

COMPARATIVE, ANALYTICAL AND VIRTUAL STUDY OF THE FLOW PARAMETERS OF THE BEARING CEMENT-AIR MIXTURE, IN A PIPELINE ROUTE

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Abstract: The method of transporting cement with the help of an air jet through pipes is very practical and reliable. However, improper dimensioning of the constructive and functional parameters can lead to improper functioning, to cement agglomerations in certain areas of the route configuration. In order to be able to know the problem areas and geometries, in this paper a comparative, analytical and virtual study of cement transport through a pipeline route, known as geometry and dimensions, was made. Analytical calculation showed that a floating speed of cement particles of 23.45 m/s, with an air flow rate of 0.155 m³/s, is needed to be able to transport a quantity of 40 t/h (11.11 kg/s) of cement. The virtual study done in Flow Simulation showed the behavior of cement particles during transport. The virtual behavior is similar to the real one, with cement particles tending to settle in bends and on long stretches of horizontal pipes. The behavior of the air-cement mixture in the separation cyclone is well exemplified by the virtual simulation. The separation of those two components is well represented and conforms to the real phenomenon.

Keywords: flow parameters, cyclone separator, virtual study

1. INTRODUCTION

The transport of pulverulent materials such as cement occurs most often by mixing these materials with air. Air is the driving, carrying element [1]. The achievement of certain functional parameters necessary for carrying out the transport (flow, pressure and speed) for the air that will transport these powdery materials takes place with mechanical systems such as air pumps and air-powdery material mixing systems [2,3].

Functional parameters can be obtained experimentally or analytically. Currently computer-aided manufacturing systems (CAD, CAM, CAE) are able to simulate many of the real manufacturing processes. In this paper, a comparative analytical-virtual study of the flow of the cement-air mixture will be carried out by using a specific analytical calculator and a program for simulating the flow of fluid-material mixtures. The results will be analyzed and commented [4,5].

2. ANALYTICAL CALCULATION OF PNEUMATIC TRANSPORT PARAMETERS

The calculation aims to determine the functional parameters necessary for the transport: the volume and pressure of the transport air, the transport speed and the diameter of the transport pipes. For the analytical determination of these quantities, the auxiliary quantities must first be determined: the floating speed, the

concentration of the mixture and the equivalent length of the route [5,6].

Float speed

It is the velocity of the air stream directed vertically from bottom to top, at which a particle of material remains in suspension without moving from top to bottom. The dynamic air pressure exactly balances the self-weight of the particle.

The force due to the dynamic air pressure is expressed by the relation (from the condition of homogeneity and verified experimentally) [7]:

$$F_a = \Psi \cdot \rho_a \cdot A \cdot (v_a - v_m)^2 \quad (1)$$

in which:

Ψ – is a dimensionless coefficient, depending on the shape and nature of the particle's surface;

ρ_a – air density, in [kg/m³];

v_a – air speed, in [m/s];

v_m – velocity of the particle in [m/s];

A – the surface of the particle projection on a plane perpendicular to the direction of air speed, [m²].

In the case of floating particle $v_m = 0$.

For a spherical particle of diameter d and specific weight γ_m , the floating condition is expressed by the equilibrium relation [8]:

$$\frac{\pi \cdot d^3}{6} \cdot \gamma_m = \frac{\Psi \cdot \gamma_a}{g} \cdot \frac{\pi \cdot d^2}{4} \cdot v_p^2 \quad (2)$$

where from:

$$v_p = \sqrt{\frac{2 \cdot d \cdot \gamma_m \cdot g}{3 \cdot \Psi \cdot \gamma_a}} \text{ [m/s]} \quad (3)$$

in which:

v_p – is the floating speed [m/s];

γ_m – specific weight of the particle [kg/m³];

γ_a – specific weight of air [kg/m³].

If the particle is of any shape, the floating speed takes the expression:

$$v_p = \sqrt{\frac{28,4 \cdot d' \cdot \gamma_m}{\gamma_a}} \text{ [m/s]} \quad (4)$$

in which:

d' – is the diameter of a sphere of the same specific weight and total weight with the particle, in [m];

k – a coefficient that depends on the shape of the particle.

The floating velocities of the different materials are given in table 1. The specific weights of the particles, which exceed several times the volumetric weight of the respective material, are also listed [9, 10].

Table 1. Floating speeds of different powders (indicative figures)

Material	Granulation [microns]	Specific weight γ_m [t/m ³]	Floating speed v_p [m/s]
Cement 000	60	3.2	0.22
Cement 00	86	3.2	0.34
Coal dust	70	1.4	0.14

It is important that the air does not have a speed below the floating speed anywhere in the pipe; otherwise a separation of the material from the carrier air occurs. Transport speed must be a multiple of float speed.

Mixture concentration μ (by weight).

It is another important functional parameter and represents the ratio between the weight of the material and the weight of the air that passes in the same unit of time through a point of the pipe. The notion of volume concentration is used less often [4,7].

For the uniformity of the expression, the beginning of the pipeline for suction installations and the end of the pipeline for discharge installations are considered, i.e. those points where the air is at atmospheric pressure, with the speed v_0 corresponding to this pressure and with the average specific weight $\gamma_0 = 1,2 \text{ kg/m}^3$.

Under these conditions, the expression of the concentration of the mixture becomes:

$$\mu = \frac{Q}{3,6 \cdot A \cdot v_0 \cdot \gamma_0} \quad (5)$$

in which:

Q – is the productivity of the installation, in [t/h];

A – the surface of the inner section of the pipe, in [m²];

v_0 – air speed, in [m/s], at $p \cong 1 \text{ at}$;

γ_0 – specific weight of air, $\gamma_0 = 1.2 \text{ kg/m}^3$.

The choice of the value of μ depends on the nature of the material and the type of installation [8].

Equivalent length

L_{equiv} of the transport pipeline is the horizontal length that is introduced in the calculations and that opposes the same resistance as the real pipeline, including bends, bifurcations, etc. The pressure difference corresponding to the level difference between the beginning and the end of the pipe is added separately to the calculation.

The equivalent length expression is therefore [11]:

in which:

$\sum L_H$ is the sum of the horizontal portions of the pipe, [m];

$\sum L_V$ – sum of vertical portions, [m];

$\sum L_c$ – sum of the equivalent lengths of the bends, [m];

$\sum L_B$ – sum of the equivalent lengths of the bifurcations and, possibly, of other local resistances, [m].

Based on the experimental research, the values of the equivalent lengths of the 90° elbows were established depending on the ratio R_0/d_i of the average radius of curvature of the elbow compared to the inner diameter.

Higher values refer to more abrasive materials and higher transport speeds.

Transport speed

It is chosen as a multiple of the floating speed, given by relation (5), and is consequently proportional to the square root of the specific gravity of the particles. At the same time, the longer the pipe, the higher the speed.

An empirical formula is the following:

$$v_0 = \alpha \cdot \sqrt{\gamma_m} + B \cdot L_{\text{equiv}}^2 \text{ [m/s]} \quad (7)$$

in which:

α – is a coefficient that takes into account the grain of the material;

γ_m – specific weight of particles, in [t/m³];

$B = 2 \cdot 10^{-5} \div 5 \cdot 10^{-5}$, is a coefficient that increases with the size of the granulation;

L_{equiv} – the equivalent length, in [m].

In general, for suction installations, $v_0 = (2,5 \dots 2,8)v_p$, depending on the complexity of the route.

The speed v_0 given by formula (7) is understood for the section of the pipe where there is a pressure close to the atmospheric pressure (for simplification, $\gamma_a \cong 1.0 \text{ kg/m}^3$ was taken as a basis), i.e. the beginning of the pipe for suction installations and the end of the pipe for with discharge [12, 13].

In the transport pipe, the pressure decreases from the beginning to the end of the pipe and the drop can be considered isothermal, that is, between the pressure p and the volume of the same amount of gas V there is the relation:

$$p \cdot V = \text{const.} \quad (8)$$

If we refer to the amount of gas that flows out in one second, at any point in the pipeline there is:

$$V = A \cdot v \text{ [m}^3/\text{s]} \quad (9)$$

where A is the surface of the free pipe section, in $[\text{m}^2]$.
From relations (9) and (10) results for two points of the pipeline, characterized by indices 1 and 2, the ratio:

$$\frac{p_1}{p_2} = \frac{V_2}{V_1} = \frac{A_2 \cdot v_2}{A_1 \cdot v_1} \text{ and } \frac{p_1}{p_2} = \frac{\gamma_1}{\gamma_2} \quad (10)$$

Pneumatic transport pipelines can be constructed in two ways:

- with a constant section along the entire length, in which case the speed varies inversely proportional to the pressure;
- with constant speed, in which case the section must vary inversely proportional to the pressure.

Preference is usually given to the first system, i.e. with constant section. In this case it follows from relations (10), if we consider a certain point and the point (p_0, v_0, γ_0) with atmospheric pressure:

$$\frac{v}{v_0} = \frac{p_0}{p} = \frac{\gamma_0}{\gamma} \quad (11)$$

$$\text{And } v = v_0 \cdot \frac{p_0}{p} = v_0 \cdot \frac{\gamma_0}{\gamma} \quad (12)$$

The speed v_0 from this relation corresponds to v_0 from relation (9).

The diameter of the transport pipe

It is done on the basis of the concentration relation (7) from which it follows [11, 14]:

$$d_i = 0,6 \cdot \sqrt{\frac{Q}{\mu \cdot v_0 \cdot \gamma_0}} \quad (13)$$

in which:

Q – is the productivity, in $[\text{t/h}]$;

μ – concentration coefficient by weight;

v_0, γ_0 – speed and specific weight of air at the beginning of the pipe (suction installations), respectively at the end of the pipe (discharge installations), in $[\text{m/s}]$ and $[\text{kg/m}^3]$, respectively.

For pipes with a constant section, the diameter d_i given by the relation above is kept along the entire length; for those with variable section, the pipe is divided into several sections with equal diameters and the above calculation is made for the conditions in each section, using relations (11).

In a pipe with constant velocity v_0 in some section:

$$d_i = 0,6 \cdot \sqrt{\frac{Q}{\mu \cdot \gamma_0 \cdot v_0 \cdot p}} \quad (14)$$

The external diameter of the pipe is chosen, taking into account, apart from the pressure, the degree of abrasiveness of the material [15].

Determining the required air flow

For transport, everything is done based on the concentration relation (6):

$$V_0 = A_0 \cdot v_0 = \frac{Q}{3,6 \cdot \mu \cdot \gamma_0} = \frac{Q}{4,3 \cdot \mu} \text{ [m}^3/\text{s]} \quad (15)$$

where V_0 is given for atmospheric pressure, as is usual when sizing air pumps.

3. THE ACTUAL STUDY MODEL. SIZING CALCULATIONS

The purpose of this study is the comparative analysis of the results obtained from the analytical calculation, according to the formulas from point 2 and the constructive parameters presented in fig. 1 and the functional ones shown below.

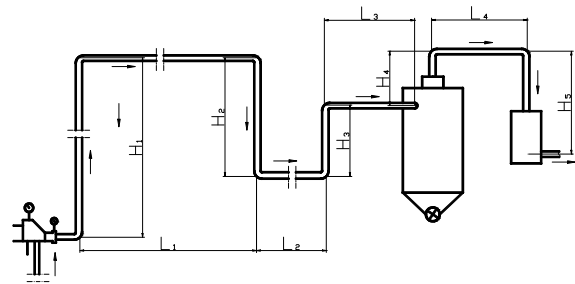


Figure 1. Pipeline, cyclone and filter

Route lengths and heights are:

$L_1 = 8 \text{ m}, L_2 = 20 \text{ m}, L_3 = 5 \text{ m}, L_4 = 7 \text{ m};$

$H_1 = 6 \text{ m}, H_2 = 4 \text{ m}, H_3 = 2 \text{ m}, H_4 = 1 \text{ m}, H_5 = 3 \text{ m}$

The results of the analytical calculation are:

a – the equivalent length of the conveyor:

- Horizontally: $\sum L_H = 40 \text{ m}$

- Vertically: $\sum L_v = 16 \text{ m}$

The changes of direction, in the vertical plane, are bends at 90° . When changing from the horizontal direction of travel to the vertical one, the curve must be executed with a small arc (fig.2.a) and in the opposite direction with a large arc (fig.2.b).

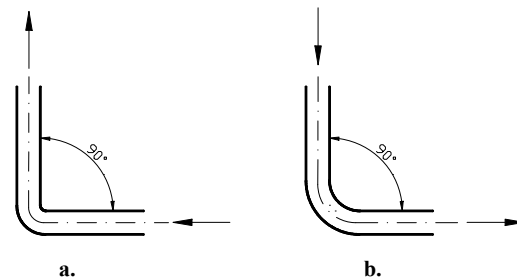


Figure 2. Changes in the direction of the pipes

- The equivalent length of the bends: $\sum L_H = 40 \text{ m}$

- Total equivalent length: $L_{echiv} = 100 \text{ m}$

b – Transport speed: $v_0 = 23.45 \text{ m/s}$ (for powders with grain size: $0.001-1 \text{ mm}$)

c – The diameter of the transport pipe: $d_i = 120 \text{ mm}$

d – Required air flow rate: $V_0 = 0.155 \text{ m}^3/\text{s}$

e – Pressure drop:

$$h_d = 1418.75 \text{ mm H}_2\text{O}$$

$$h_v = 960 \text{ mm H}_2\text{O}$$

$$h_H = 411.58 \text{ mm H}_2\text{O}$$

$$h_s = 159.03 \text{ mm H}_2\text{O}$$

$$h_c = 70.07 \text{ mm H}_2\text{O}$$

$$h_j = 100 \text{ mm H}_2\text{O}$$

$$h_{\text{tot}} = 3120 \text{ mm H}_2\text{O}$$

f - Additional pressure losses: $p_c = 1.89 \text{ at}$

5. VIRTUAL STUDY, SIMULATION OF THE FLOW OF THE AIR-CEMENT MIXTURE

The virtual study is based on the real model of the transport pipe route for the air-cement mixture, modelled according to the dimensions in fig. 1 and the results given by the analytical calculation (equivalent transport lengths, pipe diameter etc.).

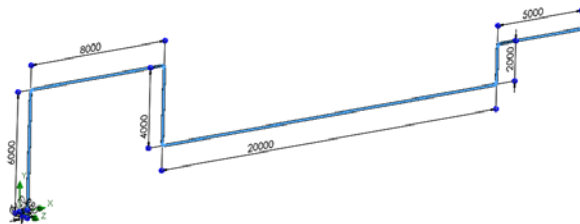


Figure 3. The virtual pipeline route

Description of the virtual study

The flow simulation is done with Flow Simulation in SolidWorks which is based on FEA (FEM) and everything related to fluid mechanics theories. For the simulation, the functional parameters and the conditions resulting from the analytical calculation were respected:

- transport speed: $v_0 = 23.45 \text{ m/s}$ (for powders with grain size: $0.001\text{-}1 \text{ mm}$)
- the diameter of the transport pipe: $d_i = 120 \text{ mm}$
- required air flow rate: $V_0 = 0.155 \text{ m}^3/\text{s}$
- cement powder flow rate $Q = 40 \text{ t/h} = 11.11 \text{ kg/s}$

Study conditions:

- The virtual study was performed on the configurations:
- only the pipeline route, up to the entrance to the cyclone;
- the study of the flow of the air jet, without the cement particles;
- study of flow with cement particles.
- the pipeline route and with the cyclone at the end:
- the study of the flow of the air jet, without the cement particles;
- study of flow with cement particles.

Air jet flow study

The study of the flow of the air jet without the cement particles was done with the imposition of the air flow rate of $0.155 \text{ m}^3/\text{s}$ and a velocity of 23.45 m/s .

When the air enters the pipe, the air has a laminar flow, up to the first bend at 90° . The change in direction, from horizontal to vertical, leads to an increase in speed on the

inside of the bend and a decrease in speed on the outside of the bend.

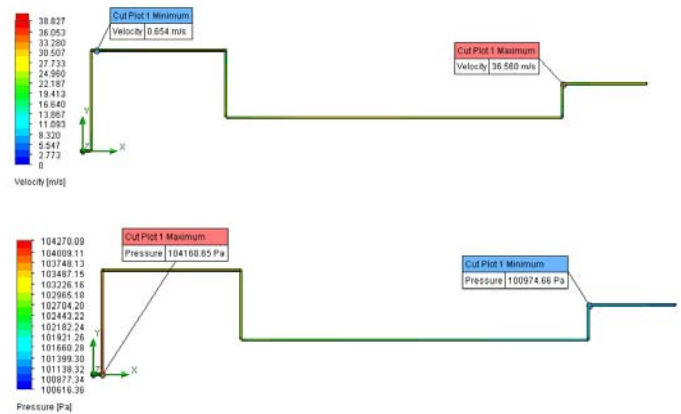


Figure 4. Velocity and air pressure in the pipe

Two areas appear where the velocity drops below the bearing value (23.45 m/s). The phenomenon occurs almost equally in all bends, regardless of its position in the pipeline route configuration.

Areas where cement particles may no longer be carried by the air flow are those on the outside of bends. The minimum speed zones at the exit of bends are not dangerous for certain positions of the bend in the given configuration. Only in those bends (Fig.5.a.2 and Fig.5.b.6), where the change of direction takes place from a vertical ascent to a horizontal direction, cement powder deposits can occur.

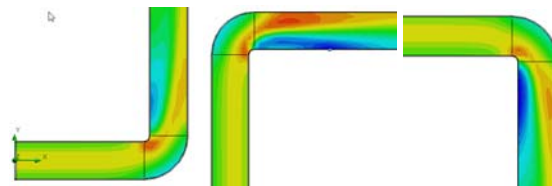


Figure 5.a.Viteza aerului în primele trei coturi

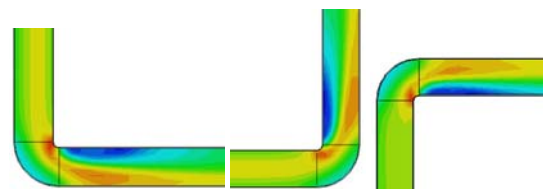


Figure 5.b.Viteza aerului în ultimile trei coturi

The way the air speed varies in the pipe route is also given by the graph in Fig.6. The air speed in the bends has the behavior given by the curve in the figure. The rapid increases to the maximum value (38.827 m/s) take place on the inside of the bends, after which the

reduction of the speed follows, to the value necessary for the floating of the cement particles, on the linear portions of the route.

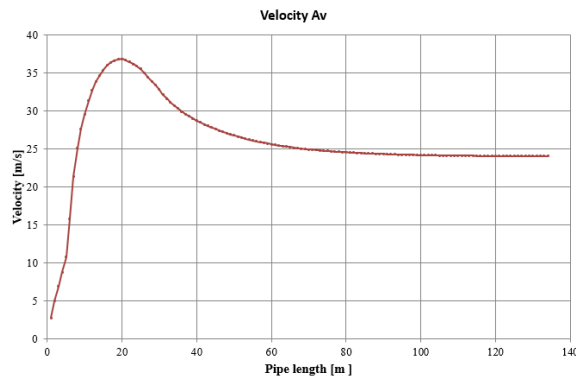


Figure 6. Air velocity in the duct

The phenomenon of dust deposition on the outside of the bends is also confirmed by the air pressure when passing through them (Fig.7). Low pressure areas correspond to those areas where the air velocity is lower than the lift velocity of the cement powder.

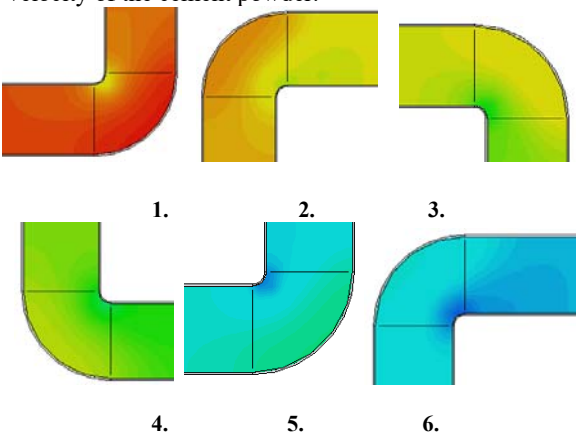


Figure 7. Air pressure in the six bends

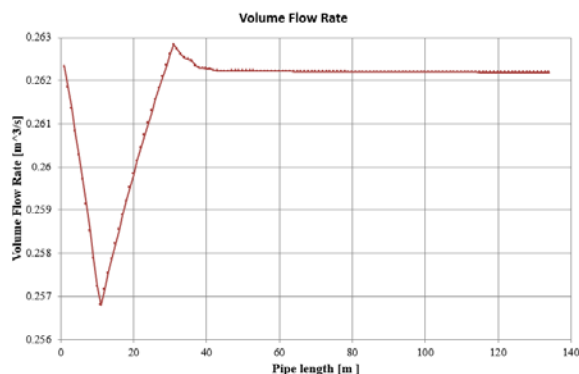


Figure 8. Duct air flow

Flow study with cement particles

Flow Simulation can simulate what happens to a particle (sphere) when it is in an air flow. The basic parameters of the study are:

- particle type (specific gravity): cement;
- particle size (average particle diameter): 0.0005 m;
- transported mass flow rate: 40 t/h = 11.11 kg/s;
- initial speed (floating speed): 23.45 m/s;
- initial temperature of the particles: 20.05°C.

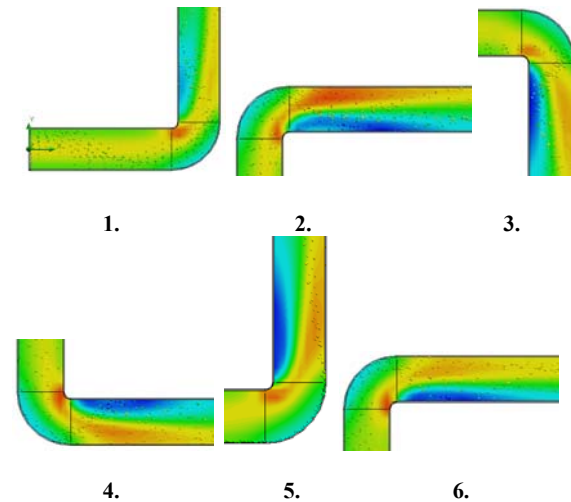


Figure 9. Velocity of cement particles and air in the six bends

The cement particles are carried by the air, but in the areas with velocity < 23.45 m/s the particles touch the inner wall of the bend, on the outer bend and on the linear pipe portion, immediately after exiting the pipe bend (fig.9). In configurations 3, 4, and 5 (fig. 9) where the low speed areas are at the top, the particles cannot accumulate, due to gravity. Problems occur in configurations 1, 2 and 6 (fig. 9) where the float velocity is low at the bottom of the elbow or linear pipe.

Another problem is the length of the linear pipes. On short paths the particles are carried by the air jet (fig. 10.1 and 10.3), on the longer path (20 m) the particles are agglomerated at the lower part of the pipe (fig. 10.2).

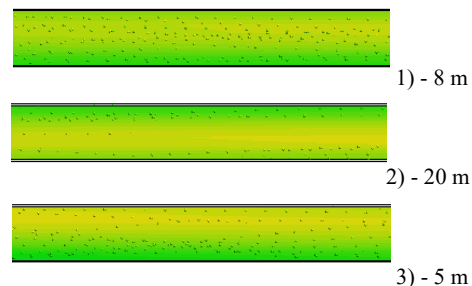


Figure 10. Floating of cement particles on linear paths

Study of air jet flow in cyclone

In the second part of the study, a cyclone was attached to the end of the transport path. The role of the cycle is to reduce the speed and pressure of the air jet as much and

as quickly as possible to separate the cement particles. Fig.11 shows the velocity and pressure values in the cyclone.

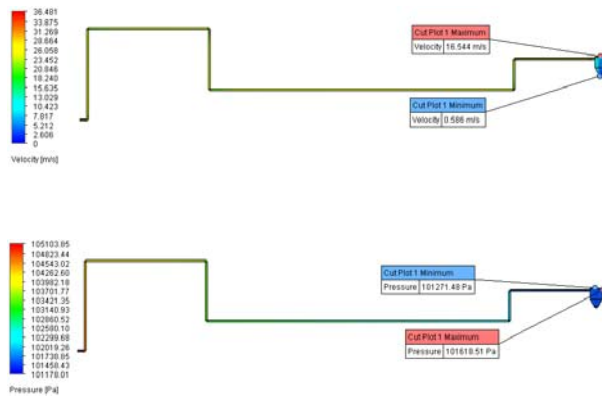


Figure 11. Speed and air pressure in the track and cyclone

The air speed in the cyclone decreases a lot compared to the floating speed, according to the simulation. And the pressure is low inside the cyclone. Thus, the conditions are created for the separation of cement particles from the carrier air.

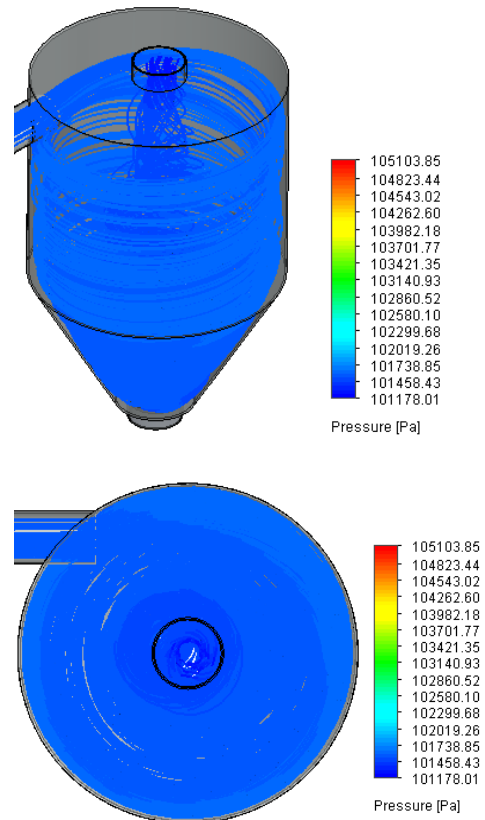


Figure 12.b. Air pressure in the cyclone

The positioning of the pipe with a certain eccentricity with respect to the central axis of the cyclone leads to the formation of the spiral (cyclone) of air and the loss of speed and pressure (fig.12.a.b).

Study of flow with cement particles in cyclone

The simulation of the behaviour of the cement particles, according to the conditions previously exposed, can be seen in figure 13.

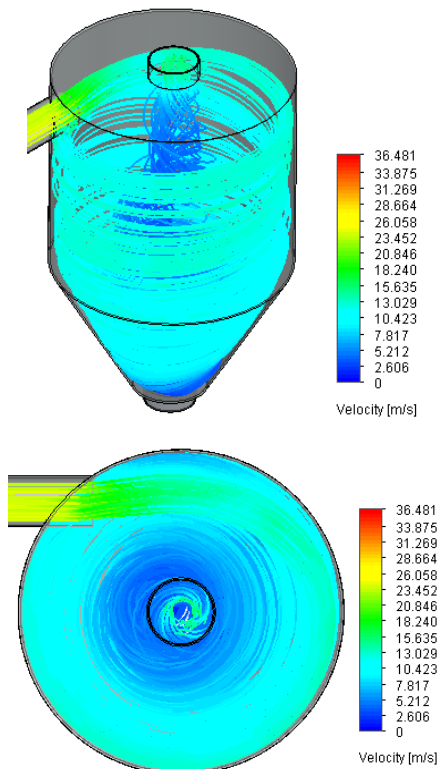
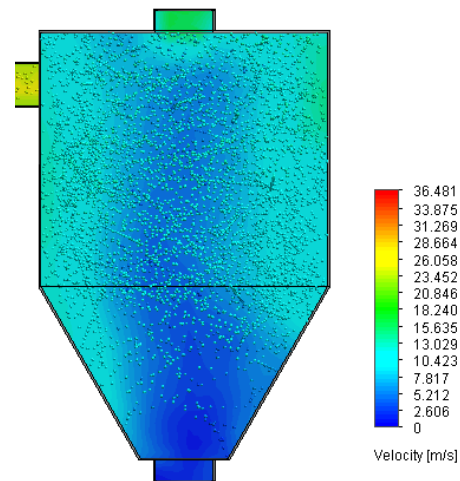


Figure 12.a. Velocity in the cyclone



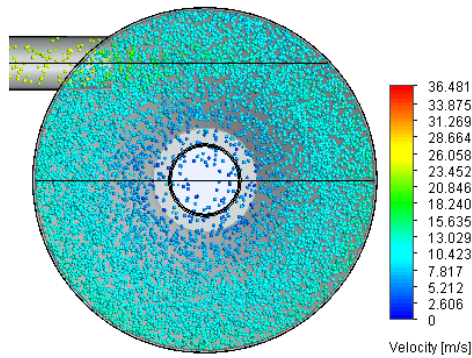


Figure 13. Velocity of cement particles in the cyclone

At the entrance to the cyclone in the pipe, the velocity is greater than the minimum lift velocity (23.45 m/s). Inside the cyclone, the velocity decreases rapidly and the particles begin to agglomerate towards the lower part of the cyclone. In the middle of the cyclone, the air speed is low (~ 2 m/s), which helps the air to rise through the central tube of the cyclone, preventing the floating and evacuation of cement particles on the upper part.

5. CONCLUSIONS

The simulation with the Flow Simulation program of the phenomena that occur when flowing through pipes or closed spaces with different shapes and sizes is a great advantage in the design of pneumatic conveyors.

The dimensioning of the routes, the connecting radii, the cyclones, can be easily done following the results obtained from this kind of simulation.

Optimizing the geometry of the route leads to a decrease in pressure losses and an increase in the efficiency of the installation. Avoiding pressure drops in the bends means that cement deposition no longer takes place, making the installation work correctly.

The simulation of air flow and air-cement mixture showed that the real phenomena are similar to the virtual ones. For the route analyzed, it was shown that cement particles tend to deposit and agglomerate in areas where the air speed is below the lift value. Long sections of pipes are not favorable because here too the cement particles lose their buoyancy and agglomerate at the bottom of the horizontal pipes.

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