Prof. Ing. Dario Pozzetto

Department of Engineering and Architecture – University of Trieste

Via Valerio, 10 –34127 Trieste – Tel: 040.558.3805 / 7982 Fax: 040.558.3812

E-mail: pozzetto@units.it

INDUSTRIAL PLANTS

Chapter twenty-tree:

Pneumatic conveyors

DOUBLE DEGREE MASTER IN
“PRODUCTION ENGINEERING AND MANAGEMENT”

SEAT OF PORDENONE
UNIVERSITY OF TRIESTE

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

There are several approaches that permit the sizing of a pneumatic transport plant:

- **traditional approach valid for the plants at low pressure**

  Notes the salient features of operation (physical properties of the material to be transported, points and systems for loading and unloading of the transported material, type of operation and development of the horizontal and vertical transport circuit), one should choose the type of plant and the minimum speed required of the mean load-bearing. Based on these values will determine the diameter of the pipe and the size of the accessory organs (loading, unloading, shut-off and diversion of the route, separators, filters etc.). Determine the pressure drop that is used to determine the prevalence of the machine you use (fan, blower, compressor);

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There are several approaches that permit the sizing of a pneumatic transport plant:

- **mathematical approach**

  Chosen the type of plant, it adopts a mathematical model which takes account of some characteristic (length and diameter of the pipe, the pressure drop between inlet and outlet section, speed of the carrier medium in the inlet section, the mass flow and density of the mean load-bearing, and the mass flow rate of the solid material to be transported) and on the use of data available on the transport characteristics of the solid material. In the case of existing plants is carried out the verification of the potential of the existing plant based on the use of mathematical models and on the use of data available on the transport characteristics of the solid material;

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There are several approaches that permit the sizing of a pneumatic transport plant:

- **mainly experimental approach**

  Based on experimental data carried out on models, is designed the pneumatic conveying. This system is used when it is intended to transport a new type of solid material;

- **numerical approach**

  Is designed using specific programs.

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Think of designing a system that transport of the wood chips from a centralized to a silo.

The first step for the dimensioning of the maximum is to choose the mode of operation. Is chosen to adopt a pneumatic conveyor functioning in pressure; this system, in fact, gives the possibility to realize complex paths with a minimum of space and aspirate easily the material in cargo holds, in a vehicle to download or in a storage silo.

The plants in pressure, also, compared to those in depression, are simpler, inasmuch as they seek the material from the pile more easily and prevent the passage of material through the aspirator.

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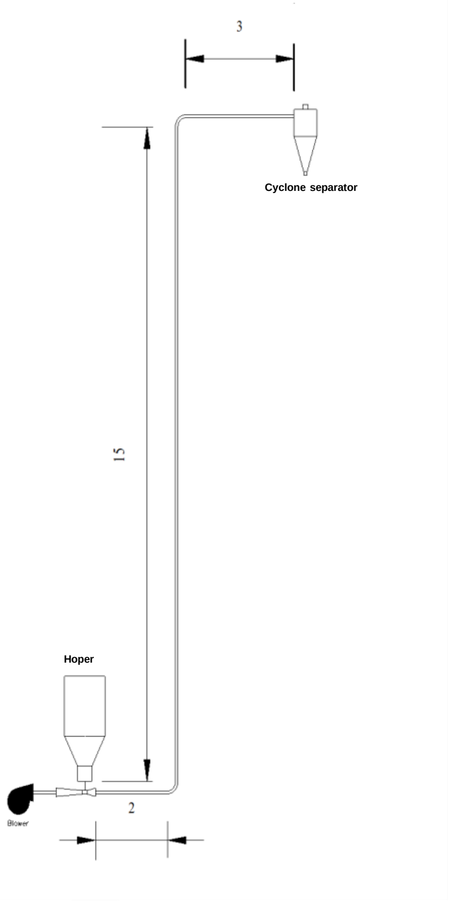
The material to be transported is wood shavings, that is characterized by:

- absolute specific weight $\gamma_{assoluto}$ = 7000 N/m^3;
- apparent specific weight $\gamma_{apparente}$ = 3000 N/m^3
- potentiality = 70 kN/h = 19,4 N/s.

The trend plan-elevation of the plant is shown in the scheme, in which shows the dimensions of the pipes and the difference in height between the point of loading of the material and exhaust in the cyclone separator.



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Important data to be fixed to obtain the system more suitable for the transport are the air velocity v (m/s) and the relationship r_v between the volume of air necessary to A (m^3/s) to transport in the pipes of the system the volume of material to be transported V (m^3/s), the latter defined by the ratio between the weight of material per unit of time Q (kg/s) and its absolute specific weight $\gamma_{assoluto}$:

$$r_v = A \cdot \gamma_{assoluto} / Q$$

Varied and diverse are the solutions suggested by various authors, the reality is that the optimal values of these variables can be determined only with pilot plants or through experience.

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There are many methods you can use; the following is considered the most reliable.

The first variable fixed is the speed. As reported by Zignoli (Trasporti meccanici, HOEPLI editor, Milano, 1970) for materials depending on size, are the following relations:

- powder materials: 0.9 $(\gamma_{assoluto})^{1/2}$
- materials in small grains and cereals: 1,1 $(\gamma_{assoluto})^{1/2}$
- materials in irregular in size: 1,4 $(\gamma_{assoluto})^{1/2}$

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Being the material in irregular size, the air speed is:

$$v = 1{,}4\ (\gamma_{assoluto})^{1/2} = 1{,}4\ (700)^{1/2} = 37\ m/s$$

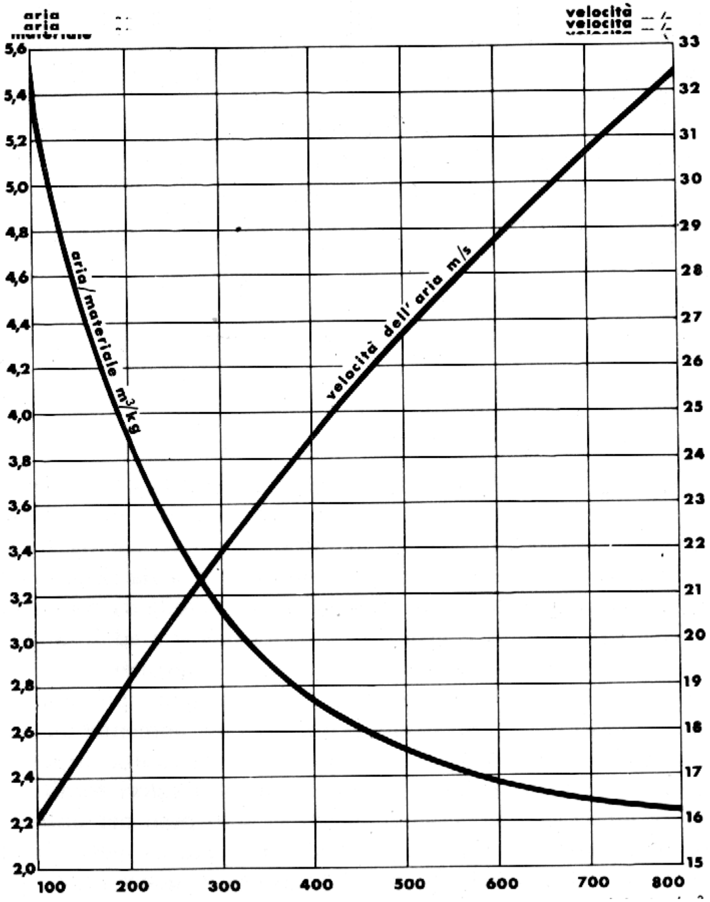
This value between the other is in line with what suggested by the american experts of the sector:

$$v = 45\ (\gamma_{assoluto}/1000)^{1/2} = 45\ (0{,}7)^{1/2}$$
$$= 37\ m/s$$

value higher than the average planned for this type of plant and visible from figure 29.4 is from Monte.

From the same figure 29.4 is obtained the ratio rv, which is:

$$r_v = 3{,}1\ m^3/kg$$



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From the value of the ratio $r_v = 3{,}1\ m^3/kg$ and from the potentiality for transport of $Q = 2\ kg/s$, is possible to determine the air flow necessary to transport that is:

$$A = 3{,}1 \times 2 = 6{,}2\ m^3/s$$

From which it is possible to determine the transport section which is equal to:

$$S = A/v = 6{,}2 / 37 = 0{,}168\ m^2$$

which corresponds to a diameter of the pipe of:

$$D = 0{,}462\ m$$

Searching the normalized diameter of the pipe closest to the calculated one, it has been found a tube having the following characteristics:

$$D_{esterno} = 508\ mm,\ D_{interno} = 483\ mm,\ \text{PN 64, Fe 440 without welding}$$

With these new features you get:

$$S = 0{,}183\ m^2 \text{ e } A = 6{,}77\ m^3/s$$

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

Fixed these preliminary data, we proceed with the calculation of the load losses that come into play and that must be overcome by implementing of the right choice of a fan (Monte, Elementi di impianti industriali)

AIR

a) Energy of start (or dynamic loss)

In order to give to the air, which moves in the ducts of a plant for pneumatic transport, the speed necessary to transport the material, it undergoes a pressure drop equal to:

$$h_{1A} = \gamma_a \, . \, v^2/(2 \cdot g) = 1{,}2 \text{ x } 37^2/(2 \text{ x } 9{,}81) = 84 \text{ kg/m}^2$$

b) Entry into the circuit

Experiments carried out on plants, allow to assume for the entry of air into the circuit a pressure loss, for systems operating in pressure, equal to:

$$h_{2A} \sim 4 \cdot h_{1A} = 336 \text{ kg/m}^2$$

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c) Friction in the ducts

In the more general case, the pressure loss (or load) caused by friction of a fluid that moves inside a conduit of length L (m) and a diameter D (m) is given by the *law of Fanning-Darcy*:

$$h_{3A} = 8{,}12 \cdot 10^{-4} \cdot \gamma_a^{0{,}85} \,.\, v^2/D^{1{,}3} \cdot L = 8{,}12\ 10^{-4} \cdot 1{,}2^{0{,}85} \,.\, 37^2/0{,}483^{1{,}3} \cdot 20$$

$$= 67\ \text{kg/m}^2$$

d) Height difference

The loss of load for overcoming by the air of a height difference H (m) is:

$$h_{4A} = \gamma_a \cdot H = 1{,}2 \cdot 15 = 18\ \text{kg/m}^2$$

e) Changes of section and direction

It is accidental resistances that can be merged in the calculation as equivalent lengths of pipe. In our case we have L · D = 10 (see table below):

$$h_{5A} = 2 \cdot 8{,}12 \cdot 10^{-4} \cdot \gamma_a^{0{,}85} \,.\, v^2/D^{1{,}3} \cdot 10 \cdot D = 2 \cdot 8{,}12\ 10^{-4} \cdot 1{,}2^{0{,}85} \,.\, 37^2/0{,}483^{1{,}3}$$

$$\cdot\ 10 \cdot 0{,}483 = 67\ \text{kg/m}^2$$

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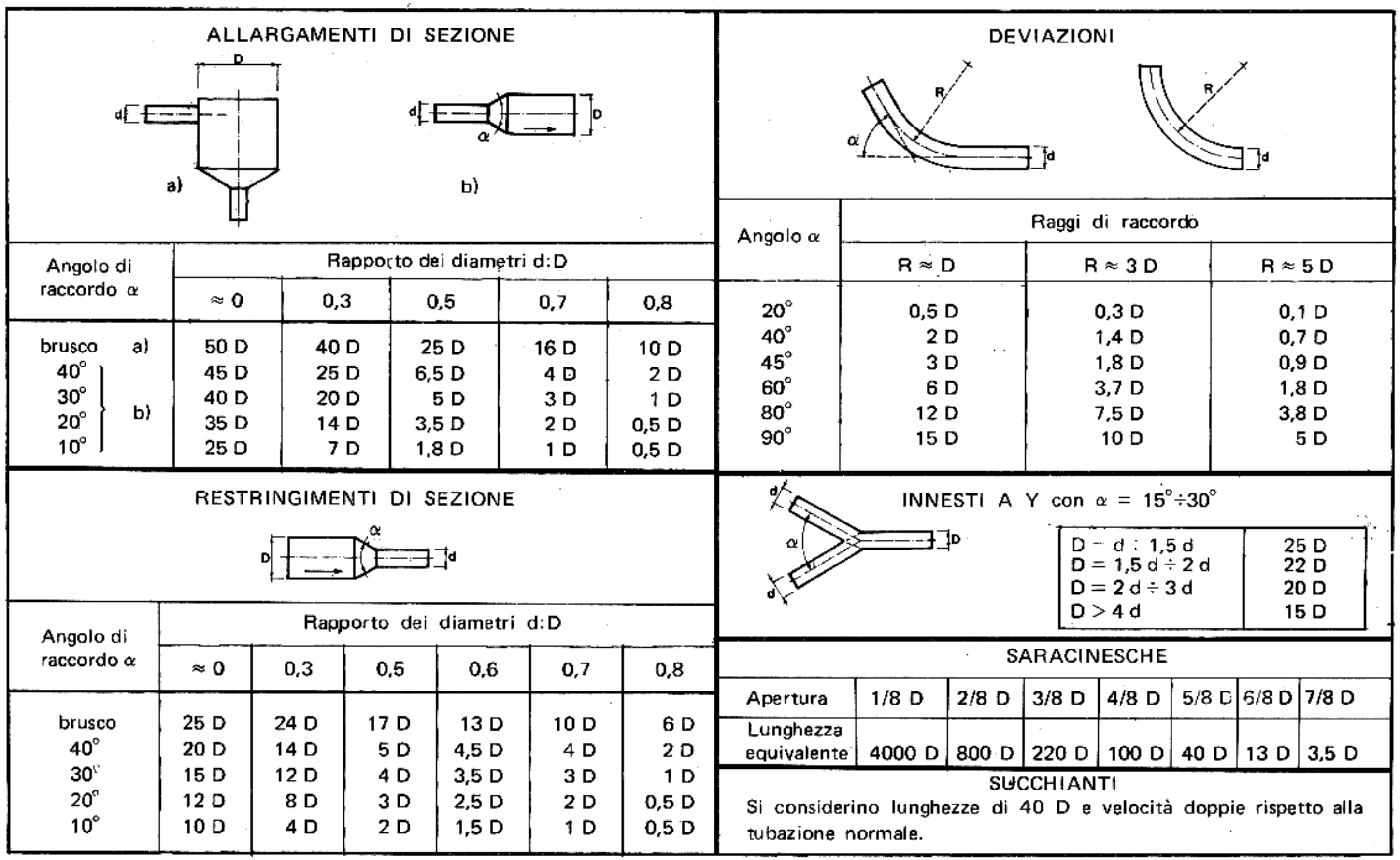
Table 29.VII - Losses due to accidental resistors (deviations, changes of section, inputs and outputs from the circuit, etc.). expressed in lengths of pipe equivalent



ALLARGAMENTI DI SEZIONE

Angolo di raccordo α	Rapporto dei diametri d:D				
	≈ 0	0,3	0,5	0,7	0,8
brusco a)	50 D	40 D	25 D	16 D	10 D
40° b)	45 D	25 D	6,5 D	4 D	2 D
30° b)	40 D	20 D	5 D	3 D	1 D
20° b)	35 D	14 D	3,5 D	2 D	0,5 D
10° b)	25 D	7 D	1,8 D	1 D	0,5 D

DEVIAZIONI

Angolo α	Raggi di raccordo		
	R ≈ D	R ≈ 3 D	R ≈ 5 D
20°	0,5 D	0,3 D	0,1 D
40°	2 D	1,4 D	0,7 D
45°	3 D	1,8 D	0,9 D
60°	6 D	3,7 D	1,8 D
80°	12 D	7,5 D	3,8 D
90°	15 D	10 D	5 D

RESTRINGIMENTI DI SEZIONE

Angolo di raccordo α	Rapporto dei diametri d:D					
	≈ 0	0,3	0,5	0,6	0,7	0,8
brusco	25 D	24 D	17 D	13 D	10 D	6 D
40°	20 D	14 D	5 D	4,5 D	4 D	2 D
30°	15 D	12 D	4 D	3,5 D	3 D	1 D
20°	12 D	8 D	3 D	2,5 D	2 D	0,5 D
10°	10 D	4 D	2 D	1,5 D	1 D	0,5 D

INNESTI A Y con α = 15°÷30°

D = d ÷ 1,5 d	25 D
D = 1,5 d ÷ 2 d	22 D
D = 2 d ÷ 3 d	20 D
D > 4 d	15 D

SARACINESCHE

Apertura	1/8 D	2/8 D	3/8 D	4/8 D	5/8 D	6/8 D	7/8 D
Lunghezza equivalente	4000 D	800 D	220 D	100 D	40 D	13 D	3,5 D

SUCCHIANTI

Si considerino lunghezze di 40 D e velocità doppie rispetto alla tubazione normale.

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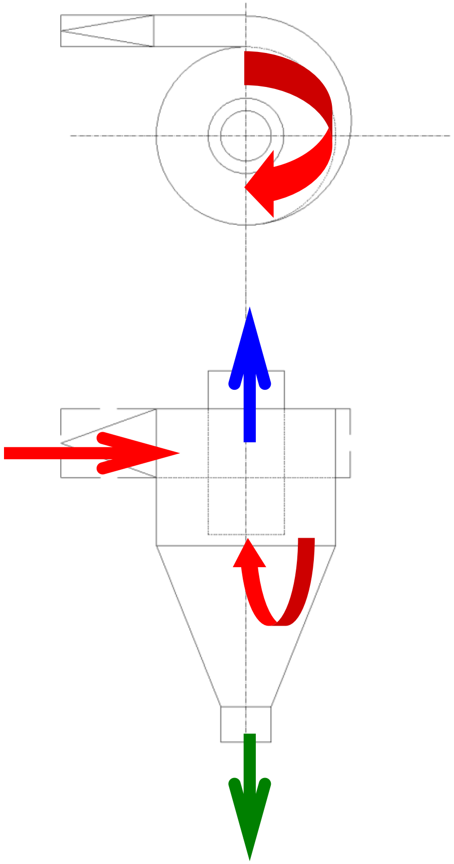
f) Cyclone separator



To determine the load losses of the cyclone separator, which depend directly on its size, reference is made to the parametric expressions which have led to the definition of the geometry of figure.

For the calculation of the pressure drop of the cyclone, it is proposed the following relationship:

$$h_{5A} = 10 \cdot \gamma_a \cdot v^2/(2 \cdot g) =$$

$$10 \cdot 1{,}2 \cdot 37^2/(2 \cdot 9{,}81) = 837 \text{ kg/m}^2$$

Effects of separation of solid particles from the air in the cyclone:

- enlargement of the section at the entrance and reduction in speed,
- centrifugal force and impact of solid particles on the wall,
- change of direction.

In all three cases, the gravity allowing the separation of solid particles which are extracted from the bottom.

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g) **Filter**

For the various types of filters on the market, the manufacturers provide the main features, including the loss of load h_{6A}. Sometimes, as in the case analyzed the separator and the filter are installed so as to constitute a single system.

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MATERIAL

a) Energy of start (or dynamic loss)

The loss of load in order to give the material the force required is given by the relation:

$$h_{1M} = Q \cdot (k \,.\, v)^2/(2 \cdot g \cdot A) = 2 \text{ x } 37^2/(2 \text{ x } 9,81 \text{ x } 6,77) = 20,6 \text{ kg/m}^2$$

having denoted by:

Q = weight of material to be transported per unit time (kg/s)

V_a = air flow rate necessary to ensure the transport (m^3/s)

k·v = speed of the material, corresponding to the product of air velocity multiplied by a coefficient k depending on the physical characteristics of the material. It can be k = 0.75, but if it is preferable to take k = 1 to take account of the resistance due to relative motion of the material with respect to air.

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b) Entry into the circuit

Experiments carried out on plants, allow to assume for the entry of material into the circuit a pressure loss, for systems operating in pressure, equal to:

$$h_{2M} \sim 2 \cdot h_{1M} = 41{,}2 \text{ kg/m}^2$$

c) Friction in the ducts

The loss of pressure (or load) caused by friction between the material and the pipes depends on the angle of friction of the material transported on the steel, constituting the conduits of the plant. Said φ the angle (detectable by appropriate tables) and c a coefficient that takes into account the fact that only a part of the material strip along the piping (in practice, c = 0.2), the pressure drop is equal to:

$$h_{3M} = c \cdot tg\varphi \cdot Q/A \cdot L = 0{,}2 \cdot 1 \cdot 2/6{,}77 \cdot 20$$

$$= 1{,}2 \text{ kg/m}^2$$

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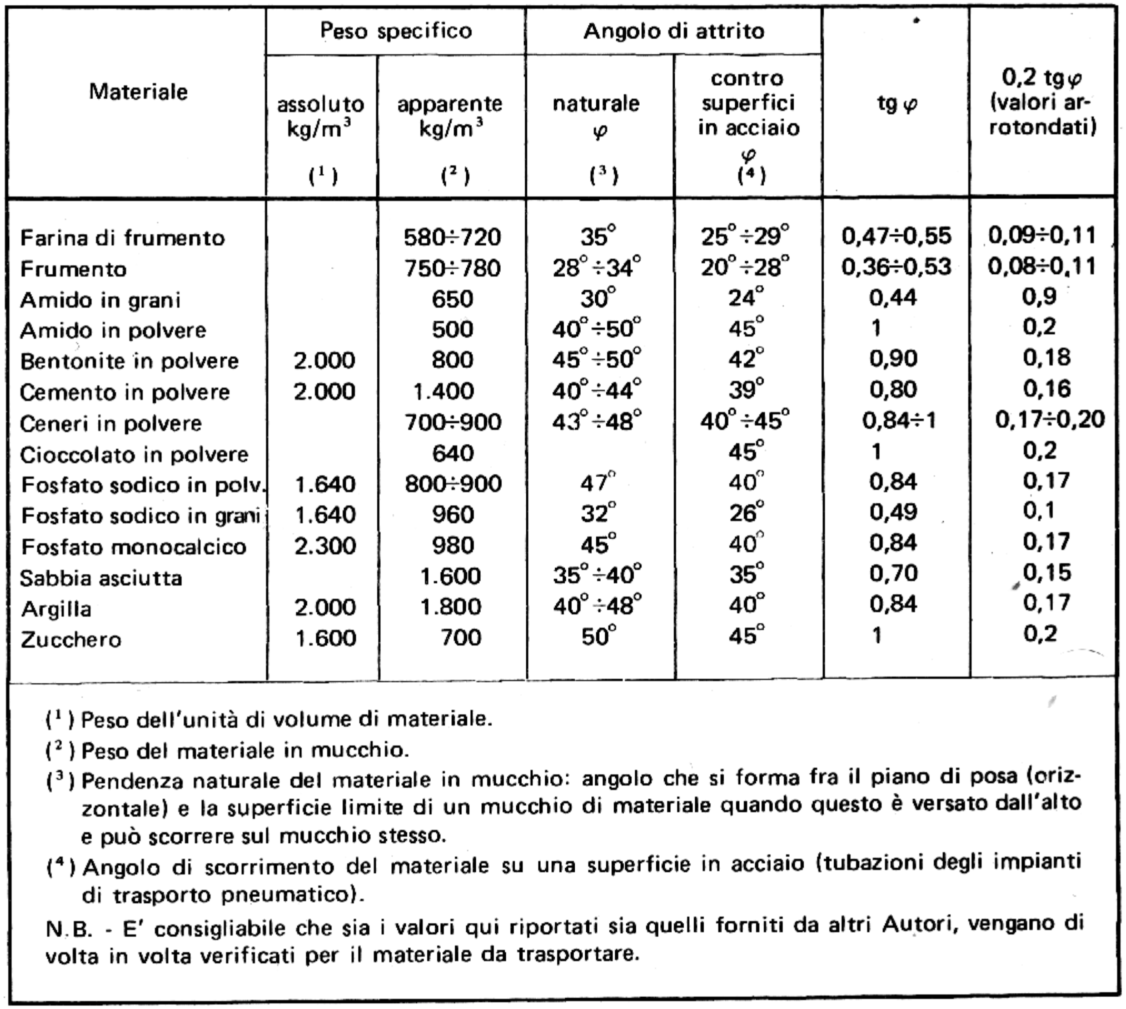
Table 29.IX - Absolute and apparent specific gravities, angles of friction and sliding of some natural materials



Materiale	Peso specifico		Angolo di attrito		tg φ	0,2 tg φ (valori arrotondati)
	assoluto kg/m³ (¹)	apparente kg/m³ (²)	naturale φ (³)	contro superfici in acciaio φ (⁴)		
Farina di frumento		580÷720	35°	25°÷29°	0,47÷0,55	0,09÷0,11
Frumento		750÷780	28°÷34°	20°÷28°	0,36÷0,53	0,08÷0,11
Amido in grani		650	30°	24°	0,44	0,9
Amido in polvere		500	40°÷50°	45°	1	0,2
Bentonite in polvere	2.000	800	45°÷50°	42°	0,90	0,18
Cemento in polvere	2.000	1.400	40°÷44°	39°	0,80	0,16
Ceneri in polvere		700÷900	43°÷48°	40°÷45°	0,84÷1	0,17÷0,20
Cioccolato in polvere		640		45°	1	0,2
Fosfato sodico in polv.	1.640	800÷900	47°	40°	0,84	0,17
Fosfato sodico in grani	1.640	960	32°	26°	0,49	0,1
Fosfato monocalcico	2.300	980	45°	40°	0,84	0,17
Sabbia asciutta		1.600	35°÷40°	35°	0,70	0,15
Argilla	2.000	1.800	40°÷48°	40°	0,84	0,17
Zucchero	1.600	700	50°	45°	1	0,2

(¹) Peso dell'unità di volume di materiale.

(²) Peso del materiale in mucchio.

(³) Pendenza naturale del materiale in mucchio: angolo che si forma fra il piano di posa (orizzontale) e la superficie limite di un mucchio di materiale quando questo è versato dall'alto e può scorrere sul mucchio stesso.

(⁴) Angolo di scorrimento del materiale su una superficie in acciaio (tubazioni degli impianti di trasporto pneumatico).

N.B. - E' consigliabile che sia i valori qui riportati sia quelli forniti da altri Autori, vengano di volta in volta verificati per il materiale da trasportare.

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

d) Height difference

The loss of load for overcoming by the material of a height difference H (m) is:

$$h_{4A} = Q / A \cdot H = 2 /6,77 \cdot 15 = 4,4 \text{ kg/m}^2$$

e) Changes of section and direction

Multiply the corresponding load losses calculated for the air by the ratio of the weights r_p defined by the relation:

$$r_p = Q/(\gamma_a \cdot A) = 2 / (1,2 \text{ x } 6,77) = 0,246$$

which allows to determine the relative load losses:

$$h_{5M} = h_{5A} \cdot r_p = 67 \text{ x } 0,256 = 17,2 \text{ kg/m}^2$$

It is not considered any resistance due to the filter, in that the solid material not passing through it.

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

Total pressure

Adding up all the load losses listed above is obtained by the total pressure H_t necessary for the operation of the plant and which is equal to:

$$H_t = \Sigma_i h_{iA} + \Sigma_j h_{jM} = 1409 + 84{,}6 = 1493{,}6 \text{ kg/m}^2$$

The value found is placed below the 3000 kg/m^2 (low-pressure system), for which you may adopt a centrifugal fan suitably sized.

The power absorbed P_{ass} by the fan is equal to:

$$P_{ass} = H_t \cdot A /(102 \cdot \eta_v) = 1493{,}6 \text{ x } 6{,}77/(102 \text{ x } 0{,}7) = 141{,}5 \text{ kW}$$

with:

η_v = efficiency of the fan (product of mechanical efficiency and the hydraulic efficiency)

Considering an electrical efficiency η_{el} of 0,85, the power absorbed by the engine is:

$$P_{ass\ mot} = P_{ass} /\eta_{el} = 141{,}5/0{,}85 = 166{,}5 \text{ kW}$$

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The fan selection is performed based on the performance obtainable in catalogs of various manufacturers.

The work that the fan must make in the isentropic compression of the air Lu, per unit mass treated, that is:

$$L_u = \frac{k}{k-1} RT \left(\beta^{\frac{k-1}{k\,\eta_y}} - 1 \right)$$

where:

k = exponent of the isoentropic = 1,4

R = constant of elasticity of the air = 29,3 m/K

T = absolute temperature in entry in the machine

β = compression ratio = $(h_1+H_t)/h_1$= (10329+1493,6)/10329 = 1,14

h_1 = atmospheric pressure (kg/m^2)

η_y = hydraulic efficiency of the machine (~0,8)

Whereby:

$L_u = 1{,}4/0{,}4 \times 29{,}3 \times 293\ (1{,}14^{0{,}4/(1{,}4 \times 0{,}8)}-1) = 1041$ kg m/kg

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

To size the cyclone separator is required to define the following two parameters (Monte):

- diameter of the cyclone D_c (m), which decreases at the increases of the centrifugal force of separation
- input speed of the transport stream v_i defined by:

$$v_i = 8 \cdot A / D_c^2 \qquad \text{(m/s)}$$

- minimum diameter of the particles separated d_{min}:

$$d_{min} = 5\,(D_c / (v_i \cdot \gamma_{assoluto}))^{½} \qquad \text{(mm)}$$

- by Zignoli, taking into account the diameter of the particles to be separated d_m, is detectable:

$$d_{min} = d_m / \beta \qquad \text{(mm)}$$

being β: 0,36 for complete separation (100%), 0,55 for incomplete separation at 70% and 0,12 for incomplete separation at 10%

Combining the three relations and assuming β = 0,36 and d_m = 10 mm we obtain:

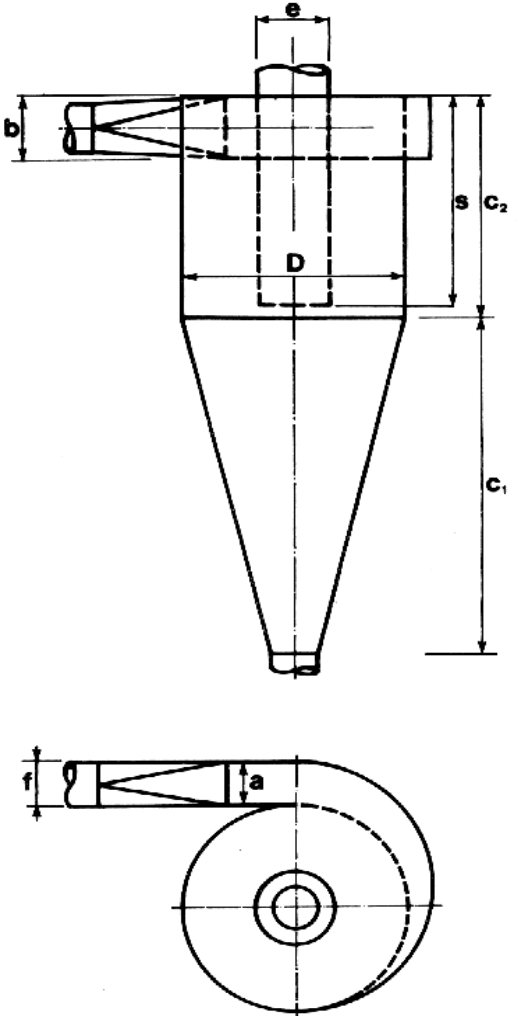
$$d_{min} = 10 / 0{,}36 = 27{,}8 \text{ mm}$$

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

$D_c = (d_{min}^2 \cdot 8 \cdot A \cdot \gamma_{assoluto} /25)^{1/3} =$
$(0{,}0278^2 \times 8 \times 6{,}77 \times 700 /25)^{1/3} = 1{,}055$ m

$v_i = 8 \cdot A / D_c^2 = 8 \times 6{,}77 / 1{,}055^2 = 48{,}7$ m/s

The diameter of the outlet pipe f is assumed, for simplicity of construction, equal to the diameter of the duct D =0,483 m



The other dimensions of the cyclone is shown in the following expressions:

- width in the inlet conduit:
  $a = 0{,}2 \cdot D = 0{,}2 \times 0{,}483 = 0{,}097$ m
- height in the inlet conduit:
  $b = A /(v_i \cdot a) = 6{,}77/(48{,}7 \times 0{,}097)=1{,}433$ m
- height of the conical part:
  $c_1 = 2{,}25 \cdot D = 2{,}25 \times 0{,}483 = 1{,}087$ m
- height of the cylindrical part:
  $c_2 = 1{,}35 \cdot D = 1{,}35 \times 0{,}483 = 0{,}652$ m
- length of the adduction tube inside:
  $s = 2{,}5 \cdot a = 2{,}5 \times 0{,}097 = 0{,}242$ m

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

To size the bag filter is required to define the following two parameters (Zignoli):

- filter surface S_{fil} as a function of the air flow flowing A

$$S_{fil} = 0,3\ m^2/m^3/\text{minute air flowing} = 0,3 \times 406,2 = 121,9\ m^2$$

- crossing speed of the filtering surface v_a:

$$v_a = A / S_{fil} = 6,77 / 121,9 = 0,055\ m/s$$

By adopting a compression filter with automatic shaker to 125 m^2 of filter surface, one can determine the diameter of the tube (90 mm), the useful height (2.5 m) and the body dimensions (length, depth and height), and the weight of the body, which are available from brochures of the manufacturers.

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

The choice of the type of cloth is conditioned by the maximum size allowed for the particles which escape. In compliance with legal regulations on emissions, we assume a granulometry of 0.2 mm, so the filtering that is used will be 0.17 mm holes having the following characteristics: wire diameter 0.22 mm, number of wires 25 per cm, weight 0.230 kg/m^2 and a coefficient of loss of load 2.97 mbar/m/s speed.

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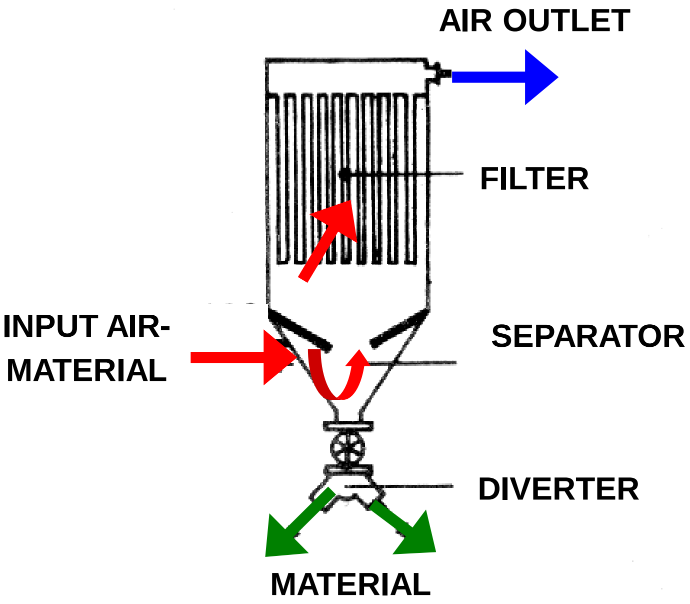

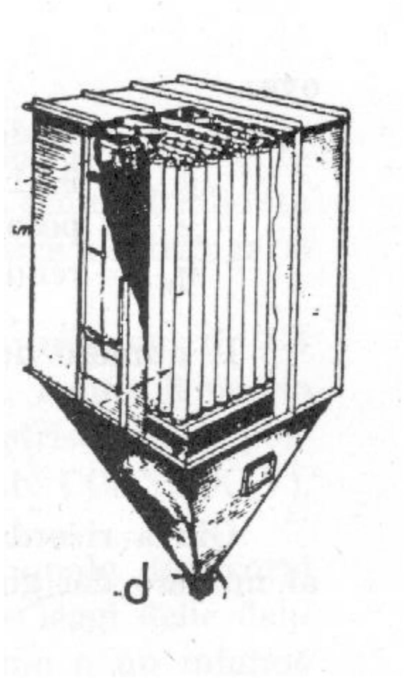

Effects of separation of solid particles from the air in the cyclone:

- enlargement of the section at the entrance and reduction in speed,
- change of direction;
- effect of filtering sleeves.

In all three cases, the gravity allowing the separation of solid particles which are extracted from the bottom.

Preliminary design of a pneumatic conveyors in fluid phase with the traditional method

Sleeve filter