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ASSESSMENT OF ELECTROSTATIC HAZARDS DUE TO THE FLOW OF CHARGED SOLID PARTICLES IN PNEUMATIC TRANSPORT

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Theoretical considerations are shown in which an attempt is made to combine the parameters characterizing the pipe flow of solid particles with the well-known expressions for an electric field strength in order to obtain the 'dynamic' safety criteria. Those criteria allow one to assess the probability that electrostatic discharges can occur which, in turn, can lead to the fire and/or explosion hazard. The criteria are in a very simple form and can easily be adopted and applied in various alarm and control systems.

1. INTRODUCTION

A close interconnection exists between the charging of particulates in pneumatic transport and the parameters of a flow (velocity, volume loading, mass flow rate, turbulence, etc.). During transport operations with dusts and powders and when these are conveyed to and stored in silos strong electric fields are established which can lead to electrostatic discharges which, in turn, can cause the fire and/or explosion hazard to occur.

Systematic studies are carried out upon electrostatic charging of dusts and powders in pipes of pneumatic transport. Moreover, the flow parameters are of great interest and particular attention is being paid to measurements of the average velocity of flow and mass flow rate of charged particles in two--phase flows.

The methods used for measuring the resultant (net) charge and the average velocity of flow of solid particles being transferred through pipes are inductive, non-contact (non-intrusive) ones and are described in [1, 2 and 3]. Now the cross-correlation method for determining the average velocity of flow is also being used with good results in laboratory experiments when analysing electric, stochastic signals that are detected, identified and processed by a specially designed, computer-based measuring system [2].

Efforts are also directed to the solution of a problem of the prevention of and protection against fire and explosion hazards that relate to the occurrence of static electricity during pneumatic conveying of powdered solids. In this connection, the adequate and reliable safety criteria for the maximum values of a charging level (resultant or specific charge, electric field intensity, potential, etc.) depending, amongst other things, on the parameters of a flow should be selected, examined and established.

The hitherto existing and well-known criteria are rather 'static' An attempt is now being made at obtaining the 'dynamic' ones in which the parameters of a flow and an electric charge of solid particles in pneumatic transport are time-dependent and random variables.

2. THEORETICAL CONSIDERATIONS

For the sake of the simplification of a mathematical notation used in the considerations, the symbols: σ, V, υ, Q, etc. denote the time-dependent functions and are used instead of: $\sigma(t)$, $V(t)$, $\upsilon(t)$, $Q(t)$, etc., respectively. The above-mentioned symbols are used when deriving formulae but their final forms ('dynamic' safety criteria) also include the total values of quantities, e.g. the increase in electric charge ΔQ or mean values, e.g. $\langle\upsilon\rangle$ that are to be determined over the time Δt which is the time of 'observation' (or 'measuring' time). For example, the total electric charge determined over Δt is the sum of single charges - charges representing the resultant charge of each portion of charged particles as is explained in [1]. Such an approach seems to be more helpful and useful than the assessment of a hazard on the basis of measurement of instantaneous values; the factor of time is very important while considering the potential fire and/or explosion hazards caused by the level and duration of a charging state of matter: electric charge → electric field strength → potential → existing and favourable conditions → energy → spark breakdown → fire and/or explosion.

2.1. Flow of Particulates

The flow of solid particles is a stochastic (stationary and ergodic) process and can be characterized by the flow parameters like velocity, volume loading, mass flow rate and other which are random variables.

Attention is now being focussed on the average velocity of flow and volume loading which will be discussed and used later.

The average velocity of flow $\langle\upsilon\rangle$ [m/s] can be determined from the instantaneous, time-dependent velocity denoted by $\upsilon(t)$ as follows

$$\langle\upsilon\rangle \overset{\text{df}}{=} \frac{1}{\Delta t} \int_{t_1}^{t_2} \upsilon(t)\, dt \tag{1}$$

where $\Delta t = t_2 - t_1$ is the time of 'observation' (or 'measuring' time) [s].

The average velocity of flow in a given cross-sectional area of a pipe can be measured with use of: the 'zero-crossing' [2, 3], the cross-correlation [4, 5] or another well-tried, reliable and efficient method.

The volume loading σ $[m^3/m^3]$ is defined as follows

$$\sigma \overset{\mathrm{df}}{=} \frac{V}{V_o + V} \tag{2}$$

where V is the volume of all solid particles (a disperse phase) in transporting gas (air) $[m^3]$ and V_o is the volume of this gas $[m^3]$. Under real conditions of pneumatic transport $V_o \gg V$ and the expression (2) may be written in the form

$$\sigma \approx \frac{V}{V_o} . \tag{3}$$

It is assumed that the volume V varies with time: $V = V(t)$, and that the volume V_o is approximately a linear function of time: $V_o \approx \dot{V}_o t$ ($\dot{V}_o \approx$ const and is the volumetric flow rate $[m^3/s]$) which is as follows

$$V_o = A\, \upsilon_o t \tag{4}$$

where $A = 0.25\Pi D_p^2$ is the cross-sectional area of a pipe $[m^2]$ which diameter is D_p [m]; υ_o is the velocity of gas ($\approx$ const) [m/s] and t is time [s].

2.2. Dynamic Safety Criteria

During the turbulent two-phase flow of powdered solids dispersed in fluids (a disperse phase) the electrostatic charging occurs along the whole length of a pipeline made of conducting material and the electrical discharges can be observed between the flux of charged particles and a wall or any nearby earthed surface of a pipeline.

Bright [6] and Bailey [7] carried out investigations upon the potentially hazardous discharges that can occur from the powder column to the pipe wall, and to the silo wall.

Now it is of importance to define some quantities that will be used in further considerations. At first, the 'static' space charge density of solid particles q^s_{vp} $[C/m^3]$ is determined by the expression

$$q^s_{vp} = \frac{Q}{V} \tag{5}$$

where Q is the total electric charge of particles [C] which volume is V $[m^3]$, and is assumed to be a constant quantity.

Transforming and introducing (5) into (3) one obtains

$$\sigma = \frac{Q}{q_{vp}^{s}\ V_o} \tag{6}$$

or

$$\sigma\ q_{vp}^{s} = \frac{Q}{V_o}\ . \tag{7}$$

The product $\sigma\ q_{vp}^{s}$ is denoted by q_{vp}^{d} [C/m^3] and will be **named the dynamic space charge density** that is a function of time ($Q = Q(t)$ and $\dot{V}_o$ = const):

$$q_{vp}^{d} = \frac{Q}{V_o} \tag{8}$$

or taking into account (4)

$$q_{vp}^{d} = \frac{Q}{A\ \upsilon_o t}\ . \tag{9}$$

For the fully developed turbulent flow one can assume that solid particles flowing in a pipeline form a powder column. Since the particles are charged, the well-known expression for the electric field strength E_p [V/m] at the surface (edge) of a powder column, treated as a charged cylinder, will be used

$$E_p = \frac{D_p}{4\varepsilon\varepsilon_o}\ q_{vp}^{d} \tag{10}$$

where ε is the relative permittivity (dielectric constant) (= 1 for air) [-] and ε_o is the permittivity of free space (= $8.854 \cdot 10^{-12}$ F/m).

The equation (10) is found to be a good safety criterion when E_p is being compared with its upper limit, namely $E_M \approx 3 \cdot 10^6$ V/m (breakdown strength of air), as cited by Bailey [7]. Here, this equation is given in a modified form in comparison with the one appearing in the literature of the subject, namely the **dynamic** space charge density is introduced instead of a **static** one.

Inserting (9) into (10) and substituting $0.25\Pi D_p^2$ for A one obtains

$$E_p = \frac{1}{\Pi\varepsilon\varepsilon_o}\ \frac{1}{D_p\upsilon_o}\ \frac{Q}{t}\ . \tag{11}$$

Assuming that the electrical discharges will not occur when the condition $E_p < E_M$ is fulfilled and comparing E_p with E_M one can write

$$\frac{1}{\Pi\varepsilon\varepsilon_o}\ \frac{1}{D_p\upsilon_o}\ \frac{Q}{t} < 3 \cdot 10^6 \qquad \text{[V/m]} \tag{12}$$

or multiplying both sides by $\Pi\varepsilon\varepsilon_o$

$$\frac{1}{D_p\upsilon_o}\ \frac{Q}{t} < 83.45 \cdot 10^{-6} \qquad \text{[C/m}^2\text{]} \tag{13}$$

The flow velocity of gas υ_o in a pipe is greater than the average flow velocity of a disperse phase (solid particles) υ: $\upsilon_o > \upsilon$. The average velocity $\langle\upsilon\rangle$ is inserted into (13) instead of υ_o, and also the instantaneous quantities are substituted by the mean and total values of those quantities, respectively, and then the inequality (13) is

$$\frac{1}{D_p \langle\upsilon\rangle} \frac{\Delta Q}{\Delta t} < 83.45 \cdot 10^{-6} \qquad [C/m^2] \tag{14}$$

In the case of filling of silos one can apply formulae given by Maurer [8] which are very convincing when calculating the electric fields in silos as well as in pipelines.

The electric field E_s in a silo is

$$E_s = \frac{D_s}{6\varepsilon\varepsilon_o} q^d_{vs} \tag{15}$$

where q^d_{vs} is the dynamic space charge density of solid particles in a silo above a heap of powder in bulk $[C/m^3]$ and D_s is the silo diameter [m].

If the dynamic space charge density in a pipe just before entering a silo is q^d_{vs} then [8]

$$q^d_{vs} = q^d_{vp} \frac{D_p}{D_s} \tag{16}$$

and

$$E_s = \frac{D_p}{6\varepsilon\varepsilon_o} q^d_{vp} \tag{17}$$

After simple transformations and bearing in mind that $E_s < E_M$ one gets

$$\frac{1}{D_p \upsilon_b} \frac{Q}{t} < 125.17 \cdot 10^{-6} \qquad [C/m^2] \tag{18}$$

or

$$\frac{1}{D_p \langle\upsilon\rangle} \frac{\Delta Q}{\Delta t} < 125.17 \cdot 10^{-6} \qquad [C/m^2] \tag{19}$$

3. RESULTS AND DISCUSSION

The inequalities (14) and (19) show that the simultaneous measurement of the quantities: υ, Q and t gives possibility to assess the potential hazard. The electric charge Q can be measured using a method described in [1, 2] and the average velocity of flow $\langle\upsilon\rangle$ can be measured or determined applying one of the methods cited in Section 2.1.

In order to properly apply and use the criteria presented here, the continuous and simultaneous measurement of all the parameters appearing in the inequalities (14) and (19) has to be performed and all the data obtained has to be put into the left sides of the inequalities so as to calculate actual values that should immediately be compared with criterial ones - the right sides of the inequalities.

The special computer program is now prepared to realize an algorithm of adequate calculation, and a measuring system [2] is being restructured for an analysis of random electric signals generated by the flow of charged solid particles in pipelines of pneumatic transport.

4. CONCLUSIONS

It is believed that the further stages of the research work and their results will confirm the proposal presented in this paper. The interconnections between the electro(quasi)static charging of dusts and powders, and their flow (dynamic behaviour) in pipelines are observed wherever pneumatic transport is used. These connections were the basis of the idea and the inclusion of the flow parameters into the adequate static safety criteria seems to be valid and useful.

There is the urgent need for the precise safety criteria in order to properly recognize, assess and reduce the fire and/or explosion hazards in industry. The proper precautions taken with regard to the influence of a flow itself and its parameters can distinctly reduce the hazards in powder handling and processing, and in pneumatic transport and storage systems, as is assumed.

In this context, it seems that such **dynamic safety criteria** as presented here should be fulfilled and should come up to expectations in practice, but first they should be verified very carefully and critically before being adopted and applied.

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