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doi:10.15199/48.2016.03.16

Computer – aided design of the safe deduster with bifilar winding for dedusting materials in agri – food industry

Streszczenie. *Zjawisko oddziaływania pola elektrycznego na cząstki pyłu zaobserwowano pod koniec XVIII wieku. Jednak pierwsze udane próby budowy elektrofiltrów przeprowadzono dopiero na początku XX wieku. Obecnie filtry elektryczne, zwane elektrofiltrami, to urządzenia elektrostatyczne. Ten typ filtrów jest stosowany do odpylania pyłów w przemyśle hutniczym, wydobywczym i energetycznym. Chociaż charakteryzują się one dużą skutecznością odpylania (nawet powyżej 99%), nie znajdują jednak zastosowania w obiektach, w których pyły mają charakter wybuchowy, np. pyły w młynach, kaszarniach itp. W tej gałęzi przemysłu powszechnie stosowane są filtry tkaninowe. Elektrostatyczne oczyszczanie gazów jest w dalszym ciągu dynamicznie rozwijającą się technologią. W połączeniu z technologiami usuwania zanieczyszczeń stanowi z pewnością podstawę dalszego rozwoju elektrofiltrów. (**Komputerowe wspomaganie projektowania bezpiecznego filtra z uzwojeniem bifilarnym do odpylania materiałów w przemyśle rolno-spożywczym**)*

Abstract. *The phenomena of the impact of electric field on the dust particles were observed in the late 19th century. However, the first successful attempts to build electrostatic precipitators were carried as late as at the beginning of the 20th century. Currently, electric filters, called electrostatic filters, are electrostatic devices. This type of filter is used for extraction of dust in metallurgy, mining and energy sectors. Although they are characterized by high efficiency dust collection (even above 99%, they) are not applied in facilities generating explosive dusts e.g. in mills, groat plants etc. The fabric filters are commonly used in this sector. Electrostatic gas cleaning is still a rapidly growing technology. In conjunction with the decontamination technologies is certainly the basis for the further development of the electrostatic precipitators..*

Słowa kluczowe: projektowanie, filtr, pył, uzwojenie, odpylanie.
Keywords: design, deduster, dust, winding, dedusting.

Introduction

Most of the processes in manufacturing industrial facilities is accompanied by dust generation and emission phenomena unfavorably affecting ambient environment and, in case of dusts forming explosive mixtures with air, may create potential explosion hazard. The indoor air should be checked continuously because it impossible to completely eliminate the contaminations.

The hazard for health and safety of persons working in dusty environment depends on the type of substances contained in dust, its concentration in air, particles size and shape, solubility in organic fluids and crystalline structure of dust.

The dust emission sources i.e. emitters can be subdivided into the following groups:
- point emitters, e.g. high chimneys of electric power plants, thermal power plants and industrial facilities;
- linear emitters (one – dimensional emission sources) e.g. highways or sewage ducts;
- planar emitters (two – dimensional emission sources): complex of open reservoirs in sewage treatment plant or all the small chimneys on the roofs of residential buildings;
- spatial emitters (three – dimensional emission sources) for instance various industrial systems.

The following essential technical parameters can be determined for specified emission source:
- emission source location;
- surface area of emitter;
- height of emitter point,
- emission value (contaminations stream flow rate);
- type of emitted contaminations.

Possible types of harmful dust impact on the humans:
- irritating (particles of carbon, iron, glass, aluminium, boron compound etc.);
- fibrogenic (particles of quartz, asbestos, talc, kaolin, iron ore dusts and coal);
- cancerogenic (asbestos, refractory ceramic fibres, hard wood dusts – beech and oak);
- allergenic (dusts of plant or animal origin, medicines, dusts of arsenic, copper, zinc and chromium).

Owing to such significant impact of dusts on the humans, it is necessary to make the efforts leading to their effective reduction or elimination from the workplaces.

Dust control consists in the solution of some basic issues:
- to limit the amounts of generated dusts;
- maximum separation of emitted dusty contaminations;
- their thorough treatment in dedusting equipment to the extent enabling the emission of dedusted gazes to atmosphere.

In recent years, fabric filters or combinations of fabric filters with cyclone have been introduced. An alternative solution is possible in the form of electro-filters which are competitive devices in terms of investment and operation costs and meet the requirements in the scope of environment protection. The electrostatic precipitation process is associated with the following mechanisms and effects:
- high voltage applied to emission electrodes causes corona discharge;
- as a result of free electrons emission, gas particles within corona range are turned into negative ions;
- under the influence of electric field, charged gas particles are moving to electrodes with opposite polarity.

The fire and explosion hazard in the grain milling industry is caused by the possibility of self – ignition and explosion of grains used as raw material as well as processed and stored in disintegrated form. Grain seeds have hygroscopic properties. Water contained in grains accelerates respiration process in the bed. In course of respiration process, the grains produce large amount of heat. Furthermore grain seeds are characterized by poor thermal conductivity. It is extremely dangerous because it is impossible to quickly remove the heat generated in grain seeds mass due to the fact that the grains surrounding this area perform the function of insulating layer. Therefore the temperature in grain seeds mass increases and consequently may lead to its self-heating.

Large amounts of dusts are generated in course of grain cleaning and transportation process in grain elevators, stores and mills. Therefore explosive dusts concentrations are generated in grain cleaning and disintegration process.

The research carried out in the Department of Computer and Electrical Engineering of Lublin University of Technology demonstrated that a bifilar windings can be used for filtration. This winding is supplied with voltage without corona effect occurring in case of electro-filters. Therefore dedusting attempts have been commenced for the dusts generated in floor and groats production area. Bifilar electro-filter is characterized by a new design solution making it possible to capture particles of dusts of organic and nonorganic origin with dielectric properties.

The filter subject to tests was equipped with variable number of filtering stages (1, 2, 3 – stages) located in various position in relation to filter chamber. The stages were designed in the form of frames with bifilar winding. The research demonstrated that non-uniform intensity of electric field generated around bifilar windings appeared to be sufficient to capture particles of dusts of organic origin. Filtering efficiency in dedusting device achieved in laboratory conditions was equal almost to 98%.

Granulometric analysis

In order to properly select a filter, it is necessary to precisely determine the physicochemical parameters of purified gas (chemical composition, temperature, humidity, actual volume stream etc.) and dust parameters (chemical composition, density, specific resistance, flammability, adhesive properties, granulometric composition). The results of granulometric analysis of dust particles, determining mass percentage of individual dust grain fractions because the effectiveness of dedusting process mechanisms i.e. gravity, inertial force, diffusion force, centrifugal forces, electrostatic forces, coagulation etc is associated with particle size.

Depending on source of origin, solid particles of dust are characterized by diversified regular or irregular shapes. Volatile ashes particles, particularly the shapes of those created in course of coal dust incineration are almost spherical and often create larger agglomerates consisting of multiple individual properties. Dust grains often have the following shapes:

- spherical – active carbon, PVC and other plastic, iron oxides aerosol;
- irregular bullet shapes - cement and aluminium oxides,
- flat – mica, graphite and soot;
- fibrous – textile and cellulose fibres.

Depending on measurement method, diameters of grains with irregular shapes are determined as follows:

- projection diameter determined by means of optical or microscope, equivalent to the diameter of circle with the surface area equal to the particle surface area;
- equivalent diameter expressed as the diameter of sphere with the volume equal to the volume of particle;
- sedimentation diameter (Stokes diameter) the diameter of sphere with the density and sedimentation velocity equal to the particle density and sedimentation velocity.

The granulometric analysis of separated dust sample, depending on measurement method, makes it possible to determine the number or mass of particles with determined size. The number or mass of these particles can be determined as a fraction or cumulative (total) value.

Dielectric permeability of a mixture

Electric properties of dusts e.g. resistivity and dielectric permeability are of particular importance for dedusting efficiency in electrostatic filters.

In order to determine the dielectric permeability of dust and air mixture, several equations have been developed by various scientists.

The general equation for a non-uniform mixture consisting of ellipsoidal randomly arranged particles created by Polder' and Van Santen:

$$\varepsilon_m = \varepsilon_0 + v_i / 3(\varepsilon_i - \varepsilon_0)\bar{\varepsilon}_0 \sum_{j=1}^{3} [(\varepsilon_0 + A_j(\varepsilon_i - \bar{\varepsilon}_0)]^{-1} \quad (1)$$

where: ε_0 and ε_i are the values of magnetic permeability of two components of a mixture in the volume proportions of v_0 and v_i ($v_0 + v_i = 1$), $\bar{\varepsilon}_0$ is the value of electric permeability of medium surrounding the particle, Aj – depolarization coefficient along j axis of ellipsoid (A1 + A2 + A3 = 1).

However DeLoor demonstrated that: $\varepsilon_0 \le \bar{\varepsilon}_0 \le \varepsilon_m$. Initially, the equation was deduced for small values of vi but it is also possible to extend it to higher values of vi by analogy. Very often the particles constituting the mixture components can be treated as spherical ones; hence

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$$\frac{(\varepsilon_m - \varepsilon_0)}{3\varepsilon_m} = \frac{v_i(\varepsilon_i - \varepsilon_0)}{(2\varepsilon_m + \varepsilon_i)} \quad (2)$$

This formula is characterized by symmetry in v_i and v_0. As a result of substitution of denominator $3\varepsilon_m$ in the equation presented above by $\varepsilon_m + 2\varepsilon_0$, Rayleigh's equation has been obtained:

$$\frac{(\varepsilon_m - \varepsilon_0)}{(\varepsilon_m + 2\varepsilon_0)} = \frac{v_i(\varepsilon_i - \varepsilon_0)}{(2\varepsilon_0 + \varepsilon_i)} \quad (3)$$

Rearranging this equation and integrating between limits ε_0, ε_m and 0 to v_i Bruggeman obtained:

$$\frac{(\varepsilon_i - \varepsilon_m)}{(\varepsilon_i - \varepsilon_0)} = \frac{(1 - v_0)}{(\varepsilon_m / \varepsilon_0)^{1/3}} \quad (4)$$

This equation often satisfactorily describes electric permeability at higher concentrations of mixtures but ε_m must be determined from third order equation. Furthermore this equation is not symmetrical in v_i and v_0.

Appropriate criteria are necessary for analysis and quantitative assessment of dedusting process and consequently for analysis and quantitative assessment of particles emission mechanisms. So called total dedusting efficiency is assumed as the basic criterion. It is the ratio of mass stream of dust captured in deduster to the mass of introduced dust (with gas to be cleaned) into deduster, i.e.:

$$\eta = \frac{m_z}{m_w} \quad (5)$$

and:

$$\eta = \frac{m_z}{m_z + m_o} = \frac{m_w - m_o}{m_w} \quad (6)$$

where:

m_o - mass of dust leaving the deduster in purified gas, kg.

The penetration is another factor used for evaluation of dust leaving the deduster. The penetration (*p*) is defined as the ratio of mass of dust leaving the deduster to the mass of introduced dust:

(7) $$p = \frac{m_o}{m_w} = 1 - \eta$$

The knowledge of deduster capability to separate of individual grain classes is also of importance for full deduster evaluation. It described by fractional dedusting efficiency η_f, defined as the ratio of dust mass in specified grain classes captured in deduster to the mass of this fraction introduced into deduster:

(8) $$\eta_{f,i} = \frac{m_{w,i} - m_{o,i}}{m_{w,i}} = \frac{m_{z,i}}{m_{z,i} + m_{o,i}}$$

where: $\eta_{f,i}$ – dedusting efficiency for i-th fraction; $m_{z,i}$ – dust weight of -th fraction captured in the deduster, kg, $m_{w,i}$ – dust weight of -th fraction introduced into deduster, kg, $m_{o,i}$ – dust weight of -th fraction leaving the deduster, kg,

The following relationships exist between total dedusting efficiency and fractional efficiency:

(9) $$\eta = \sum_{i=1}^{n} \eta_{f,i} u_{w,i}$$

where: $u_{w,i}$ represents mass share of -th fraction introduced with gas into deduster.

Deduster designing procedure consists of the following phases:

- the first phase of the design encompasses the general analysis of deduster specification, anticipated density of dust particles on deduster outlet, specific physical limitations. Deutsch equation is used in order to determine characteristics and dimension of the deduster;
- the second step encompasses gas flow simulation and optimization in the electro-filter;
- the third phase consists in simulation of particles emission mechanisms;
- the fourth step encompasses detailed engineering and contains complete mechanical specifications, cost estimate and deduster construction planning.

For example, dust capturing effectiveness in the electro-filter can be describe by means of Deutsch equation in planar electric field system:

(10) $$\eta = 1 - \exp(-w\frac{A}{V}) = 1 - \exp(-w\frac{L}{h\nu})$$

where: w – particles migration velocity, m/s, V – flowing gas volume stream w m^3/h, A – surface area of collection electrodes, m^2, L – length of electric field, m, ν – average velocity of gas flow through the deduster, m/s, h – distance between emission electrodes and collection electrodes m.

Using the equation presented above, it is possible to identify the following factors contributing to the improvement of electro – filter effectiveness:

- introduction of design changes in the deduster structure;
- modification of gas velocity distribution in electro – filter chamber,
- modification of chemical composition of flue gases and physicochemical properties of dust;
- electro – filter voltage type control and modification of electric systems,
- modernization of the electro – filter control and diagnostic systems; and
- optimization of the electro – filter operation conditions.

Wheat milling fractions obtained from grain milling process in the mill have been used in the deduster tests. PM 6306 impedance analyser has been used for capacitor capacitance measurement. The electric permeability of milling fractions has been measured in accordance with the following procedure:

- calibration of impedance analyser,
- installation and configuration of a program enabling automated measurements by means of impedance analyser,
- SW63W Component View was started. This program is dedicated for measurement data acquisition and visualization,
- type of computer – to – meter connection was selected via RS-232,
- frequency range used for continuous measurement of capacitor capacitance was established after measurement option selection (Scanning Mode).

Frequency characteristics for complex electric permeability components for dust have been determined on the basis of completed measurements and calculations.

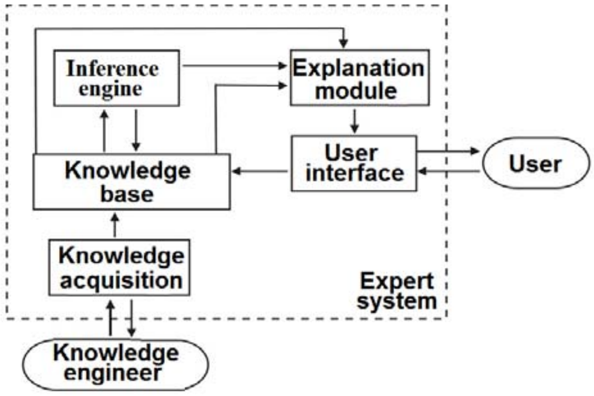

Fig. 1. Expert system functioning diagram

Expert system in deduster designing

The expert system stands for a computer system emulating decision making process by the man. This could be achieved by means of software capable to draw conclusions and make decisions on the basis of detailed knowledge, acting like humans. In expert system, the knowledge in specified domain (database) is separated from the remaining part of the system incorporating appropriate inference mechanism (program which makes it possible to ask questions and to search the answers to the questions asked).

This system consists of the following physically independent elements which cooperate with each other:

- knowledge base containing all the information in the scope of selected domain;
- inference engine searching the solution for specified problem, on the basis of gathered knowledge – the engine is separated from knowledge base; therefore its functioning is identical in the expert systems for any domain as well as in framework expert systems; searching algorithm contains several strategies in the scope searching, heuristics and inference methods – the strategies determine successive searching steps, heuristics are of help to optimize the searching space and the methods determining the way of thinking process (forward chaining, backward chaining or other methods);
- explanation procedures – they explain inference strategy, the way to solve the problem and show more detailed data for solution;
- interface dedicated for communication with the user enabling man – system communication (interactive work) – to be used to obtain information, to present generated result and to explain inference process – structure and appear-

ance of this interface depends on programming language used for development of expert system and on its operating system;

- modules dedicated for knowledge gathering and modification – knowledge gathering enables automatic improvement of the system.

Determination of forces depositing dust particles on bifilar winding

The value of force depositing a dielectric material particle on bifilar winding can be determined by means of equations (11, 12).

The value of force density can be calculated by means of equation:

$$f = -\frac{1}{2}\varepsilon_p \, gradE^2 , \tag{11}$$

where: ε_p – relative electric permeability of dielectric material particle.

The value of ***gradE***^{2} can be determined by means of equation:

$$gradE^2 \cong \frac{E^2(y_2) - E^2(y_2)}{y_2 - y_1} \vec{1y} \tag{12}$$

where: y_1, y_2 – coordinates of measurement points,

$E(y_1)$, $E(y_2)$ – the value of field intensity in measurement points.

Measured value of ε_p should be considered in determination of the value of force density.

From the equations (26) and (27) it appears that the knowledge of electric field intensity distribution is needed in order to determine the value of force density. Therefore it is possible to perform theoretical analysis using a program dedicated for field analysis e.g. FEMM or Flux3D.

Summary

Nowadays, climatic changes and limited resources of energy materials are the principal challenges.

However, placing a lot of weight on the protection of natural environment and human working environment safety is of the same importance. The savings of energy consumption are possible through rooms heating control and automation as well as lighting and ventilation control. Distributed intelligence systems are particularly suitable for this task.

The analysis of correlation between energy production and energy demand at determined time is an important element in the selection of autonomously operating systems.

The examination of relationship between dielectric permeability of dust and deduster attraction force (acting in the direction perpendicular to the direction of particles movement in a manner identical to bifilar cylindrical filters) is essential for its correct operation.

The impact of frequency characteristics of the dust on deduster operation effectiveness and selection of its specific parameters (mechanical and electrical) is also essential.

The important phase of deduster tests consists in the determination of potential percentage of its operation effectiveness improvement (e.g. in case of particle permeability increased by 10% as a result of its humidity change or permeability variations (within 10%) vs. frequency e.g. increased by 10% above 1 GHZ, what will be the impact on deduster effectiveness.

From variations of the electrostatic field induction distribution it appears that the field non-uniformity decreases with the increase of layer thickness of dust covering the winding being considered. These circumstances lead to reduced effectiveness of dust particles attraction to the winding. From the results of computer simulation it appears that the field distribution in the space between the conductors is not changed. However the increase of field induction is observed in windings conductors surrounded with thicker layer of dust (D_x = 26,5·10^{10} C/m^2 for layer of dust with the thickness of g_p = 0,35 mm and D_x = 19·10^{10} C/m^2 for layer of dust with the thickness of g_p = 0,25 mm).

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