Determination of Dustiness of Bulk Materials

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Abstract: A risk of dust explosions exists wherever combustible dusts are handled and is depending not only on the established safety characteristics, but also on a parameter describing the tendency to form a dust cloud, called dustiness. A system for use in laboratories is developed and presented to measure the dustiness. The principle is that the dust concentration of the free falling bulk material is determined by a dust concentration meter, which based on light absorption and light scattering according Lambert-Beer's Law. Therefore, the dust is moved by a screw with a defined variable-speed into the measuring chamber. To avoid bonding of the particles the electrical charges are removed by a ring ionizer. The determination of a dust concentration a calibration curve is necessary to remove the extinguishing coefficient in Lambert-Beer's Law. This is realised with a special calibration system, where the dust collected subsequently on small glass plates is weighted and analyzed with the dust concentration meter. At least a dimensionless dustiness coefficient S is introduced, which allows the characterization and classification of different types of dust. The dustiness coefficient for different dust types used in process industries is presented.

Keywords: Dustiness, Bulk material, Safety characteristics, Dust explosion

Introduction

A risk of dust explosions exists wherever combustible dusts are handled. Therefore, the aim is to have the most precise knowledge possible of the risk factor "dust" so that handling of the same can be designed to be safer. Safety characteristics of dust shall investigated experimentally according VDI 2263 Part 1 or EN 14034-x[1]. However, experience has shown that these characteristics do not always suffice to fully describe the potential hazard posed by a combustible dust in practice.

For instance, the tendency of a dust to form dust clouds is of great importance to the hazard it poses. Some dusts are but difficult to raise and are, therefore, considerably less hazardous than dusts that form an ignitable mixture at the weakest movement. Although this is known, no characteristic describing the tendency of a dust to form dust clouds is available. Handling bulk materials in industrial applications often raises questions that cannot be answered without knowing the tendency of the relevant bulk material to form dust clouds. This is particularly true for risk analyses that have to be conducted with regard to dust explosion protection.

Several attempts to determine the dustiness have be published[2, 3]. Those methods are not developed for the dustiness of dust explosions but for fractions of respirable dust or the dust concentration are not measured directly but only calculated[2].

This paper describes a measuring system and measurement procedure serving to determine the safety characteristic "dustiness". The procedure described in the following yields a characteristic for the dustiness of dusts, which can be used in particular for the assessment of dust explosion hazards.

1. Measuring Equipment

The measuring equipment consists of a feeding system, a measuring chamber, a dust concentration meter, a measured-data memory and a computer with analysis software. Fig.1 shows schematically the assembly.

1.1 Feeding system

The sample container with lid is used for the storage and feeding of the sample material during the measurement. It has a capacity of 10l and can be removed from the measuring system for filling.

By opening the gate (Item 1b in Fig.1), sample material can be transported from top to bottom. The horizontal agitator (Item 1c in Fig.1) is arranged in the bottom section of the sample container and serves to avoid bridging.

The feed device (Item 1d in Fig.1) is a variable-speed, unidirectional, double-concave screw with vertical discharge stub, producing a continuous and constant falling volume flow rate of 1 ± 0,1 dm^3/min.

The feed screw and the agitator in the sample container are controlled by the control circuitry (Item 1e in Fig.1).

1.2 Ring ionizer

The ring ionizer consists of a high-voltage source (Item

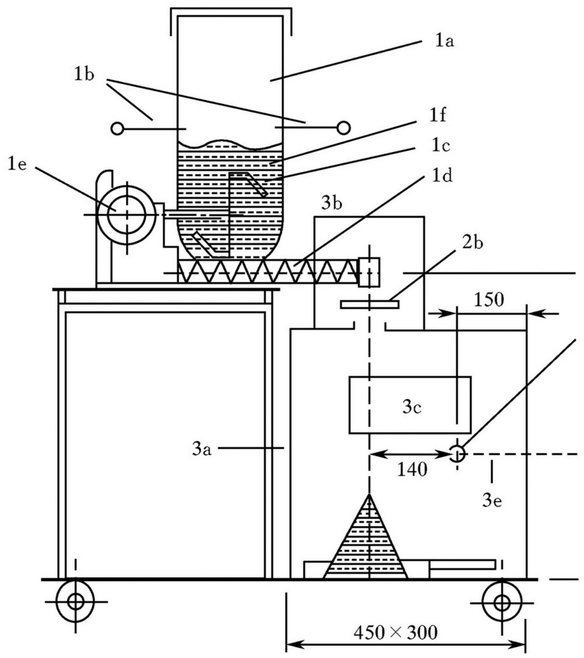

Fig.1 Schematical diagram of the measuring system

1a Sample container
1b Gate
1c Agitator
1d Feed screw
1e Control circuitry
1f Dust

2a High-voltage source
2b Ring electrode
3a Measuring-chamber container
3b Protective casing
3c Filter
3d Apertures for the measuring head
3e Calibration rail with dust collection plates

2a in Fig.1) and the ring electrode (Item 2b in Fig.1).

The ring ionizer neutralizes any electrical charges that the sample may have absorbed while passing through the feeding system. Such neutralization is necessary as electrostatic charges of the sample considerably influence the dustiness coefficient, S due to bonding of the dust particles.

1.3 Measuring chamber

The measuring chamber (Item 3 in Fig.1) is the place where the dust concentration is measured. Underneath the feed screw, the measuring-chamber container (Item 3a in Fig.1) with internal dimensions 560 mm × 450 mm × 300 mm is located. The height of fall of the bulk material is 670 mm at the beginning of the measurement. The container is made entirely of stainless steel to prevent external electrical fields from entering the measuring-chamber container and to ensure that the walls of the measuring-chamber container are at zero potential. For ease of product discharge, a hinged door is integrated into the container front. The aperture, inlet stub and ring electrode are covered entirely by a protective casing made of sheet steel (170 mm×220 mm×250 mm).

At one side of the measuring-chamber container a filter housing with filter material (filter class F5) (Item 3c in Fig.1) is attached, through which the air displaced by the product entering the measuring-chamber container can exit in a cleaned condition.

In the two side walls of the measuring-chamber container, one each aperture (Item 3d in Fig.1) in the form of a 1″ male nipple is provided to accommodate the transmitter and receiver, respectively of the dust concentration meter.

1.4 Dust concentration meter

A dust concentration meter suitable for continuous recording of dust concentrations during technical processes has been developed. Even fast changes and instantaneous peak values of the dust concentration are rendered uncorrupted up to approx. 2000 Hz. Measuring dust concentrations between approx. $10\mathrm{g/m^3}$ and $1000\mathrm{g/m^3}$ is possible. The measuring principle is based on the reduction of the intensity of a light beam by absorption and light scattering when crossing a dust cloud. Lambert-Beer's Law describes the connection between the transmission and the dust concentration.

The dust concentration meter essentially consists of two components, i.e. the measuring head sensing the measured data and the control unit for data processing and display.

As measuring heads various types are available for the dust concentration meter, which were developed for different measurement tasks. In all types of measuring heads, an infrared laser diode, emitting light at a wavelength of λ = 950nm, and a matching receiver photodiode make up the optoelectronic elements. Both diodes have lens one each (f = 20mm) for collimation and focusing of the light beam, respectively. The voltage is supplied to, and the data are read out from, the diodes by the control unit. The lenses are held in metal pipes, with the pipe length depending on the type of measuring head. The pipes afford protection against extraneous light and, to some extent, against strong contamination of the lenses.

1.5 Calibration System

For the purpose of calibration a calibration rail (Item 3e in Fig.1 and Item 6 in Fig.2) accommodates five carriages holding thin dust collection plates made of boron silicate glass

Fig.2 Practical realisation of the system

(40 mm × 22 mm × 0, 1 mm). The calibration rail and the optical axis of the measuring-head sensors of the dust concentration meter are aligned in parallel. The five carriages are so arranged as to give an even spacing of 12 mm each between the dust collection plates over a total length of 300 mm. A narrow sealable aperture in the measuring-chamber wall allows the carriages to be removed individually during measurements (see Fig.3).

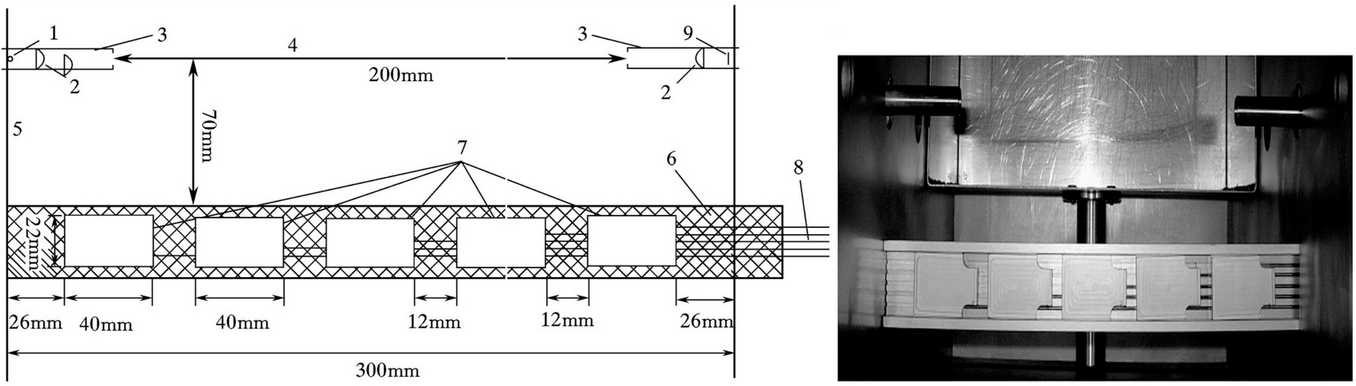

Fig.3 Schematic (top) and photograph (bottom) of calibration rail (top view)

Note: The schematic furthermore shows the wall of the measuring-chamber container (5), the infrared transmitter diode (1), the lenses (2), the casings of infrared transmitter and receiver (3), the optical axis or measuring distance (4), guided metal rods for removal of the dust collection plates (8) and the detector in the infrared receiver (9)

2. Dust Sample and Sample Preparation

Information must be available about the kind of dust (chemical composition), its potential toxicity and, as the case may be, any explosion hazard as defined by the explosion characteristics.

The required sample volume of approx. 20 dm^3 results from the falling volume flow rate (1 dm^3/min), the conveying time of 5 min during each of the three measurements, and an allowance for sufficient filling of the feed device.

Until examined, the sample shall be stored hermetically sealed and free from humidity. During sample preparation and during the examination, the ambient temperature and the relative air humidity shall be kept at 20℃ ± 5℃ and <50%, respectively.

3. Description of the Performance of Measurement

3.1 Preparations for recording of the calibration curve

Five dust collection plates made of glass are clearly marked, weighed individually, and the weights are documented. Then one of the dust collection plates is arranged within the measuring path of the calibration measuring head of the dust concentration meter in such a manner that the surface of the dust collection plate is perpendicular to the measuring path. Zero compensation of the dust concentration meter is performed with the dust collection plates in place. Then the dust collection plates are arranged on the calibration rail as illustrated in Fig.3.

3.2 Measurement procedure

A metering device conveys dust into a measuring chamber at constant volume flow rate of 1 dm^3/min. At a defined measuring point in that chamber, the dust concentration of the dust cloud forming there is recorded as a function of time, using a dust concentration meter and a connected measured-data memory and computer. (Prior to entering the measuring chamber, the dust is electrostatically discharged by means of a ring ionizer to avoid bonding of the dust particles.)

The sample container shall be filled with such a quantity of the sample material that the feed screw will still be covered after one individual measurement has been taken. When filled, the sample container is closed and re-mounted on the feed device.

Start measured-data memory; stopwatch and feed device are started at the same time. This is the actual beginning of the measurement.

During the measurement procedure, the dust collection plates present in the measuring-chamber container are successively removed and stored in a place where they are protected from air movement or other interferences. The beginning of removal and the interval between two times of plate removal depend on the level of dust concentration in the measuring-chamber container.

After five minutes' conveying time, the feed screw is switched off and the sedimentation behaviour of the whirled-up dust is recorded and stored by the measuring chain for a further 350 s. During the sedimentation process, no dust collection plates are removed. Only the phases of dust conveyance are taken into account when determining the removal times t_E.

The dust volume conveyed into the measuring chamber during the measurement is removed, weighed, and the measured value is documented.

3.3 Calculation of calibration curve

Subsequently, a calibration curve is calculated for the dust to be investigated. The five dust collection plates are weighed individually, and the results are documented. By subtracting the masses of the clean dust collection plates the dust mass, m, sedimented on each plate is obtained. Then the dust collection plates are successively placed on an *x*-*y* positioning table. By means of the *x*-*y* positioning table, 12 defined points within the dust-laden area *A* of each dust collection plate are introduced into the measuring path of the calibration measuring head of the dust concentration meter. The measuring voltages displayed are documented for all 12 points, and are then averaged.

Fig.4 shows the light beam and the pollenized glass slide. 12 measuring points on the plate are conducted and averaged to get the dust concentration according Equation (1). A is the dust-laden area, l_K the measuring distance of the IR transmitter and IR receiver of the calibration measuring head.

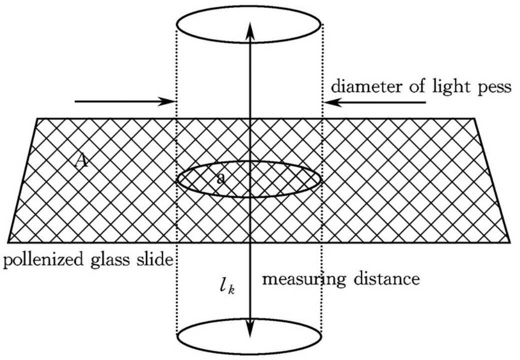

Fig.4 Schematic of dust collection plate during infrared examination using the calibration measuring head of the dust concentration meter

The measuring voltages thus determined are related to the dust concentration c using the equation

$$c = \frac{m}{A \cdot l_K} \qquad (1)$$

where l_K is the measuring distance at the calibration measuring head, according Fig.4.

On completion of the measurement, the value of the dustiness coefficient S is computed.

3.4 Evaluation

Using the calibration curve of the product (see Section 1.3), the measured voltage curves are converted into the corresponding dust concentrations over time.

The dimensionless dustiness coefficient *S* is the arithmetic mean of three individual values of the dustiness coefficient S_i.

The dustiness coefficient S_i of the individual measurement is defined as

$$S_i = \frac{m^3/g}{t_F + t_S} \cdot \int_0^{t_F+t_S} c(t)\mathrm{d}t \qquad (2)$$

Where *m* and *g* are units of length and mass, respectively, and $c(t)$ is the dust concentration measured in the measuring container of the measuring system over time. t_S is the sedimentation time and t_F the conveying time of 300 s.

4. Results and Conclusion

Different dust types used in process industries are examined. They are adopted from different branches of industries such as food industry, mining or metal industry.

Examples for different measured dust types are shown in the following table:

Sample		Wheat flour	Corn starch	Brown-coal dust	Silicon dust	Aluminium dust
Bulk density, in g/cm^3		0,564	0,620	0,5	0,607	0,670
Grain size distribution, Q_3, in %	<32 μm	27,7	100	32,0	93,8	96,8
	<63 μm	51,3	—	58,0	100	100
	<125 μm	93,0	—	83,1	—	—
	<250 μm	100	—	98,0	—	—
	<500 μm	—	—	99,8	—	—
Dustiness coefficient, *S*		0,6	10,2	112,3	5,7	9,2
Standard deviation, in%		7,4	2,9	5,0	2,2	2,2
Dustiness group		1	4	6	3	3

The results show that a dustiness behavior is measured with the above presented system as expected from experience of practice. This measuring principle is a helpful tool to determine dustiness for application in process industries that means the evaluation of the risk of the generation of dust clouds.

References

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