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The Influence of Construction of Bifilar Winding on Efficiency of Electrostatic Bifilar Deduster

***Abstract**. This paper presents a pilot scale version of the new construction of filter to remove pollution from the gas. The construction of the filter is based on the bifilar windings. The filter is designed for the removal dielectric dust particles from the air. A new chassis of bifilar winding is introduced recently. The most recent results of the filtering efficiency are presented in this paper.*

***Streszczenie.** W artykule zaprezentowano półprzemysłową wersję filtru nowej konstrukcji do usuwania zanieczyszczeń z gazu. Konstrukcja filtru oparta jest na uzwojeniach bifilarnych. Filtr zaprojektowano w celu usuwania cząstek zanieczyszczeń dielektrycznych z powietrza. W ostatnich testach wprowadzono nową ramę uzwojenia bifilarnego. W pracy zamieszczono najnowsze wyniki skuteczności odpylania zmodyfikowanego filtru. (**Wpływ konstrukcji uzwojenia bifilarnego na skuteczność elektrostatycznego odpylacza bifilarnego**).*

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

Introduction

There are two methods of the removal dust from the gas – dry and wet. In the group of the dry dedusters we can find mechanical dedusters and electroseparators. There are discharge electrofilters and bifilar electrofilters in the group of electric precipitators. Discharge electrostatic precipitators have been widely applied for dust collection [15].

The wires of windings are wounded alternately in bifilar separator. The neighbouring wires are connected to the opposite potential of a power source. The characteristic feature of this winding is the lack of inductivity [11, 12].

The dust particles are dielectric particles typically. The most of organic dusts are classified as dielectric materials. The electric charges are distributed uniformly in this kind of particles. The powered wires of bifilar winding are source of electric field. Under the influence of the electric field the distribution of the electric charges changes in the particle. It is possible to notice an electric moment under the influence of the field. The result of electric field influence on dielectric charges in the dust particle is an electric force. Generated electric force acts on the particle (Fig. 1) [5].

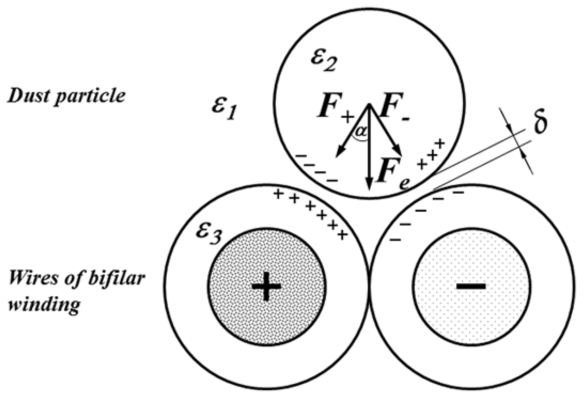

Fig. 1. Example of distribution of forces acting in a bifilar winding system [10]

It is possible to use DC and AC power source. In an alternating electric field the changes of the polarization of charges on the surfaces of dust and insulation follow the field changes. The direction of attracting force is constant. The precise calculation of the value of force is not easy [2, 14]. The attraction force depends on the intensity of the electric field and on free charge quantity that, in turn, depend on dust electric properties. The attraction force is influenced by the construction of the system of electrodes (diameter, distance between electrodes, dielectric permittivity and insulation conductivity) and dust particle parameters (dimensions, dielectric permittivity and conductivity) [5, 13].

$$F_e = \frac{\varepsilon_0 \varepsilon_1 U^2 S_{ef} \cos\frac{\alpha}{2}}{\left(2\delta + 2l_3\sqrt{\frac{\gamma_1^2+\omega^2\varepsilon_0^2\varepsilon_1^2}{\gamma_3^2+\omega^2\varepsilon_0^2\varepsilon_3^2}} + l_2\sqrt{\frac{\gamma_1^2+\omega^2\varepsilon_0^2\varepsilon_1^2}{\gamma_2^2+\omega^2\varepsilon_0^2\varepsilon_2^2}}\right)^2} \quad (1)$$

where: F_e – dielectric particle attraction force, N; U - voltage, V; α - half of the angle outlined by the centres of windings and the centre of a dust particle; S_{ef} – the mean value of the section area of the electric induction transfer a through dielectric particle, m^2; ω - pulsation of bifilar winding voltage, s^{-1}; ε_0 - permittivity of vacuum (8.85·10^{-12} F·m^{-1}); ε_1 - dielectric permittivity of environment, -; ε_2 – permittivity of attracted dust particle, -; ε_3 - permittivity of bifilar winding insulation, -; γ_1 – electric conductivity of environment, S·m^{-1}; γ_2 - conductivity of attracted dust particle, S·m^{-1}; γ_3 - conductivity of bifilar winding insulation, S·m^{-1}; δ - spacing between the dust particle and the winding, m; l_2 – distance between the dust particle contact points and the opposite windings, m; l_3 – bifilar winding insulation thickness, m.

Unlike the discharge electrofilters, bifilar electrofilters can operate without discharges. The voltage applied to the winding should be lower than the value of insulation breakdown voltage. It is possible to use this kind of the filter into agricultural sector because a bifilar winding is supplied with the voltage non causing any corona discharges. It ensures safe operation during removing flammable and explosive dusts from the air.

Test stand

The main part of electrofilter is a filter chamber. The bifilar windings are situated inside a filter chamber. The area of bifilar winding covers the cross-sectional area of the filter chamber at 80 %. The dust particles are attracted to the windings from the air stream flowing over the windings (Fig. 2).

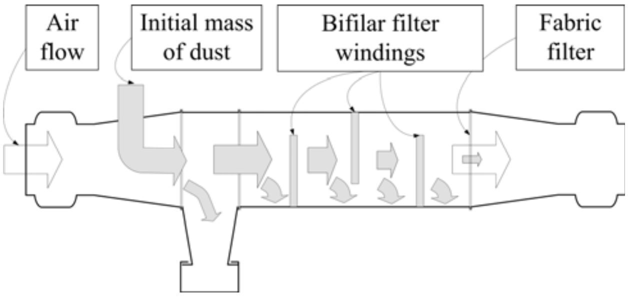

Fig. 2. Location of bifilar windings inside filter chamber [11]

There are three bifilar windings inside a filter chamber. In order to facilitate cleaning, the bifilar windings are connected together into a cassette (Fig. 3). The mounting method of winding allows changing angle of windings in relation to the air flow.

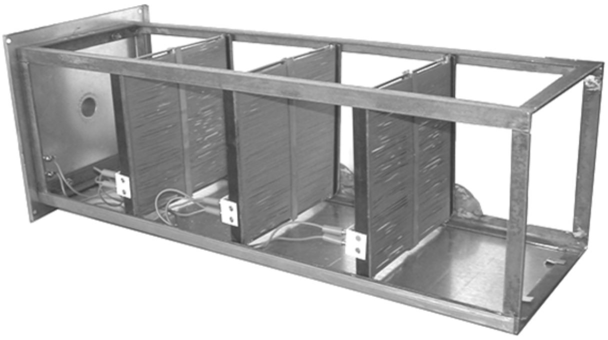

Fig. 3. Cassette with bifilar windings

A pilot scale version of filter chamber consists of standard ventilation profiles and it is made of steel. The complete length of filtration system is equal to about 1.0 m [10, 11]. The filtration cassette is placed inside a chamber (Fig. 4). The typical method of dusts removal consists in the use of impact mechanism through the striking the electrodes [4]. The „impact” cleaning method can be used in the bifilar electrofilters [1]. The frame of filtration cassette is so strong that it is possible to remove pollution using an “impact” method.

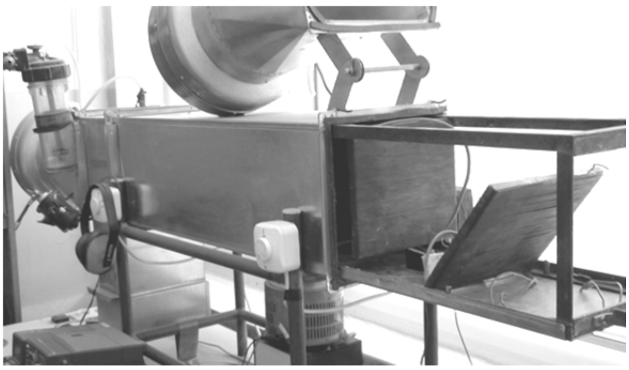

Fig. 4. Filter chamber equipped with cassette with bifilar windings

Two types of bifilar windings were utilized during filtration tests. First construction of winding was based on a bent copper pipe. The copper pipe was the backbone of the winding. The wires of winding were wound side by side (Fig. 5a). This construction is lightweight and even allows the flow of air between the wires of the winding. The disadvantage of the construction is moving relative to each other of the wires during exploitation of the filter (Fig. 5b). The resulting gap could lead to reduction of the dedusting efficiency.

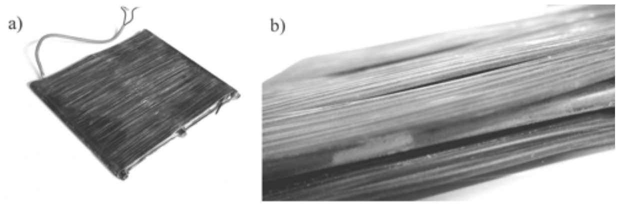

Fig. 5. Bifilar winding with a metal frame: a) general view, b) detail view

Because of windings deformation, a new construction of the winding is introduced. This construction of winding is based on an ebonite plate. The ebonite plate is the backbone of the winding. The view of winding is presented in Fig. 6a. This heavy construction is more resistant to damage. Even after many tests of dedusting of the gas and cleaning of the windings, bifilar windings wires are intact. There are not gaps between wires (Fig. 6b).

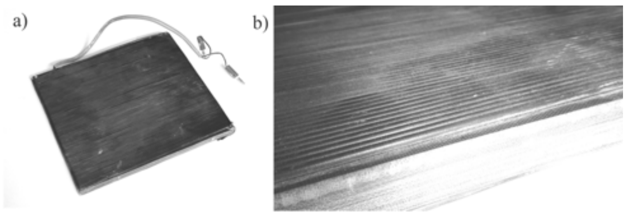

Fig. 6. Enhanced bifilar winding with a solid chassis: a) general view, b) detail view

The windings of bifilar filter are made by using typical electric wire. The wire has a copper core and insulation made from PCV. The wires have cross-section surface area equal 0.5; 1.0; 1.5; 2.5 i 4 mm^2. This paper presents the results relating to the cross-section surface area equal 1 mm^2.

Results

The dust samples are real dust obtained from “flour and pasta factory”. The samples are picked from the following places in the factory line: a porridge line (sample A); a pasta line (sample B), a flour line (sample C). The fourth sample (sample D) is dust on the basis a wheat flour. The relative moisture content of dust material is 11.4 %÷19.3 % at relative humidity 31÷51 % [10, 12].

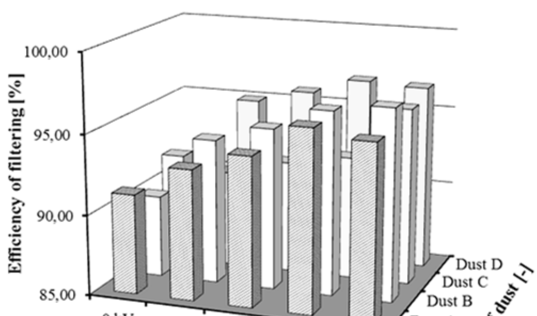

Fig. 7. Average dedusting efficiency for bifilar winding with chassis made of metal frame (wire cross-section 1.0 mm^2, gas velocity 0.18 $m \cdot s^{-1}$)

The temperature of air on the inlet of the chamber is 24.1÷27.1°C at air pressure 995-998 hPa. The air velocity is 0.18 $m \cdot s^{-1}$. The voltage of bifilar windings achieves value of 13 kV (maximal value for working without electric discharges in this configuration) [10, 12]. The following results are referred to the wire with cross sectional area of 1 mm^2 and gas velocity of 0.18 $m \cdot s^{-1}$.

The filter chamber without voltage captures 90.0-91.8% of pollutants. The dust falls down on the bottom of the chamber under the influence of gravity forces. The application of voltage increases removal effectiveness to 95.8-96.9%. The effectiveness increases together with the voltage increase. The most effective removal has occurred for the particles of dust of type B (Fig. 7).

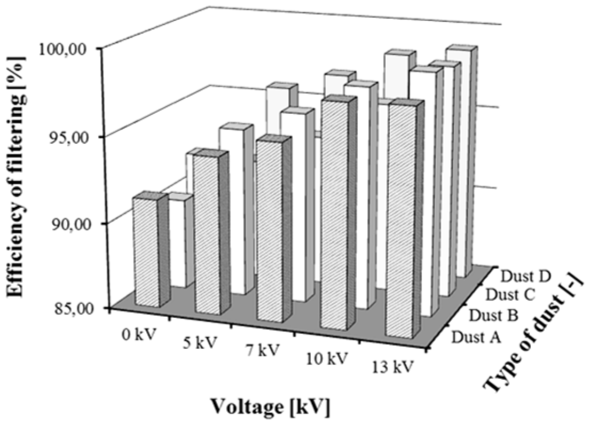

Fig. 8. Average dedusting efficiency for enhanced version of bifilar winding with chassis made of solid ebonite (wire cross-section 1.0 mm^2, gas velocity 0.18 $m \cdot s^{-1}$)

New filer cassette is equipped with bifilar windings with a solid ebonite chassis. After changing the filter set, a similar set of tests were carried out. The filter chamber without voltage captures 90.2-92.3% of pollutants.

The application of voltage increases dust removal effectiveness to 97.9-98.9%. As before, the effectiveness increases together with the voltage increase. As before, the most effective removal has occurred for the particles of dust of type B (Fig. 8).

The better bifilar filter efficiency increase can be caused by more effectiveness distribution of electric field. For the recognition of electric field distribution free available software package FEMM is used. This non-commercial product is widely used in magnetic and electric field simulation [3, 6, 8, 9].

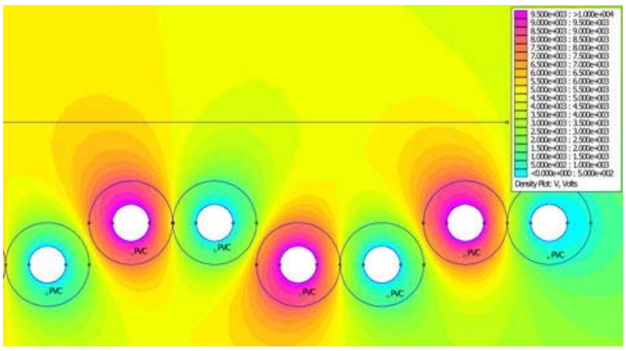

Fig. 9. Distribution of electric field intensity in bifilar winding with a metal frame (voltage 10 kV, wire cross-section 1.0 mm^2)

Two types of bifilar windings configuration are simulated. The first configuration is referred to bifilar winding with a metal frame. The view of this winding is presented in Fig. 5. A characteristic for this type of winding is the presence of winding gaps in the wire system. The distribution of electric field intensity in bifilar winding with a metal frame at 10 kV is shown in Fig. 9. A thin line above winding represents the artificial surface which can be used to analyse of the intensity of the electric field.

The intensity of the electric field at a distance of 5.5 mm above the bottom of winding was presented in Fig. 10. The intensity is changing according to the arrangement of wires. Electric filed intensity locally reaches value of $8 \cdot 10^6$ V m^{-1}.

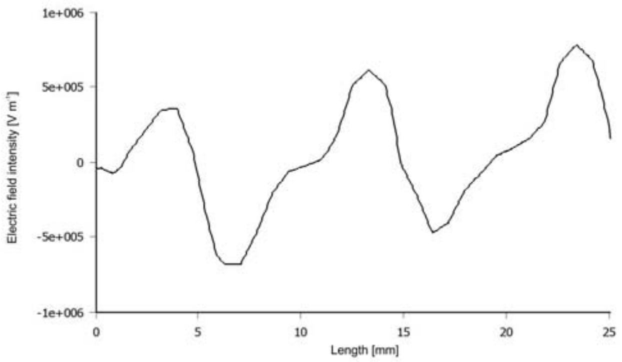

Fig. 10. Electric field intensity versus length - bifilar winding with a metal frame, voltage 10 kV, wire cross-section 1.0 mm^2

The second configuration is connected with winding with a solid backbone. A backbone is made of ebonite. The view of this winding is presented in Fig. 6. A characteristic for this type of winding is evenly, flat layout of wires. The distribution of electric field intensity in bifilar winding with a solid backbone at 10 kV is shown in Fig. 11.

A thin line above wires (used to analyse of the intensity of the electric field) is located at a distance of 5.5 mm above the bottom of winding. In this case, the distance is measured from the base made of ebonite.

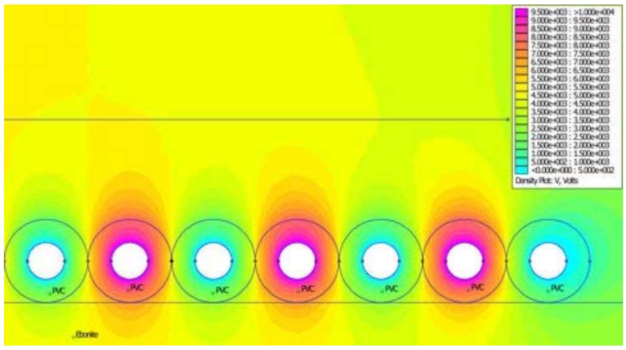

Fig. 11. Distribution of electric field intensity in in bifilar winding with a solid chassis - distance of 5.5 mm from the bottom of winding

The intensity of the electric field at a distance of 5.5 mm above the bottom of winding was presented in Fig. 11. The amplitude of changes in the electric field intensity is reduced. The direction of the electric field changes according to the potential of the wire.

Electric filed intensity locally reaches value of $1.8 \cdot 10^5$ V m^{-1}. The values of field intensity are significantly lower than intensity in the case of winding with a metal frame (Fig. 12). The scale of the change is shown in the Fig. 13. The maximal intensity values, with winding with the metal frame, are achieved in the place of deformation of wires. Similarly, in winding with solid chassis, the field intensity reaches the highest values in place located the closest to the wire.

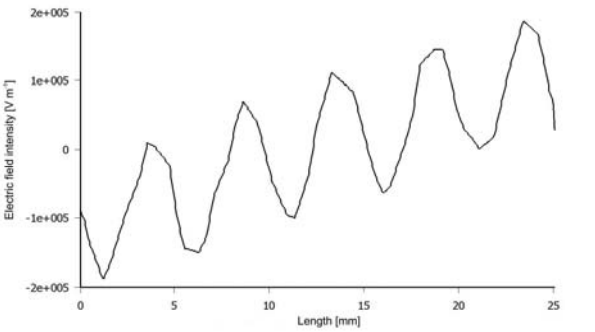

Fig. 12. Electric field intensity versus length - bifilar winding with a solid chassis, voltage 10 kV, wire cross-section 1.0 mm^2

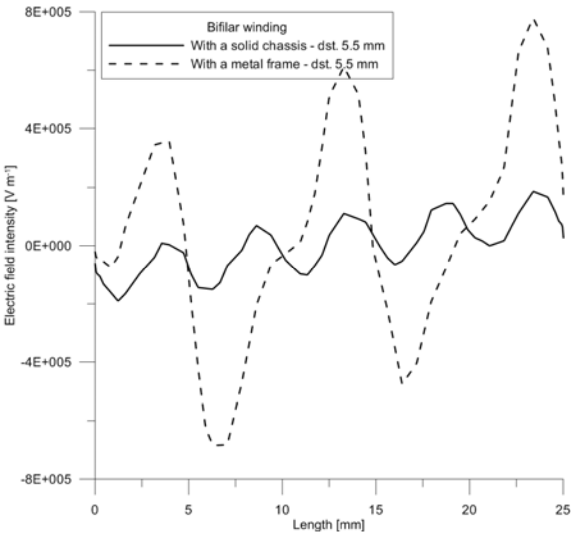

Fig. 13. Electric field intensity versus length, distance of 5.5 mm from the bottom of winding

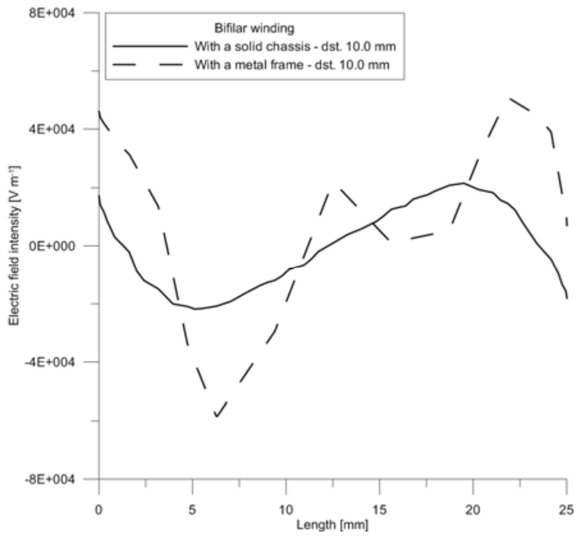

Fig. 14. Electric field intensity versus length, distance of 10.0 mm from the bottom of winding

The value of the field intensity decreases with distance from the winding. The field distribution on the surface of 10 mm away from the base of the winding is shown in Fig. 14. The maximum values of the field intensity decrease to approximately $6{\cdot}10^4$ V m^{-1} (winding with a metal frame) and $2{\cdot}10^4$ V m^{-1} (winding with a solid backbone).

Conclusions

1. The filtration efficiency practically does not change when the filter chamber operates without electric power. The filtration efficiency increases slightly by 0.1-0.5%. This means that even in the winding with empty frame, air flows over the filter structure.

2. The filtration efficiency increases when enhanced version of bifilar winding with chassis made of solid ebonite is used. The filtration efficiency increases by 0.8-1.0 % at voltage of 5 kV. The filtration efficiency increases by 2.0-2.1 % at voltage of 13 kV.

3. The filtration efficiency is not directly connected to the electric field intensity. Higher field intensity in the surrounding of the winding with the metal frame does not result in higher efficiency of filtration.

4. Change the construction of bifilar winding introduces greater mechanical strength of filter cassette. There are no damages caused during cleaning. It has a positive effect on lifecycle of the device.

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