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Monitoring of electrostatic fire and explosion hazards at the inlet to electrostatic precipitators

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ABSTRACT

The paper deals with the continuous monitoring of electrostatic fire and explosion hazards that can occur at the inlet to electrostatic precipitators (ESPs) when highly charged dust particles are transported by a gas carrier that can be the mixtures of both incombustible and combustible flue gases. The risk of ignition and even explosion is especially high in the presence of an explosive mixture of oxygen and, e.g., hydrocarbons, carbon monoxide, etc. To avoid the danger of electrostatic discharges and their consequences for a whole installation including an electrostatic precipitator a method and a specially designed and built system should effectively enable the continuous monitoring of the hazards and should immediately manage any automatic control system or some other control elements. Some theoretical considerations concerning the method proposed, the physical quantities that must be measured, and the derivation of a novel dynamic safety criterion for assessing the risk of hazardous electrostatic discharges are presented. Finally, the author presents and discusses the possible practical application of the microprocessor-based measuring system verified experimentally in the past to the continuous monitoring of the hazards and to the management of an automatic control system to be put into operation. The paper presents a certain idea and proposal of the problem's solution based on the author's many years' experience in the field of pneumatic transport of dusts, powders and granular materials, of the electrostatic measurements of electric and mechanical quantities characteristic of the particulate transport, and of the risk and prevention of discharges of static electricity in transporting pipes and silos, vessels, etc.

1. Introduction

Still little is known about electrostatic fire and explosion hazards as a result of tribocharging and electrostatic discharges especially during the pneumatic transport of solid particles in pipelines and during filling silos, vessels, bins, etc. though explosions in the foodstuffs and petrochemical industries occur rather frequently [1]. The mechanisms of tribocharging and their contribution to the final stage of charging of any solid object in both the micro- and macroscopic scales are not well recognized since there is still a lack of a general theory of electrification of a matter under dynamic conditions. The processes of charging and discharging under such conditions are not too well known and understood because dusts, powders and other granular solid materials dispersed in a gas carrier in a pipeline generate the problems in their transport that are much more complex than those in the case of liquids [2]. This is so because the process of exchanging the charge between solid particles and pipe walls is complex and depends upon many various factors, e.g., the flow velocity, the angle of impact, sliding, rolling, rubbing, and bouncing. The process also depends upon the shape, size and type of solid particle (an elastic or inelastic, or rigid body) that take part in elastic or inelastic collisions between the particles themselves as well as their impacts with a pipe's wall. This is also closely connected with the different intrinsic physical and chemical nature of both types of materials [3–7].

There are a lot of factors and parameters that characterize solid particles being pneumatically conveyed as well as the parameters of a transport installation and transport itself these having important influence on any nuisances, disturbances, and finally fire and explosion hazards in the whole pneumatic transport system including a pipeline, silos, vessels, collectors, driers, and other elements of the system. In the case of solid particles, their features and properties can be as follows: their chemistry, the size distribution, the specific surface area, the resistivity and permittivity, some critical concentration, humidity (water content = equilibrium moisture content), etc. [4–6,8–10]. Their

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pneumatic transport is characterized by its following parameters: the mean velocity, the mass flow rate, the gas carrier flow rate, the dimensions of a pneumatic transport pipe (its cross-section area and length), the dimensions of a silo, vessel, etc., the configuration and shape of pipes (bends, elbows, constrictions, and their number, that intensify turbulence and tribocharging), their material, and finally the temperature and humidity of a gas carrier [6].

All the above-mentioned features, properties, and parameters exert influence on tribocharging of solid particles and also determine the minimum ignition energy (MIE) of particulate material conveyed in a pipe [11–15]. If the maximum effective energy of an electrostatic discharge is greater than the MIE of dust particles then ignition of the dust suspended in air or in the mixture of more different gases is possible [13,16]. It is especially hazardous when an explosive mixture contains oxygen and, e.g., hydrocarbons, carbon monoxide, etc. Under favourable conditions, the flame so formed and not extinguished at once (or just in time) can result in a fire and even an explosion. This is also possible in the case of electrostatic precipitators (ESPs) [17,18].

Because the ignition source does not have to come from within an electrostatic precipitator (ESP), therefore one must continually and accurately monitor the zones in a certain distance before an ESP's inlet to properly and quickly prevent the risk of a fire and explosion. This risk can occur both when dispersed solid particles themselves have quite a high net electric charge to produce an electric spark; it is possible when an electric field strength between the charge and, e.g., the earthed duct's or ESP's wall exceeds the breakdown strength of air the value of which under atmospheric conditions is about 3×10^6 V m^{-1}. (The breakdown strengths of different solids are of one to two orders of magnitude greater than that of air.) The charge on solid particles travelling in a transporting duct can be or is a bipolar one [16] because of the heterogeneous nature of various natural materials and can separate to form a kind of capacitor within the powder column in a duct, and then there is also some risk of electrostatic discharge within the column. Both above situations can be the source of ignition of the dust itself or the dust–gas mixture. One can predict that if the material being processed or burnt in a boiler is heterogeneous, its final form or the flue gas is also of a heterogeneous nature.

The statistics show that only in Germany the electrostatic-type discharges constituted almost 8.7% of total of the 426 dust explosions in the years 1965–1985 [19]. These discharges in 18.6% were the most common and dominating ignition sources in conveying systems. There are not too many news and publications on the fires and explosions caused by electrostatic discharges in the ESPs. Some information is provided by some authors in their papers and by companies that supply products and services to protect people and industrial installations from the danger of a fire and an explosion [25–30]. FIKE Corporation in their leaflet gives the following information [29]: "Explosion history. Loss history for the past ten years due to dust explosions from FM Global Data Sheet 7-76: Four in electrostatic precipitators for a loss of $2,988,000."

To avoid, reduce, or only minimize any potential risk of nuisances or disturbances in the ESP's operation or of electrostatic discharges resulting in fires, explosions, or both in a duct at the inlet to the ESP or in the ESP's interior the author proposes to continuously monitor the electrostatic hazards during the gas–solid flows in the ducts transporting dusts, powders, and other particulates from boilers and other industrial processes to the ESPs. The idea and method for continuous monitoring the hazards and protecting the ESPs against them are presented below.

2. Theoretical considerations

2.1. About the method

The method proposed is a non-intrusive electrostatic one and based on the phenomenon of electrostatic induction, and permits the continuous real-time measurements of the physical quantities being characteristic of pneumatic transport and the constant monitoring of technological processes where required [7,20–24]. It is especially useful where the fire and explosion hazards from static electricity occur.

The method can be applied to measurements of the following physical quantities:

- the electric charge of single solid particles or droplets suspended in a gas (air) carrier in the ambient, open air or enclosed ducts or pipes as in pneumatic transport;
- the net electric charge or dynamic space charge density of solid particles or droplets in a gas (air) carrier in the ambient, open air or flowing in the pipes of pneumatic transport;
- the mass flow rate, volume loading, or concentration of charged solid particles in the pipelines;
- the mean flow velocity of charged solid particles in the pipelines.

It also enables one to compare measurement data with criteria values given in some dynamic safety criteria established by the author [25,26].

In the method electrostatic flow probes are employed that are metal and of a ring shape. (By the way, the shape can be arbitrary.) These are mounted in a specially designed and built measuring chambers (heads) that are put in a duct, e.g. between two flanges. The probes have their sensing (viewing) zones where the probes are able to detect the net or any charge within the zones, which are always somewhat longer than the axial width of the single probe. The probe has such an area where the single charged particle travelling through it starts and ends to visibly induce charge and potential on the probe by electrostatic induction [7].

The flow of charged particles in the duct or pipe generates electrostatic noise, which is a good source of information about the gas–solid flow parameters: the mass or volume flow rate, concentration or volume loading, mean flow velocity and about the particles' net charge. All the above mentioned quantities are measured indirectly through the measurement of the potential induced in the probe or of the voltage established between the probe and any nearby earth, e.g. the earthed housing of a measuring chamber in the interior of which the probe is located.

The description of the non-intrusive electrostatic method and the microprocessor-based measuring system based on it will be presented further in the text.

2.2. Some theory of measurements

To properly assess the electrostatic fire and explosion hazards in the ducts and pipes it is necessary to measure or know the net charge, as carried by dust, powder or another particulate solid both in flue gases or other gases, that flows to the ESP. The crucial parameters of the flow itself to be determined are the mass flow rate or volume loading and the mean flow velocity of solid particles.

In the further considerations instead of the ring probe, simply the probe is used because of different shapes of the cross section of a duct or pipe. The shapes can be circular, rectangular, or any other.

The mass flow rate $\dot{m}(t)$ for the constant specific density ρ of a disperse phase (solid particles), the cross-sectional area A of the transporting duct or pipe, and the mean flow velocity υ is a function of the solids volume loading $\sigma(t)$