometry and degree of finishing of the distribution ducts are of considerable importance in overall cleaning system efficiency: the better the quality of these components, the greater the performance of the system.

In any case, the diameter of a duct in the distributor system is in proportion to the
dimensions of the valves, as are the diameters of the outlets to be made on the duct for the purposes of cleaning.

4.1 Distributions with Simple Outlets

Simple outlets are straightforward holes giving on to the filters that need to be cleaned.

Some important observations must be made:
- the finish of the surfaces in the outlets is of primary importance for overall performance: burrs and irregularities created during manufacturing can cause turbulence, and high rates of energy dispersal
- this type of duct is very economical to manufacture, the only requirement being that the outlets be made accurately
- laboratory tests have shown that the distance between the outlet and the valve has a negligible influence on the flow, as long as it is less than 1 m. This conclusion was based on tests carried out on filter cleaning efficiency and on measurements of air flow from the various outlets
- using simple outlets during the cleaning process causes pressure drops at the outflow stage, due to the outflow from circular openings: the current of air is forced to contract initially, and then expand. This phenomenon occurs with all outlets placed within the said distance from the valve.

This system is the least efficient compared to the following systems, where the guides minimize the loss of cleaning gas characteristics.

4.2 Distributors with Tapered Flow Guide

In this case the opening has been designed to provide partial guidance to the outflowing current of air. The main features of this system are:
- manufacturing costs are significantly higher than for the simple outlets: special machining is required for the tapered guides
- the finishing of the outlet surfaces is important for overall system performance; excessive burring or manufacturing imperfections on the surface cause turbulence and, therefore, unwanted energy dispersal
- partial control of the flow greatly reduces pressure drops by limiting the effects of contraction caused by the outflow. Laboratory tests have shown that fluidity is improved, thereby increasing kinetic energy levels and a stronger cleaning action.

4.3 Distributors with Attachable Blast Tube Nozzles

In this case a nozzle is applied to the distribution duct outlet, providing complete control of outflowing air. The main features of this system are:
- manufacturing costs are higher than for the previous two systems; the nozzles must be applied to the outlet on the distributor duct. Furthermore, the geometry of the nozzles must be carefully designed to provide the most favorable conditions for air current acceleration: in this way, residual potential pressure energy is converted into active kinetic clearing energy.
4.4 Advantages of Venturi Ducts

The flow is disrupted at the point where the air current passes from the distribution duct into the filter to carry out the cleaning of the filter element. The space between the duct and the inlet filter element is necessary and cannot be reduced to less than a certain value, due to machine assembly requirements.

However, by inserting a Venturi duct between the duct outlet and the filter element inlet, this space can be used advantageously.

The Venturi duct features a conical section which converges from the inlet to a rectilinear middle section (with or without conical expansion section, if required); the design takes into account production-level requirements and acceptable pressure-drop thresholds. The tighter the conical angle on the initial conical section, the higher the air current acceleration. The end expansion cone is designed to guide the flow in the desired direction. During the design phase of this application it is important to take into account the configuration of the filter element, so as to avoid shadow areas during cleaning. The end expansion cone can be made very short. Venturi ducts without expansion cone can also be used.

The Venturi duct also has some interesting features, which are particularly suited to the application in question, where the potential energy of the pressurised air must be transformed into kinetic energy to maximise cleaning efficiency:

- By carefully adjusting the conical angle of the inlet cone, a compromise can be made between air current acceleration and pressure-drops, in order to maximise cleaning system performance.
- By increasing the speed the duct determines a downward pressure, which in turn exerts a suction action on static air in proximity of the duct outlet, thereby enriching the flow: slits on the side of the cone enhance the effects of this phenomenon.

The distance between the Venturi duct and the distribution duct must be as small as possible: the smaller the discontinuity between the two ducts is, the more pronounced the previously outlined effects become.

In the general layout of the machine, the Venturi duct needs to be placed as close as possible to the distribution duct: the smaller the distance, the more pronounced the effects, as seen above. Excessive distance can lead to unacceptable dispersal rates and completely neutralise the aforementioned measures.

Fig. 5 illustrates the effects of the Venturi duct on the flow of air.
5. Effects of Fabric Tension

Special attention must be paid to the tension levels of the filter element fabric, which greatly influence the effects of cleaning fluid impact.

Excessive preloading, with values above 20% of the total load capacity of the fabric, results in a violent whiplash action: this leads to intense vibrating, violent rocking, and impact to the support structure. During the initial running cycles, these effects may appear to be positive, but more thorough, long-term studies on the fabric have shown a considerable increase in wear and fraying of the fibres by abrasive particles.

In the case of no preloading, the deadening effect of having too much play will hamper cleaning efficiency: tests have shown that a large amount of cleaning fluid energy is used to tension the fabric, producing a ‘sail effect’, with no contribution to cleaning efficiency.

Tests show that ideal preload values vary between 3% and 7% of the total load capacity, according to the type of material used. These values maximise the efficiency of kinetic energy in cleaning, whilst limiting the strain on the fabric.

Fig. 6 illustrates the effects of fabric tensioning.
6. Effects of Basket Shape

The shape and dimensions of the basket, which constitutes the shell of the filter element, are quite important; the percentage of vacuum provided by the basket must be very high to avoid interference with the expanding cleaning gas, i.e. above 70%. If there is not enough, the resistance to the flow is intolerably high and uncontrollable dispersal ensues. Care must be taken to select only the baskets with the most aerodynamic profiles, in order to soften impact: perforated plates and fine mesh are to be avoided, whereas coarse mesh with thin circular cross-section wire is preferable. Due to the reduction of localised pressure drops in the filter, effect on the cut-off of transport gas is positive.

It is furthermore important to limit friction between the fabric and the basket, by making chamfered and ribbed surfaces, which determine a positive effect on the flow.

7. Effects of the Shape of the Base

The base of the filter element can be used to increase the effects of the filter fluid by adjusting its internal structure.

Various methods of base dimensioning have been tested: the best results in terms of flow direction and utilisation of energy have been obtained by placing a conical surface inside the filter. The shape and dimensions of the cone must be calculated on the basis of the shape and dimensions of the filter element itself.

Fig. 7 illustrates the effects of the shape of the base on cleaning agent flow.

8. Conclusions

This report analyses filtration efficiency maintenance by means of compressed air cleaning of the filter system assembly. A detailed quantitative analysis has been attempted, based on laboratory tests.