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The Comparison of Potential Use of Electric Filters with Bifilar Winding and Discharge Filters

Abstract. *The fabric filter represents the contamination removal technology with theoretically warranted contamination removal efficiency of 100%. The problem consisting in the periodical shutdown of filters has been eliminated in case of electrofilters. The continuous occurrence of an electric discharge or its possibility is assumed in course of the operation of electrofilters. The results obtained from the tests demonstrated it is possible to achieve the dedusting efficiency above 98% in case of bifilar filters which can be considered as a solution competing against the discharging filter.*

Streszczenie. *Filtr tkaninowy to technologia usuwania zanieczyszczeń teoretycznie gwarantująca 100% skuteczność usuwania zanieczyszczeń. Problem okresowego wyłączania filtrów wyeliminowano w elektrofiltrach. W trakcie pracy typowych elektrofiltrów zakłada się ciągłe występowanie lub możliwość wystąpienia wyładowania elektrycznego. Wyniki badań wykazały, że w przypadku uzwojeń bifilarnych możliwe jest uzyskanie skuteczności odpylania powyżej 98%, co pozwala na rozpatrywanie filtru bifilarnego jako konkurenta dla standardowego elektrofiltru wyładowczego. (**Porównanie możliwości wykorzystania elektrycznych filtrów z uzwojeniem bifilarnym i wyładowczych**).*

Keywords: electrostatic precipitator, electrofilter, bifilar filter.
Słowa kluczowe: odpylacz elektrostatyczny, elektrofiltr, filtr bifilarny.

Introduction

Several significantly diversified dedusting technologies have been already developed (Fig. 1). The operation principle of a large group of separators and dedusters is based on the gravity or inertia. These solutions are called cyclones or centrifuges. The gas containing the contaminants is set in rotation inside a cylindrical container. The particles of contaminants with the mass greater than the mass of gas particles are thrown out of the gas stream, collected on the container walls and are removed therefrom. Practically it is impossible to use the inertial separators in case of dust particles with diameter under 10 μm [6, 9].

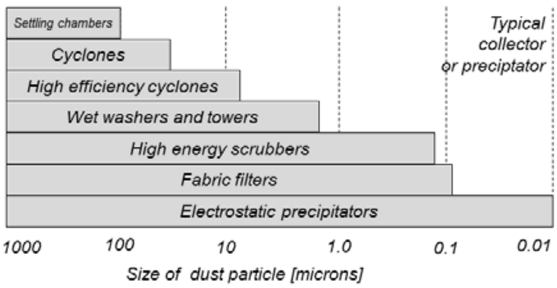

Fig.1. Separation methods and size of particle of dust [9]

„Wet" dust separators are called scrubbers. The gas containing contaminants is supplied to the container and brought into contact with turbulent flow of liquid. Most frequently water is used for this purpose. The particles of contaminants contacting with liquid increase their mass. The particles of contaminants with the mass greater than the mass of "clean" air particles can be eliminated from the air stream by means of inertia methods [9, 13].

In fabric filters, the gas containing the particles of contaminants flows through a porous membrane. The particles with diameters greater than the diameters of openings in porous material should be completely eliminated from the gas being filtered. However the layer of contaminants collected on the filtering "fabric" is problematic. This layer should be regularly removed in order to prevent the occurrence of hydraulic drags [7, 9].

The electrostatic precipitators are free of the disadvantages of inertial separators, wet scrubbers or fabric filters. They can be applied for all diameters of contaminants particles at temperatures higher than 850°C.

Discharge Electrofilter

The discharge and collective electrodes are the principal elements of the discharge electrofilter. One or more ionising electrodes is/are provided on the filter inlet or inside its chamber. A corona discharge is induced in the vicinity of the electrode owing to its high potential. The ionised contaminants particles are moved to the area influenced by the collective electrodes. Thanks to the influence of the electric field of collective electrodes, the ions of contaminants particles are attracted to electrodes (Fig. 2). There are various methods of the removal of contaminants collected on electrodes. The typical method of dusts removal consists in the use of impact mechanism through the striking the electrodes. The operation of discharge electrodes is possible at negative and positive polarization of discharge electrode [3]. In order to maximize the ionisation effect, the efforts are made to achieve the maximum values of electrical field intensity. If the limit value of voltage is exceeded for a specified configuration of electrodes, the corona discharge becomes a spark discharge. The electrofilters constitute the most efficient group of industrial dust separators in case of dusts with particles diameters under 0.5 μm.

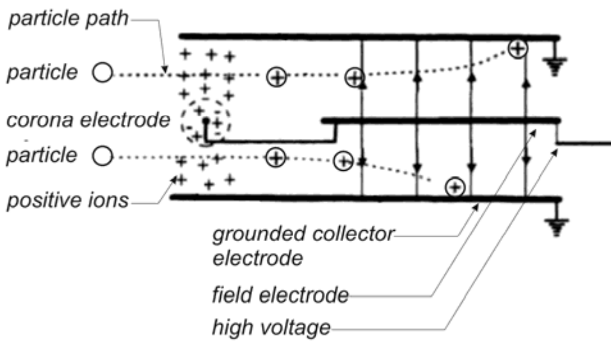

Fig.2. The principle of functioning of discharge electrofilters [3]

The force F_{el} resulting from the particle charging in the course of its movement through an ionised area can be estimated on the basis of the equation (1). Cochet model [4, 9] has been used to calculate Q_p charge. The square of electric field intensity (E) belongs to the factors affected by the filter designer.

(1) $$F_{el} = Q_p E = \left\{ \left(1+\frac{2\lambda}{d_p}\right)^2 + \left(\frac{2}{1+\frac{2\lambda}{d_p}}\right)\cdot\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right) \right\} \pi \varepsilon_0 d_p^2 E^2$$

where: F_{el} – electric force, N; Q_p – particle saturation charge, q; ε_0 – permittivity of vacuum (8.85·10^{-12} F·m^{-1}); ε_r – relative permittivity of attracted dust particle, λ – mean free path of the molecules, m; d_p – particle diameter, m; E – electric field strength, V·m^{-1}.

Bifilar Electrofilter

The lack of inductivity is a characteristic feature of the bifilar winding. This effect is achieved thanks to the windings arranged in an alternate layout [12]. In order to ensure safe operation of the dust separating device, the voltage applied to the winding must be much lower than the value of insulation breakdown voltage. Then an electric field will be generated by the filter without discharges. If the winding will be supplied with the voltage not causing any corona discharges, it is possible to introduce the filter into agricultural and food sector with prevailing flammable and explosive organic dusts.

The organic dusts are classified in dielectrics category. Their particles usually consist of symmetrically arranged charges. The particles demonstrate the presence of electric moment under the influence of the field. As a result of mutual influence between the electric field generated by electrodes and dielectric charges of the dust, electric field force is generated and attracts the particle (Fig. 3). Even in an alternating electric field the changes of the polarization of charges on the surfaces of dust and insulation particles follow the field changes, therefore the constant direction of force is maintained.

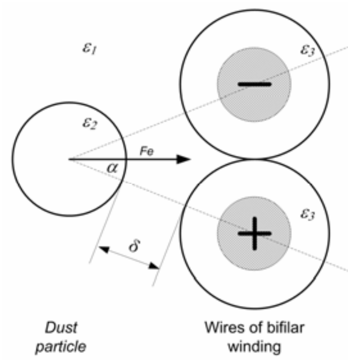

Fig.3. Typical arrangement for dielectric particle attraction force calculation [12]

The value of the force acting on the dielectric dust particle can be described by means of the following equation [7]:

(2) $$F_e = \frac{\varepsilon_0 \varepsilon_1 U^2 S_{ef} \cos\frac{\alpha}{2}}{\left(2\delta + 2l_3\sqrt{\frac{\gamma_1^2+\omega^2\varepsilon_0^2\varepsilon_1^2}{\gamma_3^2+\omega^2\varepsilon_0^2\varepsilon_3^2}} + l_2\sqrt{\frac{\gamma_1^2+\omega^2\varepsilon_0^2\varepsilon_1^2}{\gamma_2^2+\omega^2\varepsilon_0^2\varepsilon_2^2}}\right)^2}$$

where: F_p –particle attraction force, N; ε_0 – permittivity of vacuum (8.85·10^{-12} F·m^{-1}); ε_2 – permittivity of attracted dust particle, ε_3 – permittivity of bifilar winding insulation, l_2 – distance between the dust particle contact points and the opposite windings, m; l_3 – bifilar winding insulation thickness, m; S_{ef} – the mean value of the section area of the electric induction transfer a through dielectric particle, m^2; α – half of the angle outlined by the centres of windings and the centre of a dust particle; U – voltage, V.

Dielectric particle attraction force (F_p) is affected by three groups of parameters. The first group consists of geometrical and material parameters of the filter system. The dimensions and dielectric permittivity of dust should be specified in the second group describing the parameters of dust particles. The third group of parameters refers to the power supply method. Similarly to the discharge filters, the force acting on the particles is proportional to the square of the field intensity [9].

The Comparison of Electrofilters Features

The discharge electrofilters have been commonly used for almost 100 years but on the other hand, 10 years have elapsed since the implementation of the bifilar winding concept as filtering device.

Similarly to the different service lives of the both filters, the both types of filters differ in their scale. To the best knowledge of Author of the present paper, there are two functioning bifilar filters. One of them is operated in a laboratory scale and is made of mineral glass. This filter incorporates a filtering chamber about 0.5 m long [11]. Another solution has been built in a pilot plant scale and consists of standard ventilation profiles made of steel at complete length of filtration system equal to about 1.0 m [10, 12] (Fig. 4).

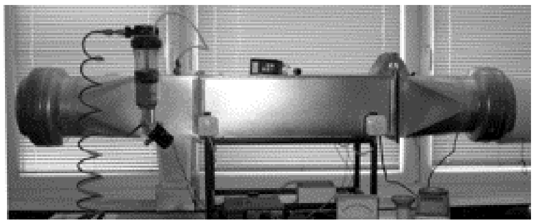

Fig.4. Bifilar filter built in a pilot plant scale [10]

The value of stream of the gas being filtered is an essential parameter describing the separator operation. The linear velocity of gas in combination with overall dimensions of filtration chamber can be used optionally. The discharge filters are operated in a wide range of linear velocity of gases. The values available in reference books are equal to 0.4 up to 3.5 m·s^{-1} [2]. The industrial electrofilter is operated with the exhaust gases stream velocity in electrofilter variable between 0.5 and 1.2 m·s^{-1}. Another range of permissible velocities of the gas stream is determined on the basis of a practical test carried out with a bifilar filter built as a pilot plant (Fig. 4). The value of efficiency is reduced to 91.4% in case of the stream velocity exceeding 0,3 m·s^{-1}.

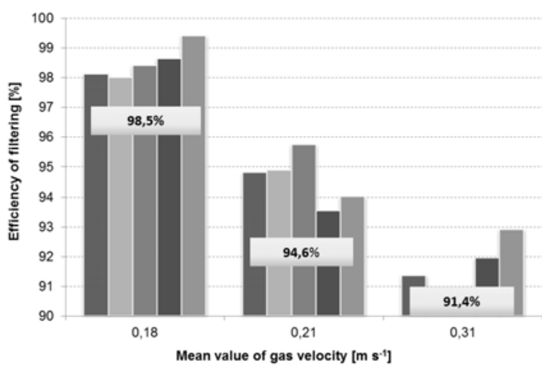

Fig.5. Efficiency versus gas velocity (13 kV, 0.5 mm^2) [10]

The discharge electrofilters can be supplied by DC and AC power sources. Other problems are associated with power input and with the shape of characteristic curves of power supply for the discharge electrodes. The industrial corona electrofilters are supplied with rectified AC power. The voltage of which is included in the range between 25 and 55 kV or even up to 100-120 kV [5]. The currents accompanying these voltages are equal to a few mA up to more than 10 A. A typical rated power of the cleaning assembly of ELWO filter ranges between 8-152 kVA.

The values of power supply voltages used for the bifilar filters are lower than those applied in industrial electrofilters. In case of flammable and explosive dusts it is necessary to prevent any disruptive discharges and spark passages. The practical limit is established as the value of cable insulation breakdown voltage. In order to prevent the insulation breakdown, one half of the value of individually determined real breakdown voltage i.e. 13 kV has been applied in practical tests.

The bifilar winding can be supplied by means of a DC source only. Additionally a capacitor system with significant capacitance is created by individual coils of bifilar winding. The practical tests demonstrated that, in particularly unfavourable configurations, when a sinusoidal voltage source is used, the operation of the system in pilot scale is possible with the current even close to 500 mA [10].

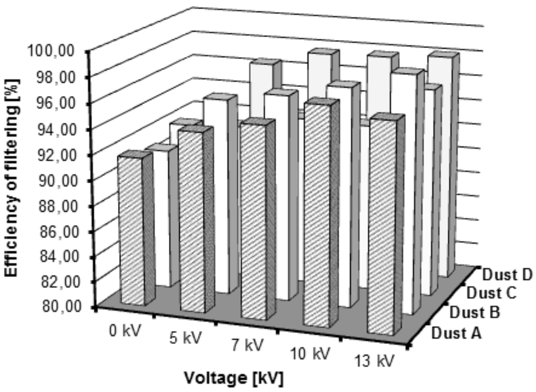

Fig.6. Average dedusting efficiency for bifilar winding made of wire with the cross – section of 0.5 mm^2

Owing to the necessity to apply the system with the highest intensity of electric field (Eq. (1), (2)) and consequential necessity to use DC voltage with the highest value as the power source for the winding in a manner free of corona phenomenon and spark passages, the voltage of 13 kV was not exceeded in course of the measurements. The bifilar electrofilters under tests have been built on the basis of commonly available DY cables (copper wire with PVC insulation) with cross – section area of 0.5 mm^2. At linear velocity of air artificially contaminated with dust of plant origin equal to 0.18 m·s^{-1}, relative dust humidity of 9.4-15.7 %, ambient temperature of 20.6-23.2°C, air humidity of 26.6-31.1%, dedusting efficiency of the bifilar electrofilter was almost equal to 98% (Figs 5 and 6). It is the value lower than in case of industrial discharge electrofilters. Multi-segment structures of the discharge electrofilters make it possible to perform the cleaning process with the efficiency of 99.5-99.9%.

Conclusions

1. The value of the electric field intensity resulting from the power supply voltage (Eq. (1), (2)) is a key factor determining the dedusting efficiency of discharge and bifilar filters. The voltages of discharge filters reach up to 120 kV. The voltages of bifilar filters are limited by the insulation breakdown voltage and were equal up to 13 kV in the course of tests.
2. In case of discharge electrofilters, it is possible to use DC, AC and pulse voltage sources as power sources. In case of bifilar filters only DC voltage supply is allowed owing to interwinding capacitances.
3. In case of comparable filters, the efficiency of 98 % was achieved by the bifilar filter. This filter should achieve the efficiency of 99.5-99.8% in order to compete with the discharge electrofilter. The dedusting efficiency almost equal to 98 % has been achieved at flow velocity of 0.18 m·s^{-1} i.e. lower than typical velocity for discharge electrofilters.
4. There are no coronary and disruptive discharges in the bifilar electrofilters. Therefore it is possible to use them in case of flammable and explosive dusts.
5. The same „impact” cleaning method can be used in the discharge and in the bifilar electrofilters [1]. However, it must be noted that such mechanical cleaning method can result in insulation damages and affect safety of service.

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