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Study material II.

Filters
Electrostatic separators

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1. Filters

The basis of filtration is the separation of particles in the filter layer. For filtration, fibrous layers are most often used, but also granular or porous masses. Waste gases pass most often through the fabric. Larger particles do not pass through the hole in the fabric and get caught on its surface. On the surface of the fabric, a filter cake is formed, which in itself forms a filter layer.

The flow rate of gas containing TZL through the filter material is controlled by:

- the sieve effect of a filter layer which does not pass through particles larger than the diameter of its pores;
- inertia and diffusion. Separation takes place on the surface and inside the filter layer;
- when the filter layer is thicker or the fabric is filled with dust, a layer of dust is formed on the front surface, which in itself forms a filter layer;

Filters for the separation of solid particles from waste gases are divided into filters for atmospheric air filtration and industrial filtration. While atmospheric air filtration is used for ventilation, air conditioning and for dedusting of the working environment, where dust concentrations are small (of the order of $^{mg.m-3}$) and filter fabrics are not regenerated, dust concentrations in industrial filtration are in the order of tens of g.m-3. A layer of dust trapped on the filter is quickly formed and it must be regenerated. Several different principles are used for regeneration (reverse flow of purified gas, pressure surge of air, burring). The individual principles of regeneration correspond to the different design of the filters, especially the gas supply and the fabrics used.

2. Filter materials

Filter materials are divided into three groups. These are filter cloths, granular layers and porous masses.

Most often, filter cloths are used, which are made either by weaving or by needle-punching. Most filter materials are produced by needle-punching. Woven fabrics are mainly used for separation at high temperatures.

Fabrics can be made of natural or synthetic fibers, porous fabrics made of plastics or metals, and granular fabrics. The most commonly used filter materials are wool and cotton, plastics are polyamides, polyesters, expanded polytetrafluoroethylene (e-PFTE), glass, etc. Filter cloths differ mainly in the environment in which they are applied, most often in temperature, as shown in Table 1:

Table 1: Examples of heat resistance of some filter materials

Materiál	Temperature [°C]
PVC	40 – 50
cotton	75 – 85
wool	80 – 90
polyamide, polypropylene	75 – 90
polyester	150
Teflon	200 – 280
glass fibres	250 –300
metal fibres	>300

The basic properties of filter materials are:

- structure
- porosity
- fineness
- strength;
- malleability;
- ductility
- resistance to temperature and chemical exposure to both dust and gas

The main operational characteristics of filter materials are:

- permeability
- specific load of the filter cloth
- separation
- poignancy

Breathability is a property by which the specific flow of textiles is expressed when the pressure drop Δp of 200 Pa is reached. For most needle-punched textiles, it reaches values of the order of hundreds of l.m-2 .$^{s-1}$. It is necessary to distinguish from breathability the concept of specific load of the filter fabric (expressed in m 3.m-2.s-1), which expresses the recommended value of the specific flow of gas through the fabric at steady state at normal pressure losses.

These properties of filter materials are interrelated and change over time. The amount of dust collected on the unit area increases with time, thus increasing the pressure loss against the gas flow Δp and increasing separability. Separation (η) is defined as the difference between the input (x) and output concentration (y) in the waste gas related to the input concentration (x):

$$\eta = \frac{x - y}{x}.$$

The absorption of the filter material is the amount of dust that the filter area unit holds at the maximum load-bearing pressure drop Δp.

Porosity means the volume of pores to the total volume of the filter mass. The separation of TZL on the filter can be increased:

- by reducing the diameter of the fibers;
- by reducing porosity;
- by increasing the thickness of the filter mass on the filter.

3. Design of filters

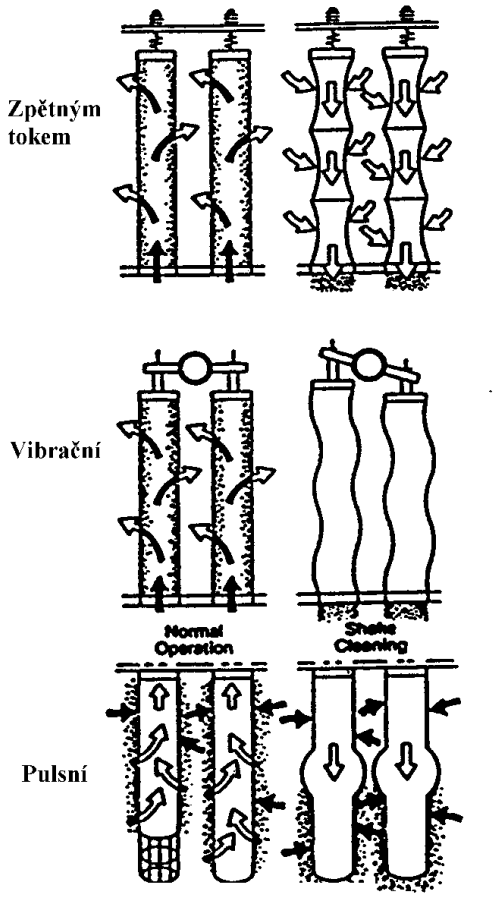
The design of industrial filters depends on the type of material used and the method of regeneration. The filter surfaces of fabric filters are arranged in the form of hoses or deep pockets. Accordingly, we distinguish filters into hose or pocket filters. Furthermore, when using granular materials, we are talking about filters with a granular or porous filter layer.

The basic methods of regeneration for hose or pocket filters are backwash or pulse blow. In the case of hose filters, backwash regeneration can also be combined with mechanical methods such as oscillating movement of hoses in the longitudinal direction or shaking in a plane perpendicular to the hose axis. Individual methods of regeneration of fabric filters are shown in Fig. 9. Regeneration is carried out only after a certain value of pressure loss has been reached, which is considered unacceptable.

Hose filters are arranged in several separate chambers of square or rectangular cross-section, and these chambers are connected in series. From the common supply pipe, each chamber has an air supply through a hopper. The hopper is a common trough, inside equipped along the chambers with partitions. The separated dust is removed by a screw conveyor installed along the entire length of the trough hopper. Each chamber has its own outlet of purified gas into a common outlet pipe. To

ensure regeneration by backwashing, closing and suction flaps are placed on the outlet pipe from the chambers. The flaps in each chamber are coupled so that when the gas supply is closed, the regenerative air supply opens at the same time. After passing through the chamber, the regenerative air is distributed to the other filtering chambers through the chamber hopper and the common pipe.

Fig. 9 Regeneration of filter



In the case of backwash filters with automatic intake of atmospheric air, a minimum vacuum in relation to the atmosphere, generally the same as the pressure drop of the filter, must be provided at the filter inlet for the correct functioning of the regeneration.

The diameter of the hoses is different for filters, most often 140 – 250 mm. The maximum length of the hoses can be up to about 10 m and the limiting factor here is the pulling out of the hoses and the subsequent poor regeneration function.

The pressure drop of back-flush hose filters depends on a number of factors. With a suitable choice of specific load on the fabric and the regeneration cycle, losses of 800 to 1500 Pa are usually achieved. For higher volume flows, filters in a circular arrangement can be assembled into filter stations. Lower pressure losses of hose filters are achieved during the application of pulse regeneration, when the pressure loss is up to 50% lower than in back-flush filters. The disadvantage is the reduced service life of the fabric as a result of increased mechanical stress.

Pocket filters, compared to hose filters, have less space requirements. The disadvantage is the need to use stiffeners, which are inserted into the pockets from the side of pure gas. Pocket filters can be easily assembled into filter stations, the recommended pressure drop is 800 – 1400 Pa and the specific load of the fabric is about 1 m 3.m-2. $^{min-1}$. At these values of specific load on the fabric and at gas filtration rates of 1 – 2 $^{cm.s-1}$ and dust concentrations up to 100 g.m-3, concentrations of < 1 mg.m-3 can be achieved for $^{non-stick}$ dusts. Regeneration is carried out by back flushing and, more recently, by pulse blow.

The separated dust falls into the separator hopper, from where it is drained for use or disposal.

In recent years, filters with a granular layer, such as sand or dolomite, have also been used. These filters can be used up to temperatures of about 500 ^{o}C and their pressure loss is 800 – 1400 Pa and is comparable to fabric filters.

When using filters made of sintered porous layers, their surface is covered with a thin porous Teflon membrane to increase separability and facilitate regeneration. The filter layer treated in this way has a higher initial loss compared to filter textiles. Particle separation occurs only on the surface of this layer, and the increase in pressure loss is no longer so pronounced, which is comparable to fabric filters.

Porous sintered layers are thick from a few mm to about 1 cm and the filter surface is arranged in different shapes. The so-called candle filters are assembled from separate pipes of larger diameters, plate filters are then assembled from interchangeable plates with an area of up to several m^2, which are mounted at certain distances next to each other. Regeneration is carried out by pulse blow.

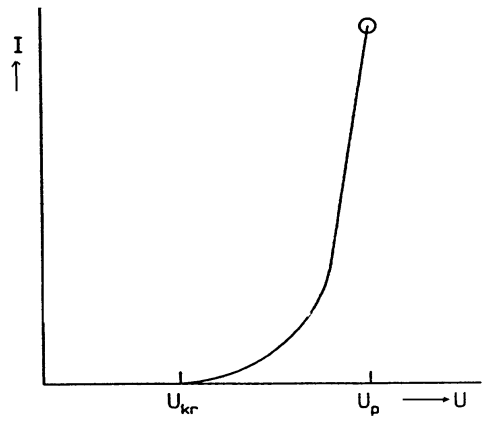
4. Electrostatic separators

Electrostatic separation of dust from waste gases consists in the use of attractive forces between electrically charged dust particles and the oppositely charged precipitation (collecting) electrode. The charge of the particles is achieved in an electrostatic field, in which the charge carrier is the ions of ionized gas. The basic functional components of the electric separator are:

- a rechargeable (or hornet) electrode with a very small area;
- a precipitation electrode with a large area through which charged particles surrender their charge, settle on it and thus separate from the gas flow;
- and are stored in a common cabinet, most often made of structural steel.

By gradually increasing the voltage inserted on the charging electrode, an electric current (the so-called corona) begins to pass through the electrode at its critical value U_{kr}. This current increases up to a critical value (U_p) (see Fig. 10), at which a jump occurs and at which the corona can no longer be formed. The critical voltage that can be inserted on the electrodes depends:

Fig. 10: VA charakteristics



on the composition of the gas passing through the separator;

- radius of the ionization electrode;
- partly also at electrode distances.

To ensure reliable operation of the electro-separator, a stable corona is required, which is a source of ions. The higher the voltage inserted on the electrodes (55 – 75 kV), the better the separation

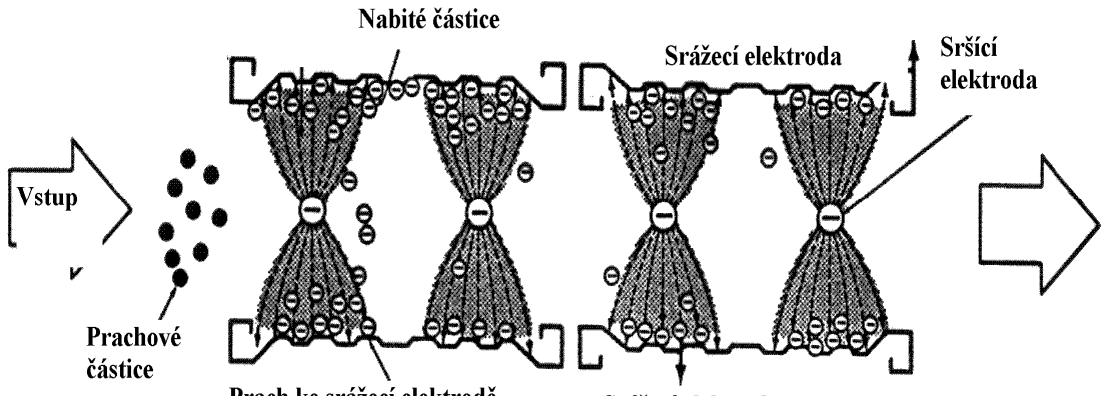
efficiency. The stability of the corona is conditioned by the small surface area of the charging electrode and the negative voltage inserted on it.

Large particles that have a larger dielectric constant than gas put less resistance to the flow of electric current. The field lines are concentrated in them, as are the gas ions. They pass on their charge to the particles and thus charge them. Small particles are charged mainly by diffusion. Electrically charged particles are attracted by a precipitation electrode that surrenders its charge. The principle of the electrostatic separator is shown in Fig. 11.

The charging electrodes are connected to a high-voltage source. Mostly they consist of wires of small cross-section, the shape of which can be round, square, rectangular or asteroid. The charging electrodes are tensioned with weights or clamped in frames. The distance between the electrodes is 15 – 20 cm depending on the spatial location of the precipitation electrodes.

Collecting electrodes are most often plate structures, the electrode has the shape of a wall. They are suitably profiled so as not to tear the separated dust into the purified gas. The plates are placed in rows at a distance of 30 – 40 cm. Precipitation electrodes must be fitted with a device to remove separated dust from the surface of the precipitation electrode. This is done most often by shaking with the help of hammers located on the shaft with an eccentric that releases the hammer and it falls on the plate of the precipitation electrode. The size of the hammers depends on the specific purpose of the application and on plate sizes. The released dust falls into a prism-shaped hopper, from where it is taken to the feeder for final storage or processing.

Fig. 11 Electrostatic Separator



Another arrangement has tubular collecting electrodes. The hornet (charging) electrode again in the form of a wire passes through the center of the pipe, the separated dust settles on the inner surface of the pipe.

1.1.1 Selection of the size of the electro-separator

The size of the separator depends on the required output concentration, which is most often taken into account as the separation efficiency. The dimensions of the separator are determined by the required separation area. The relationship between the efficiency of the electro-separator and its size is expressed by the Deutsch-Anderson equation:

$$\eta = 100\,\frac{C_p - C_k}{C_p}$$

$$1 - \eta = e^{\frac{-\omega A}{V}}$$

$$A = \ln\frac{1}{1-\eta} * \frac{V}{\omega},$$

kde: η je separation efficiency, [%]

ω migration rate, [$m.s^{-1}$]

A separating area, [m^2]

V gas flow, [m^3s^{-1}]

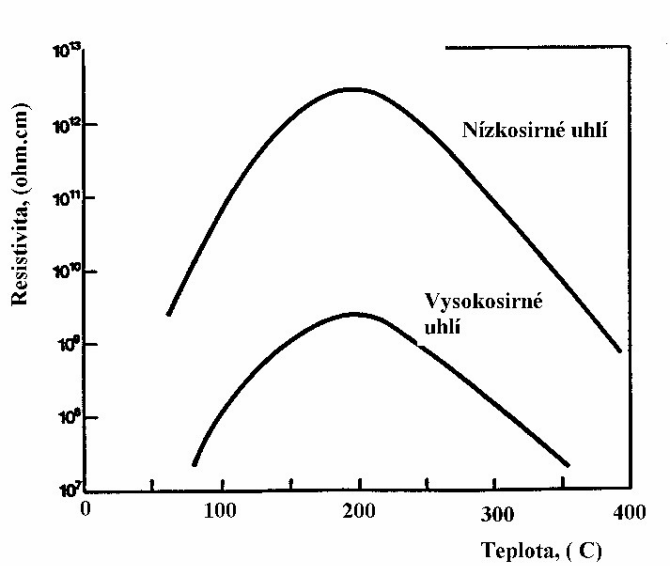
The migration rate ω is theoretically the average rate at which an electrically charged particle reaches the surface of the precipitation electrode. This speed depends on how easily the particle is charged. The value shall be chosen empirically on the basis of experience. The factors influencing the migration rate depend on the quality of the fuel and fly ash itself, on the operating conditions and on the distribution of the flow of the flowing gas.

These factors also affect the ability of the particle to receive charge. It is normally expressed by resistivity expressed in Ω.cm. Fig. 12 shows typical curves of the resistivity of two fly ashes. The high resistivity of fly ash results in a low migration rate and requires a separator with a large separation area, while the low resistivity leads to less need for a separating surface. The limit of the resistivity from which the choice of the size of the separation area depends solely on experience is considered to be 10^{10} Ω.cm.

The above example shows that the specific resistance of fly ash that low-sulfur fuels have is high, while fuels with a higher sulfur content have a lower resistivity. Coals with a higher sulphur content also have a higher sulphur oxide content in the flue gas (in the case of coal, about 1% of the total sulphur oxide content in the flue gases), which has a positive effect on the separation in the electric separator. As well as the sulphur oxide content, the higher content of water vapour in the flue gases

has a positive effect on separability. To improve separability by adding these compounds, the term "conditioning" of flue gases is used

Fig. 12 Dependence of resistivity of ash



1.1.2 Arrangement of electro-separators

The most common arrangement is cabinets oriented horizontally to the direction of gas flow and with plate collecting electrodes mounted vertically. The deposited dust is removed from the surface of the electrode by shaking. The electrodes are arranged in 2-5 sections, each of which is independently supplied with direct current. One section is selected for the reserve in the event of an outage of any of the sections in order to comply with the prescribed value of the emission limit. Vertical separators are built exceptionally, e.g. for gases with high temperatures or where necessary for distribution reasons. They are mostly made of structural steel.

Electrostatic filters are built for large waste gas flows. They are constructed with separation areas from 100 to 15000 m^2 and for the size of the separated particles 0.01 - 60 µm. The progressive rate of flue gases is up to 0.2 $^{m.s-1}$ and the pressure loss is low about 20 – 50 Pa. They are suitable for

separating dust from waste gases up to temperatures of approx. 380 ˚C. Separation efficiency often exceeds 99.9%

Electrostatic separators in the power industry for the separation of fly ash from coal combustion and for the separation of soot from mazut boilers have been the most widespread. Furthermore, in cement plants, metallurgical industry, waste incinerators, especially municipal, in the wood industry and other industrial activities, such as in the production of paper and cellulose for dedusting so-called regeneration boilers. In regenerative boilers, they capture small particles, mostly of a sticky character. Their resistivity is low and therefore it is easier to remove them from waste gases. Due to the small particle size and the possible entrainment of separated particles when knocking off precipitation electrodes, greater attention must be paid to the design of the separator. The entrainment of the separated particles is eliminated by the lower progression rate of the gases by the separator and the shape of the collecting electrodes. The achieved separation is lower than other types of dust and is 99.7 – 99.8%. Corrosion is also more significant here.

Electric separators have seen significant development in recent decades. High reliability was achieved due to the development of new efficiently operating sources of very high voltage with minimal failure rate. This allowed them to be used as a single separation stage, i.e. without pre-separators, most often cyclones, as was the case thirty years ago (e.g. in the power industry for ash separation).

1.1.3 Wet electric separators

It is usually used to separate aerosol particles, e.g. sulfuric acid aerosol. Unlike sulfur dioxide, which is easily absorbed in alkali-reacting solutions, sulfur trioxide when passing through water forms an aerosol that passes through the absorption stage unchanged. This deficiency can be solved with the help of wet electric separators.

These are distinguished from dry conventional electrical separators mainly by the materials that were used for their construction. They are usually operated at temperatures close to the dew point and the content of solid pollutants or aerosols is low compared to fly ash separation during coal combustion. Materials must withstand corrosive environments. Charging electrodes are usually constructed from a special alloy Alloy 276, precipitation electrodes again from Alloy 276, in the case of steel protected by a layer of lead. The other parts of the separator are most often protected by lead, after which acid-resistant linings or acid-resistant resins are the case.

Instead of shaking, the separated particles are removed from the surface of the precipitation electrodes by spraying them with water. Compared to dry electro-separators, these devices are small, large ones are an exception. Large devices usually consist of several modules. The separation efficiency is about 99%.