EUROPEAN UNION
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Study material I.

Separation of solid particles
Mechanical separators

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1. Separation of solid particles

The combustion of fuels and other industrial activities generates dust emissions, for which the name of solid pollutant (TZL) is often used. They are formed on a general level during processes such as crushing, grinding, blasting rocks, etc. Their separation from waste gases is necessary with a view to protecting the environment and human health.

When burning solid fuels, especially coal, the ashes contained in the coal are transformed into ash, which is carried out of the boiler with flue gases and is captured in separators, as well as is extracted from the bottom of the boiler. In the first case we are talking about ash, in the second - about cinquefoil. When burning liquid fuels, TZL forms amorphous carbon (soot). Gaseous fuels, such as natural gas, do not form TZL under the correct combustion regime, unless these have already been contained in the gas itself from the production operations in which these gases are produced (e.g. in blast furnace or coke oven gas or in natural gas as a result of corrosion of pipelines).

When burning coal, the proportion of ashes passing into the flue gases as fly ash depends primarily on the combustion technology, e.g.:

- powder boilers 80 – 90 %
- grate boilers 40 %
- cyclone 30 %
- circulating fluidized bed > 90 %

In powdered boilers, fly ash concentrations in the flue gas in front of the separators reach values of about 40 $^{g.m-3}$.

Today's separators are able to capture particles several micrometers in size. Particles that pass through highly efficient separators are predominantly submicronic in size or are aerosols called fly ash or submicronic dust.

Emission limits for TZL are getting stricter. Examples of emission limit values for fuel combustion are given in Table 1.

Tabulka 1 Examples of certain TZL emission limit values for the combustion of coal and liquid fuels

Fuel type	**Power limit [MW]**	***Emission limit*** **[mg.m $^{n-3}$]**
For existing resources		
Coal (6 % by$_2$)	> 0,2 – 5 MW TV[1)]	250
	> 5 – 50 MW TV	150
	> 50 MW TV	100
Liquid fuels (3% O_2)	> 0,2 – 50 TV	100
	> 50 TV	50
For new sources and existing sources after 2008		
Coal (6 % by$_2$)	> 0,2 – 5 MW TV	250
	> 5 – 50 MW TV	150
	> 50 MW TP[2)]	30
Liquid fuels (3% O_2)	> 0,2 – 50 TV	100
	> 50 TP	30

[1)] heat output

[2)] thermal input

The choice of separator depends on:

- particle size;
- their distribution and shape;
- certain physical properties (e.g. resistivity);
- the value of the emission limit;

According to the 1st phase of separation, the separators are divided:

- mechanical;
- filters;
- electrostatic;

Each of these groups is characterized by one or two of the following separation principles:

- mechanical separators – mainly inertia, to a lesser extent gravity;
- filters – diffusion or inertia;
- electro-separators – electrostatic forces and gravity.

According to the 2nd phase of separation, the separators in each of the above groups are divided into:

- dry;
- Wet.

2. Mechanical separators

They are based on inertia and gravity. They are divided into dry and wet.

Dry separators include:

- settling chambers;
- blinds;
- vortex.

Among the wet separators:

- vortex wet;
- level;
- foam;
- Current.

Dry separators are characterized by:

- simple construction;
- low acquisition costs;
- low power consumption;
- low separability of submicronic particles.

Their use is most often limited to separation at high temperatures and as the first stage of separation (pre-separation).

Wet separators in comparison with dry ones have the following advantages:

- higher separability due to the binding of dust to liquid on wetted walls;
- are suitable for abrasive and sticky dusts;
- the possibility of simultaneous separation of gaseous pollutants.

The disadvantages of wet separators are:

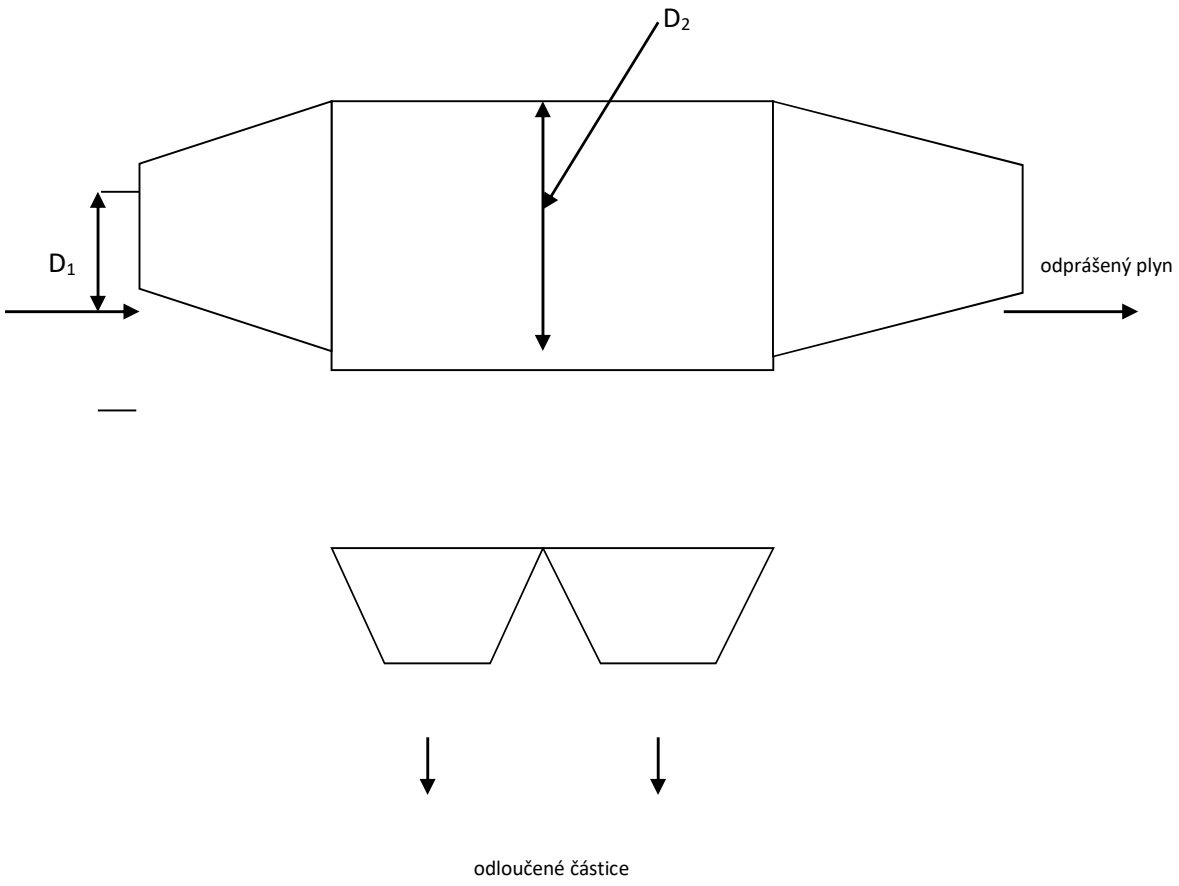
- high water consumption;
- the need to operate sludge management, more demanding maintenance and operation;
- higher corrosion rate.

3. Dry mechanical separators

3.1.1.1 Settling chambers

This is the gravitational principle of dust separation. Dust deposition occurs by reducing the gas velocity to the value of the particle stall velocity due to the extension of the diameter of the inlet pipe D_1 to the diameter D_2 in the settling chamber. The velocity of the gas in the chamber should be < 1 $^{m.s-1}$ (Fig. 1). Settling chambers were used for large particles (>10^2 µm) or as pre-separators. The flow through the chamber is horizontal, at the bottom of the chamber there are hoppers with caps. Dust deposited in the dumps is removed

Fig. 1 Dust separation on the principle of a settling chamber



The critical size of the separated particles a is calculated by:

$$a = \sqrt{\frac{18\eta h v}{l \varphi g}}$$

where the symbols mean:

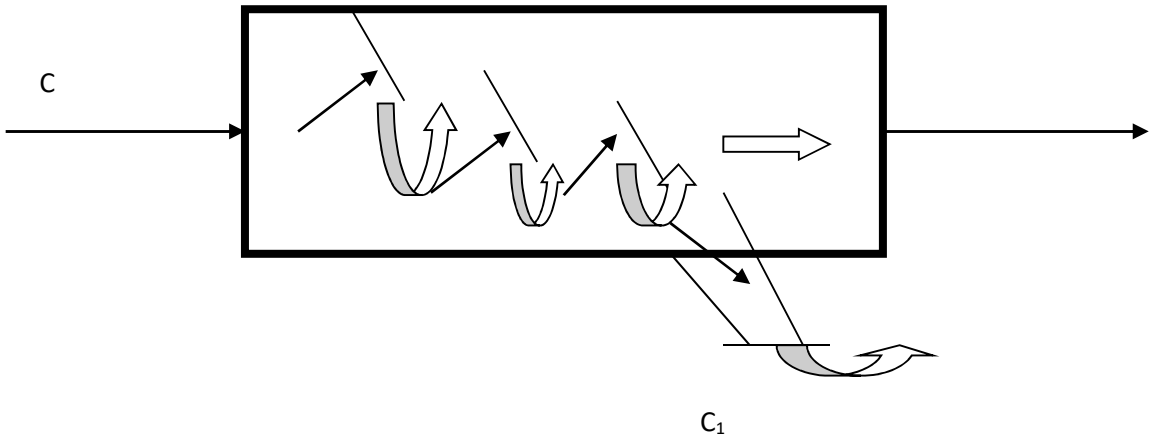
α – particle size, h – chamber height; l – chamber length, η – dynamic viscosity; ϕ – specific gravity of the environment; v – linear velocity of the gas in the chamber; g – gravitational acceleration.

Settling chambers were used for separating large particles, today they are no longer used.

3.1.1.2 Inertia separators

Inertial dust separators use the principle of inertia when gas flows through suitably profiled partitions. Compared to settling chambers, they have built-in blinds (partitions) through which the gas flow through the separator is regulated (fig. 2):

Fig. 2 Dedusting of waste gases by blind separator



by changing the direction of flow;

- particles that are not sufficient to follow the change in flow are reflected back into the flow of the incoming gas;
- the dust is concentrated in a stream C_1 which contains about 10 % of the original flow. Behind it must be a more effective separator, for example, a vortex one. It serves as a pre-separator;
- the C_o stream is partially devoid of solid particles.

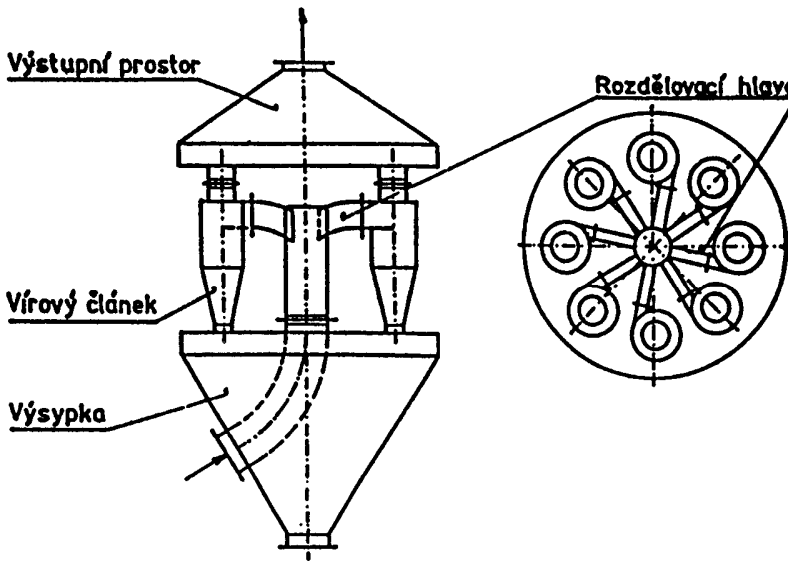
The separation limit depends:

- on the shape of the blind;
- on the leaf spacing;
- on the progressive speed of the gas;
- on particle size.

These separators are space-saving, suitable for high temperatures, for non-stick and non-abrasive dust. Their use is limited by the concentration of TZL up to 1 $^{g.m-3}$. They are little effective for small particles.

3.1.1.3 Vortex separators

Obr. 3 Group separator (multicyclon)



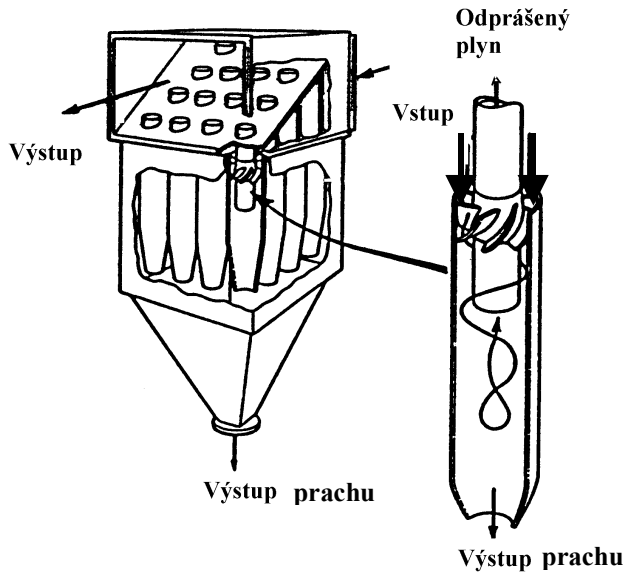
Vortex separators (cyclones) are among the most widespread mechanical separators. Separation takes place under the action of a centrifugal force acting on the particles during the spiral movement of the gas through the cylindrical or conical chamber of the separator and causing in the radial direction the relative velocity of the particle perpendicular to the separation surfaces. Thus, it puts the gases into rotational motion, with the separated particles reaching the wall of the separator, on which they separate from the gas stream. From the wall, the separated particles fall into the separator hopper, from which they are then drained.

Depending on how the gas enters the separator before it is put into centrifugal motion, we distinguish vortex separators with a tangent input (fig. 3) or with an axial input (fig. 4), where the introduction into screw movement is provided by a vane built-in inside the separator. Axial flux

cyclones are further divided into reversible flow cyclones when the gas turns inside and returns back in the axis of the incoming gas, or with a direct flow when it exits at the opposite end to the incoming gas.

A system of several cyclones in parallel is called a multicyclone. In cyclones with tangent inlet, the polluted gas enters through the central part, from which it is divided into individual cyclones arranged around the perimeter of the supply pipe (in the right part of Fig. 3 there is a multicyclone with tangent cells and Fig. 4 with axial cells).

Fig. 4 Group mechanical separator



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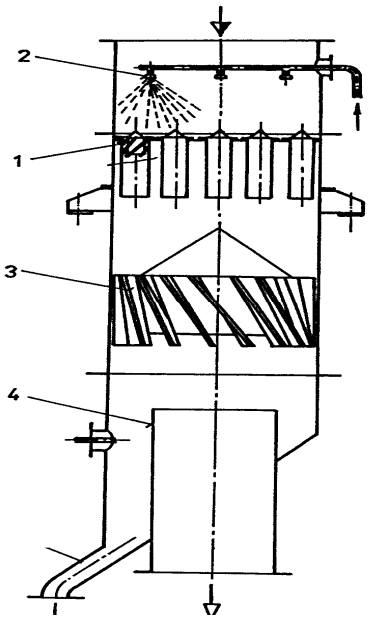
4. Wet mechanical separators

Liquids are used to capture or remove the captured particle from the separator. These are level separators with acceptable liquid consumption, Venturi washing machines with a large pressure loss, wet vortex separators and foam separators. These separators can usually also be used for the absorption of gaseous pollutants from waste gases.

Wet vortex separator

Unlike dry vortex separators, dust that has reached the wall of the separator is rinsed from the walls in a wet vortex separator by spraying them with water **2** around the perimeter at the top of chamber **1, 3** (Fig. 5). A droplet separator is installed above the water sprinkler.

Fig. 5 Wet vortex separator



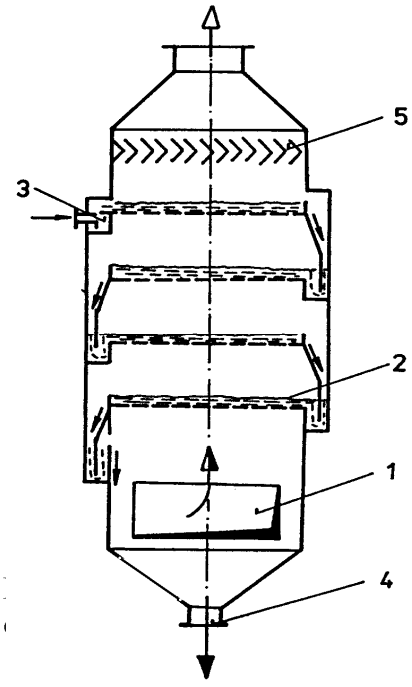
The separated dust forms sludge, which is drained through the neck at the bottom of the separator. Specific water consumption is 0.1 – 0.4 $^{kg.m-3}$, gas speed 4 m.s-1. The concentration of dust in the incoming gas for this kind of separators should not exceed 30 $^{g.m-3}$. The gas is discharged through pipe.

Reducing the diameter of the centrifugal chamber leads to an increase in separability. To cope with large flows, the individual separation elements are again sorted into assemblies.

Wet foam separator

The gas enters the separator from the bottom **1** and flows upwards through the grates, to which liquid, most often water, is supplied. Water is fed into the inlet chamber situated at the upper grate **3** and overflows through the holes in the grates **2** on the lower floors. Water with separated dust flows through pipe **4** into the sludge tank, where the sludge is drained after settling and water cleared of most of the trapped dust overflows through the pipes. The withdrawn water droplets are collected from the purified gas in droplet separator **5**, which is located at the top of the separator. The separator with four floors is shown in Fig. 6.

Fig. 6 Foam separator



Foam separators can have a double arrangement. They are either drop or overflow. Sinks are formed by a grate that passes liquid through its holes into the settling tank. In addition to the grate, similar to the absorption columns, the overflow towers also have a plate of dishes, through which part of the liquid falls into the sump or onto the next floor.

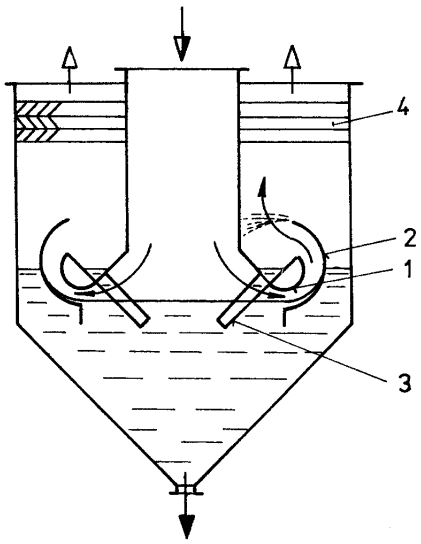
Foam separators show high pressure losses, which reach about 300 Pa per floor. The linear velocity of the gas is about 2 $^{m.s-1}$. The limit of separation of particles on one floor is about 1.5 µm and this value decreases with increasing number of floors. The specific water consumption depends on the input dust concentration. For concentrations up to 30 $^{g.m-3}$ is about 0.3 kg.m-3, for higher concentrations up to 0.6 kg.m-3.

Foam separators are suitable for wetting dusts, not suitable for cementing dust.

The advantage of foam separators is a relatively high input concentration of dust in waste gas (up to about 500 $^{g.m-3}$). The disadvantages are the small range of gas flow, which is in the range of about 20 % of the value for which the separator was designed and high pressure drop.

4.1.1.4 Surface separators

Fig. 7 Surface separator



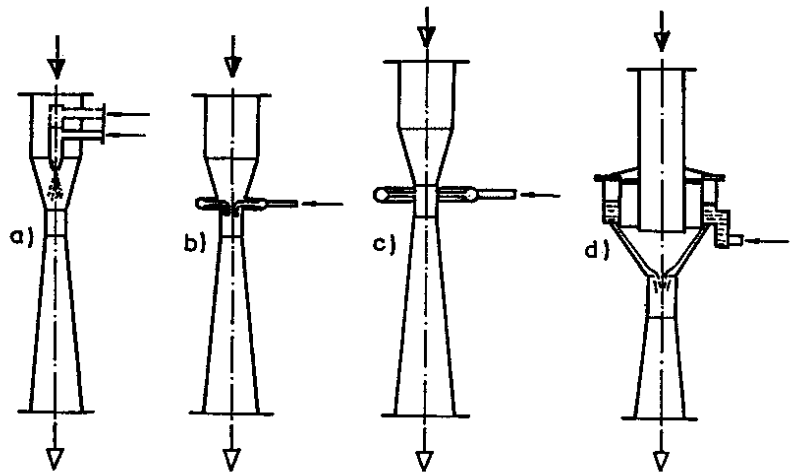
According to the design, they are divided into separators with perpendicular and tangent gas supply. An arrangement with a perpendicular gas supply (fig. 7) against the liquid level is less common. More often, level separators with tangent gas supply are used. The polluted gas is fed above the liquid level

and flows at high speed through the slot formed between the surface and the guidance blades **1**. The gas pulls liquid from the surface and in the space between the guidance blades **1** and the rectifier blades **2** there is an intensive mixing of particles and the resulting water fragmentation. Particles that have not separated already during passage through the slot and in the space between the blades are separated by passing through a water curtain on the outlet edge of the blades and, together with the liquid, flow back into the tank through channel **3**. The torn drops are separated in a drop separator **4.**

Level separators have a high separation even for small particles, the separation limit reaches values of about 1 µm. The pressure drop of the level separators is high, around 15 kPa, and is little dependent on the change in the volume of gas flowing. The correct operation of these separators depends on the height of the level setting.

4.1.1.5 Stream separators

Fig. 8 Separator Venturi



They have the highest separation from wet mechanical separators, but also large pressure losses. Separation occurs by inertia due to the high relative velocity between the polluted gas and the liquid that feeds into the neck of the venturi tube. The liquid supply can be solved in different ways (fig. 8). In Fig. 8a, the liquid is fed through an axially placed nozzle, in Fig. 8b the nozzles are inserted into a wreath located directly in the venturi neck and in Fig. 8c into a wall in the neck in a plane perpendicular to the direction of flow. In Fig. 8d, the liquid flows freely along the wall of the tube and is pulled down by the flowing gas when it enters the narrowed neck. The speed of the gas in the throat is high and reaches up to 100 $^{m.s-1}$. The dynamic effect of the gas stream is the fragmentation of the liquid into droplets up to several µm in size, which are able to separate even

submicron particles. Further separation occurs in the diffuser part of the tube due to high turbulence of the gas stream.

The high separation efficiency results from the perfect dispersion of the liquid over the cross-section of the venturi tube, which can only be ensured with smaller tubes. With increasing dimensions, the separability decreases. Therefore, small tubes are used, but in a group arrangement.

The consequence of high gas velocities in the throat is also a high abduction of the liquid phase, which is separated in the droplet separators installed at the gas outlet from the separators.

The disadvantage of current separators is the high pressure losses, which reach 5 – 10 kPa when separating the smallest particles with a size of several tenths of µm. Specific water consumption is within the limits of 0.7 – 2 l.m-3 of gas and specific energy consumption is up to 5 kWh per 1000 m^3 of gas.

4.1.1.6 Sludge management of wet dust collectors

Wet separators are based on the principle of wetting dust with liquid, so it is necessary to separate the separated dust from the liquid. Sludge management is used to separate the sludge from the liquid. Sludge settling is carried out in sludge tanks , at the bottom of which separated dust settles, which is removed from the bottom by a digging device. From the top of the settling tank, water falls into the recycling tank, from where it is fed by pump back to the separator. Water losses by evaporation and in the drained sludge are covered by the addition of additional water.