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Aspiration system design

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In **AIR POLLUTION CONTROL SYSTEMS ENGINEERS** must solve **1 CRUCIAL PROBLEM**

The **polluted air must be moved**:

- from the source point in the plant to the FAN;
- from the FAN to the Air Pollution Control Device and to the stack;
- meeting **PERFORMANCE STDs** (velocity, noise, **costs**).

↓

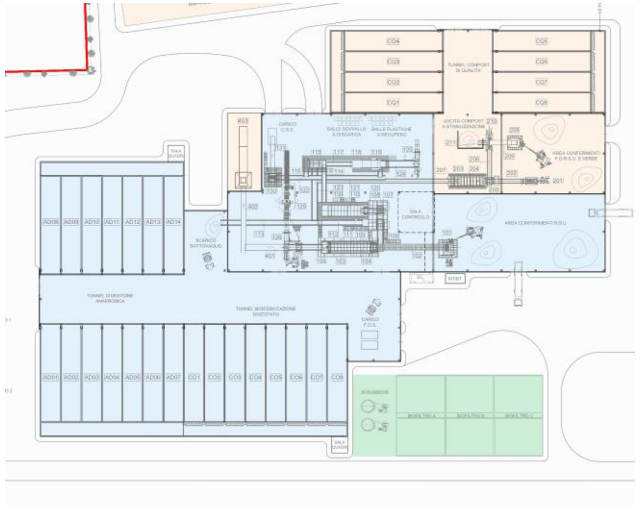
ASPIRATION / VENTILATION SYSTEM

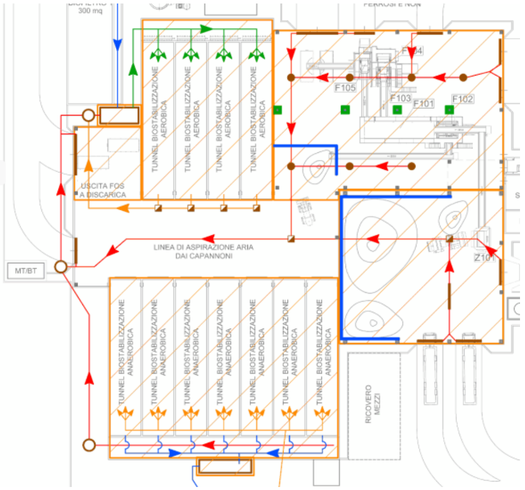
DESIGN OF THE VENTILATION SYSTEM

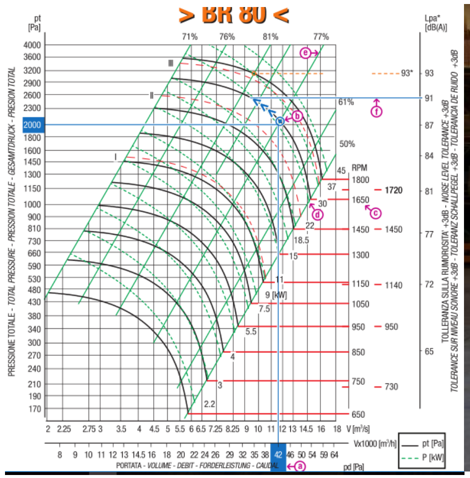
1. **Determination of the features of the airflow rate Q (Nm³/h)** to be conveyed to the APCD (air volume changes per hour for buildings, involved industrial process and contaminants, ..)

2. **Design the proper duct system** (arranging the flow pattern in the space to be served, dimensioning, selection of proper materials and auxiliary components, …)

3. **Selection of the proper FAN** (fan components, material, fan curves, needed static pressure,..)

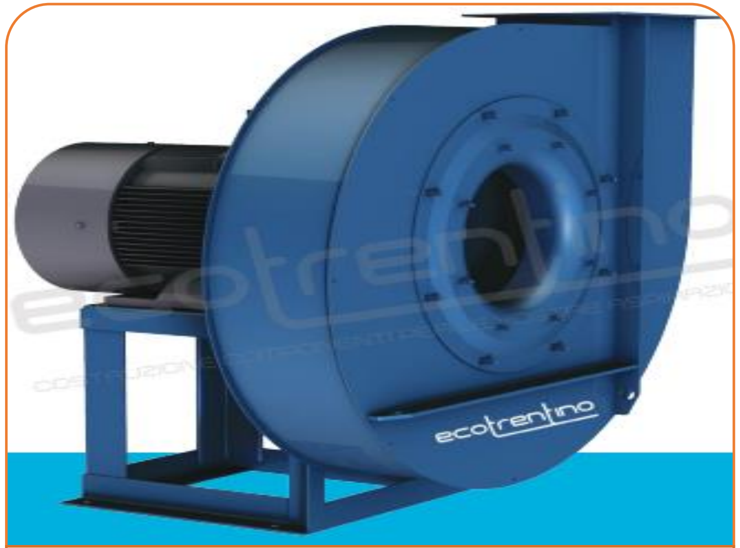






COMPONENTS OF THE VENTILATION SYSTEM

DUCTS



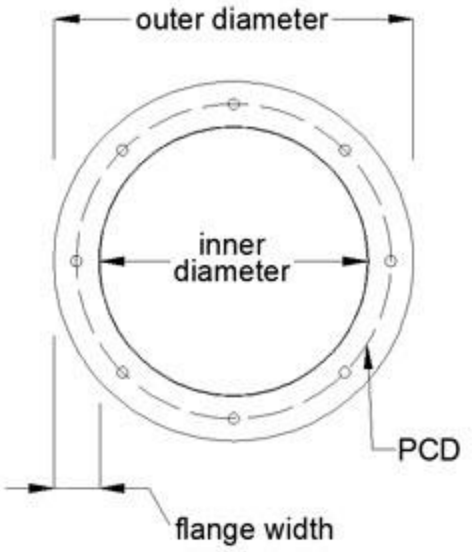
FAN

AUXILIARY EQUIPMENT

DUCTS

Design Criteria

$$D = \sqrt{\frac{4\,Q}{\pi\,V}}$$



Where:

- D = Duct INNER diameter (m)
- Q = Flowrate to be treated (m3/h)
- V = Design velocity (m/s)

!!! 10 m/s < V < 20 m/s !!!

DUST DEPOSITION
NOISE (dB)
HEAD LOSSES

DUCTS

Construction Materials (1/3)

Galvanized Steel

- Carbon Steel after a Zinc bath
- Medium-Low Resistence to Corrosion
- Medium-Low Construction Cost , High Maintenance Cost
- Low-Medium Temperature (< 100°C)

AISI 304

- Stainless Steel (18% Cr, 9% Ni)
- Medium-High Resistence to Corrosion
- Medium-High Cost, Low Maintenance Cost
- Medium-High Temperature

AISI 316

- Stainless Steel (17% Cr, 11% Ni, 2,5% Mo)
- Very High Resistence to Corrosion
- Very High Cost
- Medium - Very high Temperature

DUCTS

Construction Materials (2/3)

Polypropilene (PP)

- Plastic Polymer + additives
- High Resistence to Corrosion
- Medium Construction Cost , Medium Maintenance Cost
- Antistatic and Self-extinguishing
- Low temperature (< 100 °C)

Aluminum

- Buildings ventilation..

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DUCTS

Construction Materials (3/3)
Selection Criteria

1) AIRFLOW TEMPERATURE

Full knowledge of the industrial processes involved

2) AIRFLOW CONTAMINANTS

Humidity
H_2S , NH_3, Amines
Acid Gases (HCl, ..)
Explosive gases (CH_4, biogas, ATEX)
Dust

3) ECONOMIC SUSTAINABILITY

Beware of the higher than necessary costs!

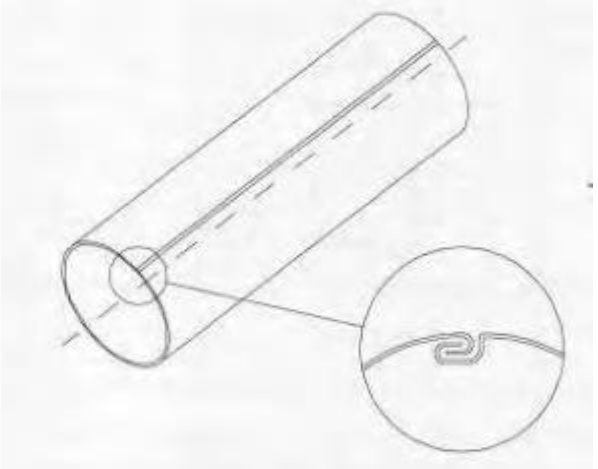
!BRAND NEW DESIGN vs. PROJECT LEGAL REQUIREMENTS!

DUCTS

Longitudinal Juctions
«Aggraffatura» a.k.a. Longitudinal welding

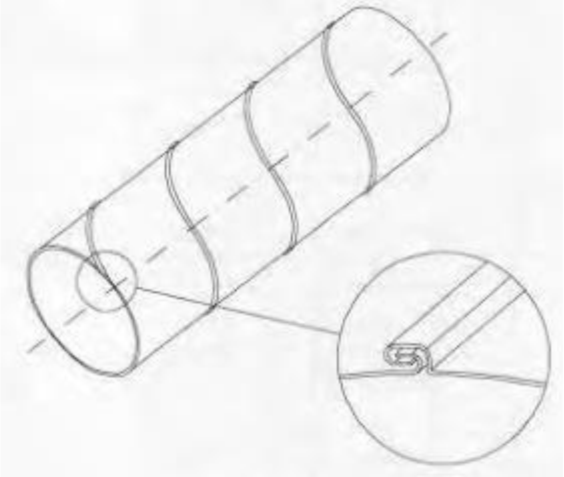
Calandered Duct

- Steel Sheet of variable height (H ≤ 1,5 m)
- Straight Longitudinal Junction
- Length of components is determined by the steel sheet height
- https://www.youtube.com/watch?v=Fdi0O_tuCbo&t=38s



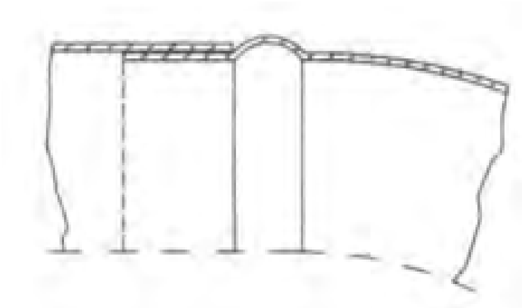
Spiroidal Duct

- Steel «Stripe» of fixed height
- Spiroidal Longitudinal Junction
- Length of components is determined by the functioning duct manufacturing machine
- https://www.youtube.com/watch?v=OLVdX0lgUUE&t=34s&index=4&list=LLLvWLv_MznK9GIiPyelzjSA



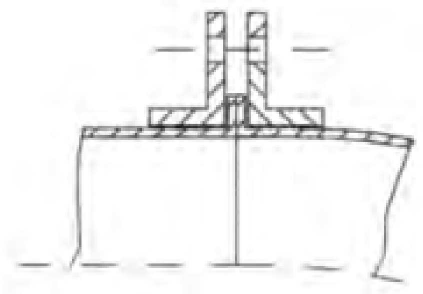
DUCTS

Cross Junctions



Spigot Junctions

- Low hydraulic leakproofness
- Low cost
- Gaskets



Flanged Junctions

- High hydraulic leakproofness
- High cost
- Gaskets

DUCTS – AUXILIARY EQUIPMENT

1. **ANTIVIBRANT FITTINGS** = flexible fittings that reduce the propagation of mechanical and / or acoustic vibrations and the expansion between two components

2. **DAMPERS** = elements inserted in the air ducts or installed on the terminals of these to allow the control in the flow rate or the complete interruption of the air flow (Automatic or manual Butterfly valve, Guillotine damper, …)

3. **MEASUREMENT DEVICES** = Temperature, Flowrate, Pressure measurement inside ducts

4. **COLLARS and WALL BRACKETS** = components to fix the ventilation/aspiration system to the building walls

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FANS

«THE HEARTH OF A VENTILATION SYSTEM»

- **Provide energy** needed to **convey** the flue gases from the emission source to the APCD;
- Energy is provided in terms of **pressure (mmH2O)**
- **Design Pressure Value** must be enough to **overcome the pressure losses due to the ventilation system and the APCDs**

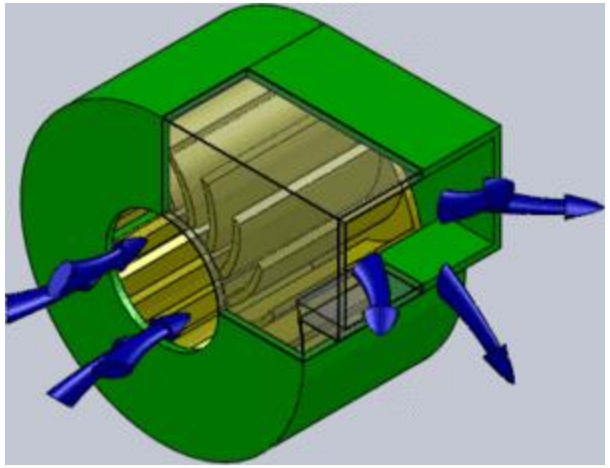
FANS – TYPES

CENTRIFUGAL FLOW FANS

Air enters in the eye of the rotor, turns at right angles, and is accelerated and compressed (the pressure arises) by centrifugal force into the discharge. Propeller movement convert centrifugal force to pressure rise

AXIAL FLOW FANS

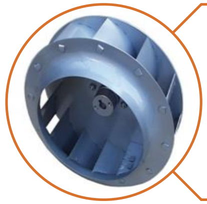
Air flows straight through the device along the axis of rotation. Propeller movement convert centrifugal force to pressure rise. Air is pulled in on the leading edge and discharge it from the trailing edge.



Generally **APC applications involve Centrifugal Fans** because of their stable and efficient operation through times (less maintenance during continuous functioning)

Axial flow Fans are instead used in Buildings Ventilation Systems

FANS – PRINCIPAL COMPONENTS & MATERIALS



PROPELLER

CASING

ELECTRICAL ENGINE + INVERTER

SOUNDPROOFING BOX

MATERIALS

Polipropilene

Galvanized Carbon Steel

AISI 304

AISI316

SPECIAL COATINGS

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FANS – TECHNICAL FEATURES (1/2)

DEFINITIONS

FAN provides ENERGY in terms of TOTAL PRESSURE (pt), which is the sum of 2 contributions $pt = ps + pd$

- **Static pressure (ps) =** It is defined as the **pressure exerted by the fluid on the walls of the pipe** or vessel in which it is contained. It acts equally in all directions and is **independent of the velocity of the fluid**. Taking the ambient pressure as a reference, the static pressure is positive when it is greater than the ambient pressure, negative when it is less;

- **Dynamic pressure (pd) =** It is defined as the **pressure corresponding to the part of** energy possessed by the mass unit of the fluid because of its velocity (**kinetic energy**). It acts in the same direction as the fluid motion and is always considered positive (it acts in the direction of the fluid).

$$pd = \frac{1}{2} \cdot \rho \cdot v^2$$

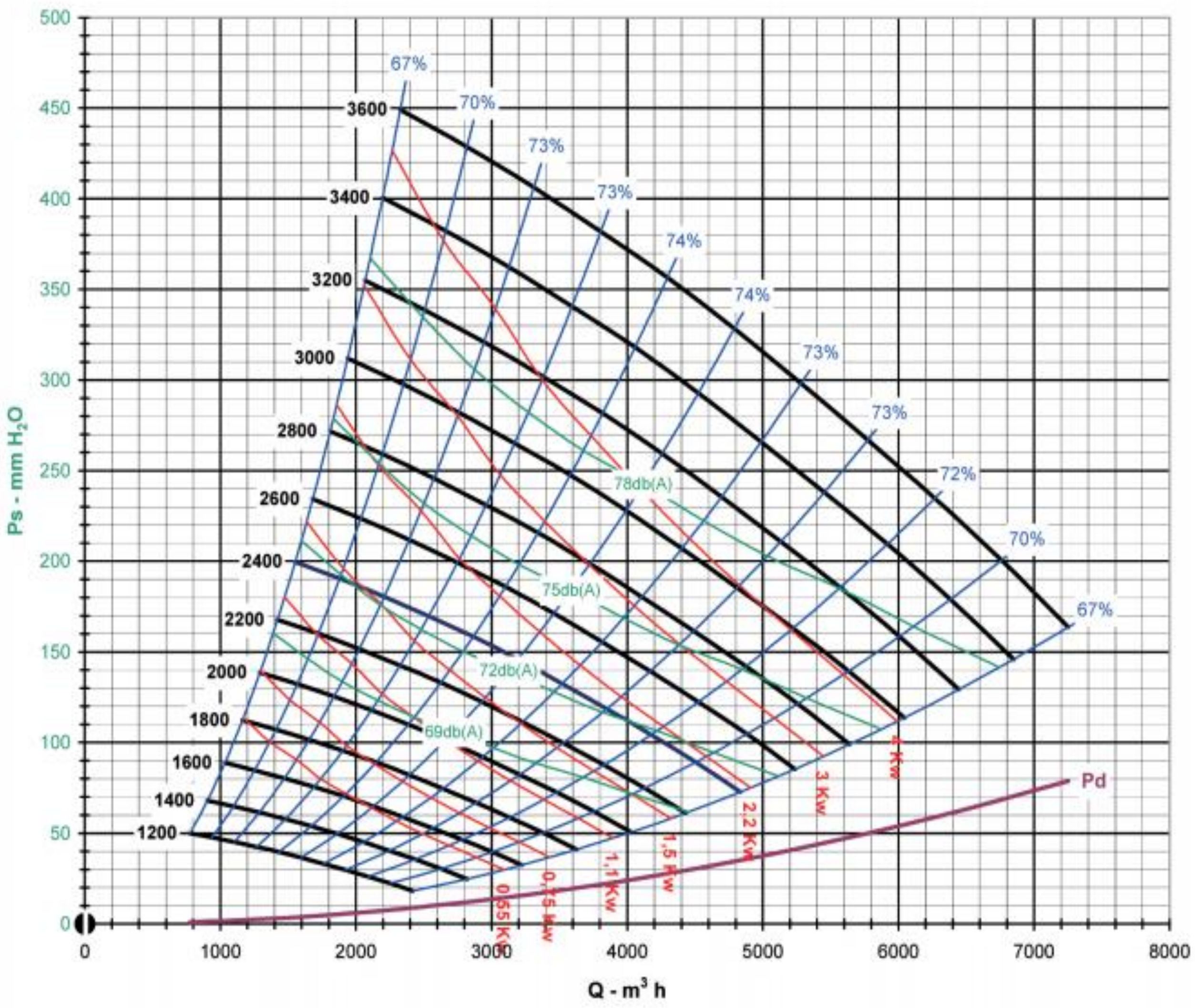
- pd = dynamic pressure (Pa)
- ρ = flue gas density (kg/m3)
- V = flue gas velocity (m/s)

FANS – TECHNICAL FEATURES (2/2)

FAN CURVES

Fan curves summarize **the performance of each fan model**, by presenting quantitative **RELATIONSHIPS** between

- **Flowrate (X axis)**
- **Static pressure delivered (left Y axis)**
- **Adsorbed Power (in red)**
- **Mechanical Efficiency (in blue)**
- **RPM (Revolutions per Minute)**



HOW TO CHOOSE THE RIGHT FAN?

1. Flowrate features
   - Q
   - Contaminants concentrations
   - Temperature
   - Density

2. Static pressure (Ps) to provide to the system

$$P_S \geq \sum \Delta P_i$$

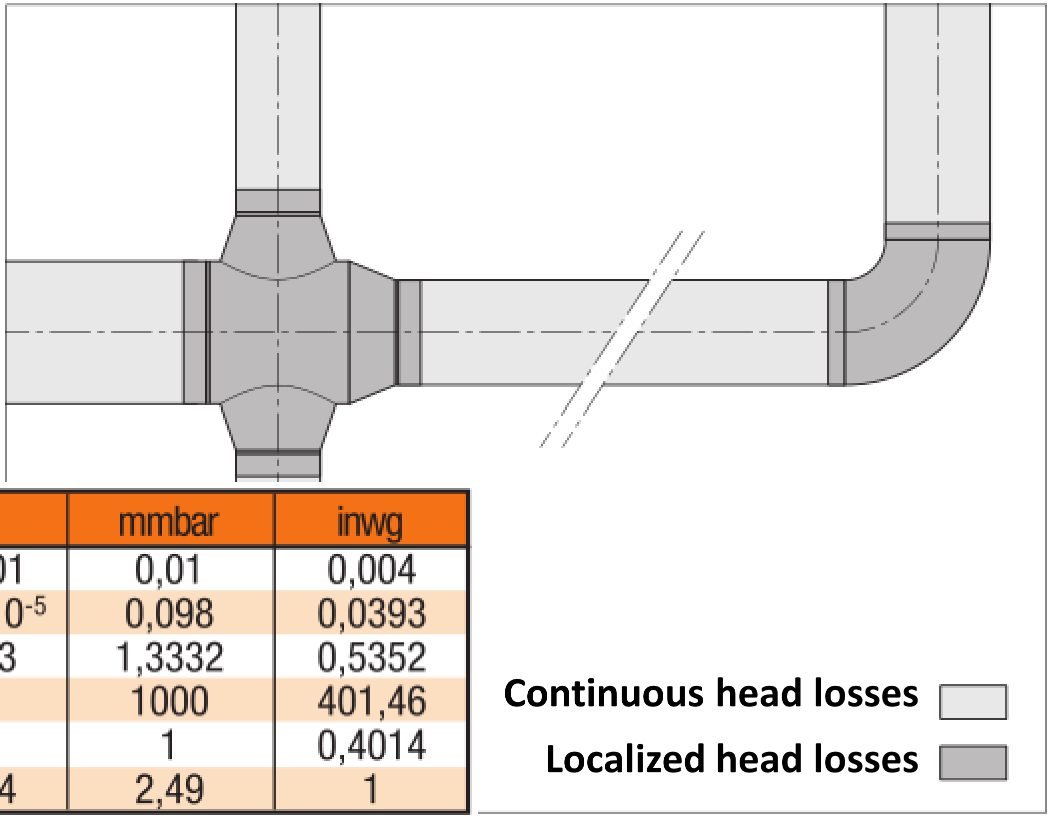
- $\sum \Delta P_i$ **= sum of system head losses**

HEAD LOSSES IN AIR DUCTS

Head losses are **pressure drops** (with irreversible transformations of mechanical energy into heat) **caused by friction forces and turbulences** acting countercurrent to the motion of a fluid through a duct.

1. **Continuos** = pressure losses caused by **friction in straight lenghts** of duct

2. **Localized** = pressure losses caused by both **friction and turbulence in** duct system **«singularities»** (e.g. bends, fittings, expansion or contraction, etc.)



unità di misura	Pa	mm H_2O (kgf/m^2)	torr (mm Hg)	bar	mmbar	inwg
1 Pa (N/m^2)	1	0,102	0,0075	0,00001	0,01	0,004
1 mm H_2O (kgf/m^2)	9,806	1	0,0735	$9{,}806 \times 10^{-5}$	0,098	0,0393
torr (mm Hg)	133,32	13,6	1	0,0013	1,3332	0,5352
bar	100.000	10197	750,06	1	1000	401,46
mmbar	100	10,2	0,75	0,001	1	0,4014
inwg	249	25,4	1,8683	0,0024	2,49	1

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CONTINUOUS HEAD LOSSES

$$r = \frac{F_a * \rho * v^2}{2D}$$

$$\rho = 1,293 * \frac{P_b}{1{,}013} * \frac{273}{273+t} \qquad \nu = \frac{1{,}5}{\rho} * 10^{-6} * \left(\frac{273+t}{413+t}\right)^{1,5}$$

$$P_b = -0,1125 * H + 1.011,5$$

- r = length specific pressure losses (Pa/m)
- ρ = flue gas density (kg/m3)
- ν = flue gas cinematic viscosity (m2/s)
- v = flue gas velocity (m/s)
- D = inner duct diameter (m)
- Pb = Barometric pressure (mbar)
- H = altitude (m)
- **Fa = friction factor (dimensionless)**
- Re = Reynolds number (dimensionless)

$$F_a = f(Re)$$

$$Re = \frac{v * D}{\nu}$$

- **LAMINAR FLOW → *Re < 2.000***
- ***TURBULENT FLOW → Re > 2.500***

APC DUCT SYSTEM → TURBULENT FLOW!

CONTINUOUS HEAD LOSSES – TURBULENT FLOW

$$\textit{Colebrook} \quad \frac{1}{F_a^{0,5}} = -2\log_{10}\left(\frac{\varepsilon}{3{,}7*D} + \frac{2{,}51}{Re*F_a^{0,5}}\right) \rightarrow \textit{Altshal \& Tsal} \quad F_a^{*} = 0{,}11*\left(\frac{\varepsilon}{D} + 192{,}3*\frac{D*\nu}{G}\right)^{0{,}25}$$

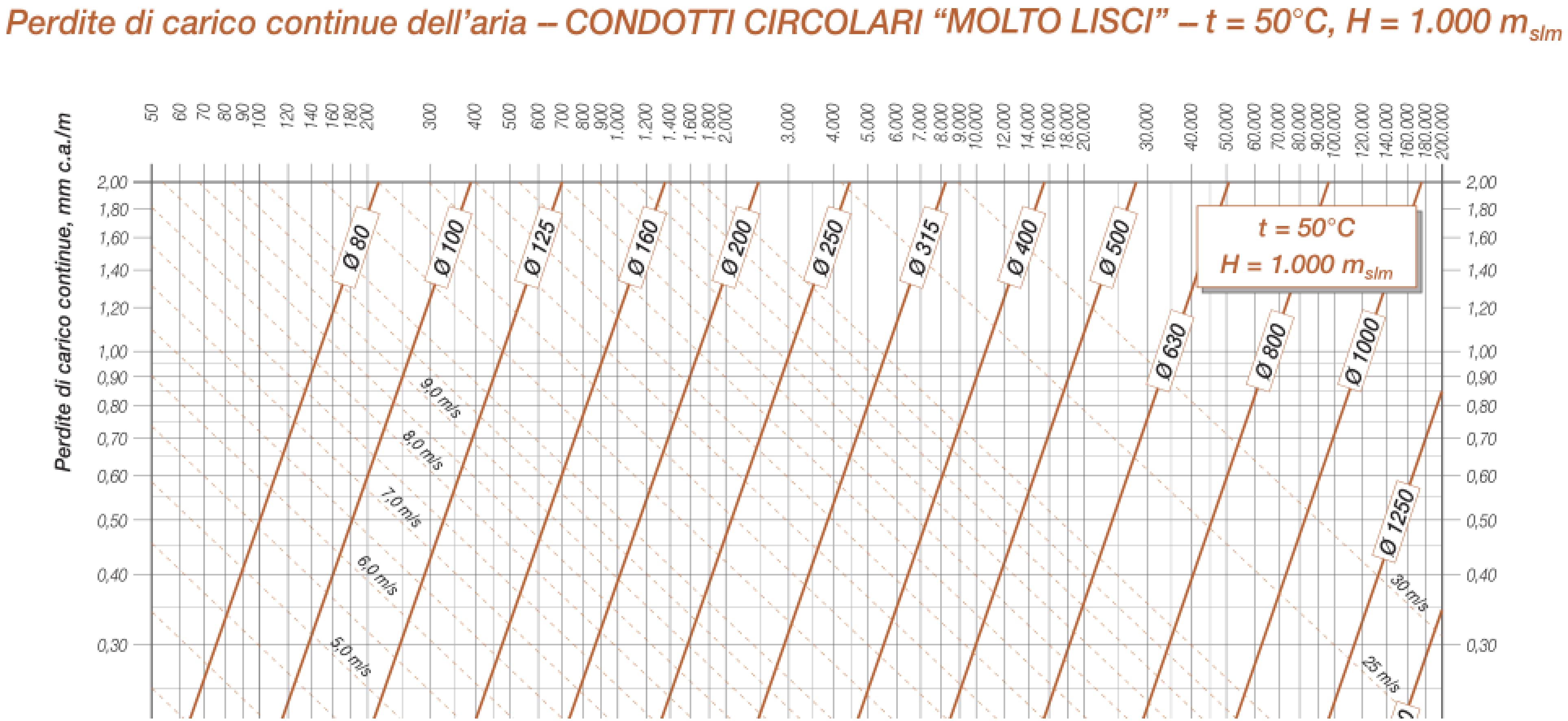
$$r = 6{,}254*10^7 * F_a * \rho * \frac{G^2}{D^5}$$

- r = length specific pressure losses (**Pa/m**)
- Fa = Friction factor (dimensionless)
- Ɛ = duct roughness (mm)
- ρ = flue gas density (kg/m3)
- G = flue gas flowrate (m3/h)
- D = duct inner diameter (mm)

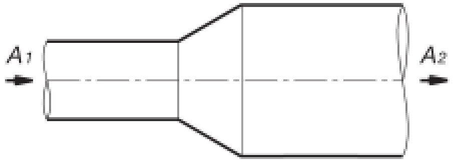
$$r = 0{,}6376*10^7 * F_a * \rho * \frac{G^2}{D^5}$$

- r = length specific pressure losses (**mmH2O/m**)
- Fa = Friction factor (dimensionless)
- Ɛ = duct roughness (mm)
- ρ = flue gas density (kg/m3)
- G = flue gas flowrate (m3/h)
- D = duct inner diameter (mm)

CONTINUOUS HEAD LOSSES – TURBULENT FLOW – REFERENCE TABLES



LOCALIZED HEAD LOSSES

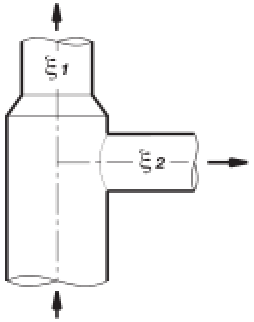


$$r = \xi * \rho * \frac{v^2}{2}$$

- r = pressure losses (**Pa**)
- Ɛ = localized head loss coefficient (dimensionless)
- ρ = flue gas density (kg/m3)
- v = flue gas velocity (m/s)

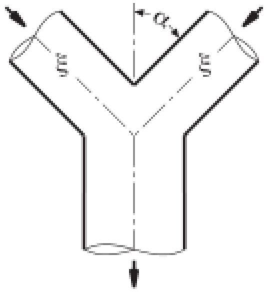
$$r = \xi * \rho * \frac{v^2}{2 * 9,81}$$

- r = pressure losses (**mmH2O**)
- Ɛ = localized head loss coefficient (dimensionless)
- ρ = flue gas density (kg/m3)
- v = flue gas velocity (m/s)



The **ξ coefficient depends on the «shape» of the singularity** (bends, Y junction, contraction); It can be determined by:

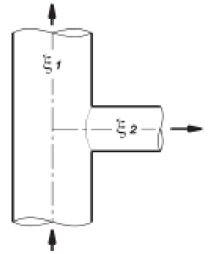
- Specific formulas (in cases of simple geometry)
- Laboratory tests
- **Tables!**



LOCALIZED HEAD LOSSES - REFERENCE TABLES

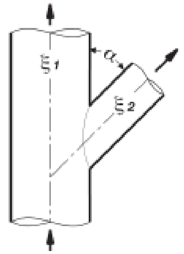
Canali circolari - valori indicativi dei coefficienti ξ - derivazioni e confluenze

Derivazione a 90°



$\xi_1 = 0{,}2$ $\xi_2 = 1{,}3$

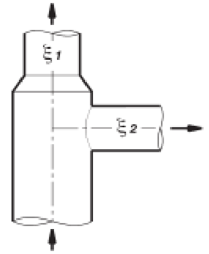
Derivazioni a 30°, 45° e 60°



$\xi_1 = 0{,}2$

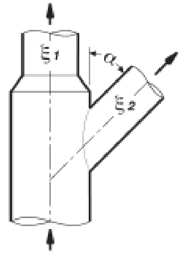
ξ_2		
α = 30°	α = 45°	α = 60°
0,4	0,7	0,9

Derivazione con riduzione a 90°



$\xi_1 = 0{,}4$ $\xi_2 = 1{,}3$

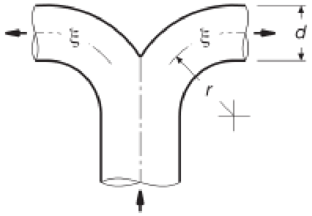
Derivazioni con riduzione a 30°, 45° e 60°



$\xi_1 = 0{,}4$

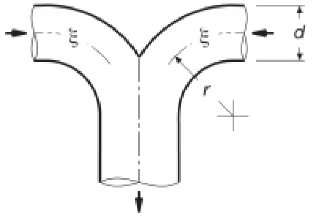
ξ_2		
α = 30°	α = 45°	α = 60°
0,4	0,7	0,9

Derivazione a doppia curva



r/d	ξ
0,50	1,2
0,75	0,6
1,00	0,4
1,50	0,3
2,00	0,2

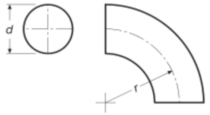
Confluenza a doppia curva



r/d	ξ
0,50	1,1
0,75	0,5
1,00	0,3
1,50	0,2
2,00	0,2

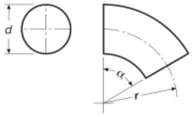
Canali circolari - valori indicativi dei coefficienti ξ - curve

Curva a 90°



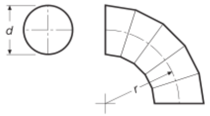
r/d	ξ
0,50	0,9
0,75	0,5
1,00	0,4
1,50	0,3
2,00	0,2

Curve a 30°, 45° e 60°



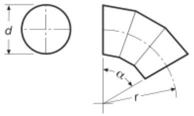
r/d	ξ		
	α = 30°	α = 45°	α = 60°
0,50	0,3	0,5	0,7
0,75	0,2	0,3	0,3
1,00	0,1	0,2	0,3
1,50	0,1	0,2	0,2
2,00	0,1	0,1	0,1

Curva a settori a 90°



r/d	ξ
0,50	1,1
0,75	0,6
1,00	0,4
1,50	0,3
2,00	0,2

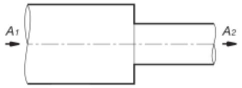
Curve a settori a 30°, 45° e 60°



r/d	ξ		
	α = 30°	α = 45°	α = 60°
0,50	0,4	0,6	0,7
0,75	0,2	0,3	0,4
1,00	0,1	0,2	0,3
1,50	0,1	0,2	0,2
2,00	0,1	0,1	0,1

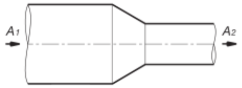
Canali circolari - valori indicativi dei coefficienti ξ - variazioni di sezione e regolatori

Restringimento senza invito



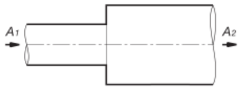
A_2/A_1	ξ
0,2	0,5
0,4	0,4
0,6	0,3
0,8	0,2

Restringimento con invito



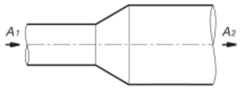
$\xi = 0{,}2$

Allargamento senza invito



A_2/A_1	ξ
0,1	0,9
0,2	0,7
0,4	0,4
0,6	0,2

Allargamento con invito



A_2/A_1	ξ
0,1	0,5
0,2	0,3
0,4	0,2
0,6	0,2

HEAD LOSSES due to APCD

APCD	Δp (mm H2O)
Scrubber	80-120
Scrubber (2 layers)	120-250
Biofilter	60-100

Comparison of Particulate Removal Systems

Type of collector	Particle size range (μm)	Removal efficiency	Space required	Max. temp. (°C)	Pressure drop (cm H²O)	Annual cost (U.S. $ per year/m³)[a]
Baghouse (cotton bags)	0.1–0.1	Fair	Large	80	10	28.00
	1.0–10.0	Good	Large	80	10	28.00
	10.0–50.0	Excellent	Large	80	10	28.00
Baghouse (Dacron, nylon, Orlon)	0.1–1.0	Fair	Large	120	12	34.00
	1.0–10.0	Good	Large	120	12	34.00
	10.0–50.0	Excellent	Large	120	12	34.00
Baghouse (glass fiber)	0.1–1.0	Fair	Large	290	10	42.00
	1.0–10.0	Good	Large	290	10	42.00
	10.0–50.0	Good	Large	290	10	42.00
Baghouse (Teflon)	0.1–1.0	Fair	Large	260	20	46.00
	1.0–10.0	Good	Large	260	20	46.00
	10.0–50.0	Excellent	Large	260	20	46.00
Electrostatic precipitator	0.1–1.0	Excellent	Large	400	1	42.00
	1.0–10.0	Excellent	Large	400	1	42.00
	10.0–50.0	Good	Large	400	1	42.00
Standard cyclone	0.1–1.0	Poor	Large	400	5	14.00
	1.0–10.0	Poor	Large	400	5	14.00
	10.0–50.0	Good	Large	400	5	14.00
High-efficiency cyclone	0.1–1.0	Poor	Moderate	400	12	22.00
	1.0–10.0	Fair	Moderate	400	12	22.00
	10.0–50.0	Good	Moderate	400	12	22.00
Spray tower	0.1–1.0	Fair	Large	540	5	50.00
	1.0–10.0	Good	Large	540	5	50.00
	10.0–50.0	Good	Large	540	5	50.00
Impingement scrubber	0.1–1.0	Fair	Moderate	540	10	46.00
	1.0–10.0	Good	Moderate	540	10	46.00
	10.0–50.0	Good	Moderate	540	10	46.00
Venturi scrubber	0.1–1.0	Good	Small	540	88	112.00
	1.0–10.0	Excellent	Small	540	88	112.00
	10.0–50.0	Excellent	Small	540	88	112.00
Dry scrubber	0.1–1.0	Fair	Large	500	10	42.00
	1.0–10.0	Good	Large	500	10	42.00
	10.0–50.0	Good	Large	500	10	42.00

[a] Includes water and power cost, maintenance cost, operating cost, capital and insurance costs.