

Keywords: Explosion, dust, meal, characteristic

Equipment and method used to characterise the flammability and explosibility of products handled during the manufacture of animal feeds

1. General

A product's flammability and explosibility potential is reflected in two criteria:

- Its **flammability** value - that can be defined as "its ignition behaviour". Knowledge of this value is crucial to the explosion prevention process (definition of maximum permissible temperatures on machine surfaces or heated bodies, control of static electricity, etc.)
- Its **explosion severity** - that expresses its "explosion behaviour". Knowledge of this value is used in the explosion prevention process (to establish device resistances, vent dimensions, etc.)

A range of parameters can be used to assess product flammability, in particular:

- **Minimum Ignition Energy (MIE)**,
- **Minimum ignition temperature in a dust cloud (MIT)**, also referred to as the spontaneous ignition temperature (SIT) in a dust cloud,
- **Minimum ignition temperature in a dust layer (MIT)**, also referred to as the spontaneous ignition temperature (SIT) in a dust layer,
- **Minimum explosibility concentration (MEC)**

The explosion severity of a pulverulent product is assessed according to two parameters:

- **The maximum pressure** reached during the explosion, expressed as (P_{max}).
- **The maximum pressure build-up rate** reached during the explosion, expressed as $(dP/dt)_{max}$. The second parameter is used to calculate a product's K_{st} (dimension explained in § 0).

2. Influence of the various parameters

Flammability and explosibility parameters are characterised experimentally using laboratory equipment. For a given product, the experimental results for flammability and explosibility parameters are expressed:

- according to the product's physical characteristics, such as:
 - **particle size distribution:** generally speaking, product flammability increases as particle size decreases.
 - **water activity:** generally speaking, product flammability increases as water activity decreases.
 - **ash content:** generally speaking, the higher the ash content, the greater the studied product's mineral matter content, resulting in lower flammability
 - Resistivity
- which depends on the laboratory equipment used and the experiment operating procedures.

Figure 1 illustrates how the particle size of pulverulent products influences their explosibility characteristics. For a given pulverulent product:

- reactivity increases as particle size decreases, i.e. the greater (or more severe) the explosive force, the greater the product's sensitivity to various ignition sources,
- the higher the maximum pressure and maximum pressure build-up rate, the greater the severity of the explosion,
- the lower its minimum ignition energy and its minimum ignition temperature, the greater the product's sensitivity to various ignition sources.

The influence of a pulverulent product's moisture content on its explosibility characteristics is generally similar to that of its particle size.

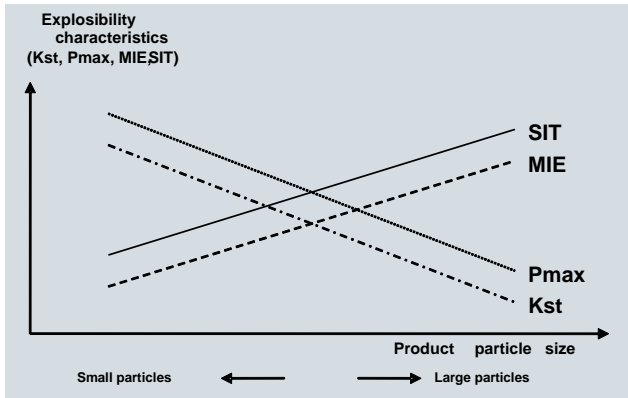


Figure 1: Influence of pulverulent product particle size on their explosibility characteristics.

Making objective use of a product's characteristic explosibility values requires data on:

- the experimental conditions (means and method) used to identify these values,
- the product's physical characteristics at the time of the experiments,
- the representativeness of these physical characteristics at the time of the experiments in relation to the product's physical characteristics under industrial operating conditions.

It is essential that lab technicians are trained in the methods and equipment used to identify the characteristic values of a pulverulent product explosion in order to guarantee an objective interpretation and usage of these values.

3. Presentation of flammability and explosibility parameters

3.1. Minimum Ignition Energy (MIE)

3.1.1. Definition

According to standard NF EN 1127-1, this is the lowest amount of electrical energy stored in a capacitor, under specified test conditions, which, at the time of its discharge, is just sufficient to ignite the most easily flammable atmosphere. This energy is expressed in millijoules (mJ).

3.1.2. Influence factors

A pulverulent product's ignition behaviour depends primarily on its type, particle size distribution, moisture content, and on the concentration and uniformity of the cloud of suspended particles.

3.1.3. Using the parameter

This parameter is used to calculate the energy value above which a pulverulent product may ignite. Knowledge of this parameter helps to prevent ignition risks.

3.1.4. Equipment and apparatus

The minimum ignition energy of a cloud of suspended particles was measured in a modified Hartmann machine, marketed by Kühner AG under the name

"Mike 3". This comprised a 1.2-litre Pyrex tube fitted with an electric spark ignition system, with an energy output that could be adjusted to between 1 to 1000 mJ, based on the following scale: 1, 3, 10, 30, 100, 300 and 1000 mJ.

3.1.5. Method

The chosen experimental protocol was that described in international standard CEI/IEC 1241-2-3 (1994). This international standard states that the minimum ignition energy ranges from the highest energy value at which ignition does not occur during at least 20 successive tests attempting to ignite the mix of suspended particles/air and the lowest energy value at which ignition occurs during 20 successive tests. Tests were also conducted to investigate how turbulence influences the flammability of a cloud of suspended particles.

The minimum ignition energy is determined statistically based on the maximum energy values that did not result in ignition and the minimum experimental energies that sparked ignition.

3.2. Minimum Ignition Temperatures (MIT) in a dust cloud

3.2.1. Definition

According to standard NF EN 1127, under specified test conditions, this is the lowest temperature of a hot surface on which the most highly flammable mix of air/suspended particles ignites. This energy is expressed in degrees Celsius (°C).

3.2.2. Influence factors

Dust cloud MIT mainly depends on the type of pulverulent product involved, its particle size distribution and its moisture content.

3.2.3. Using the parameter

This parameter is used to define the maximum permissible surface temperatures of heated bodies or of system processes and procedures.

3.2.4. Equipment and apparatus

The experiments were carried out using the Godbert-Greenwald furnace. This furnace comprises an electrically heated, vertical silica tube. The thermocouples were calibrated on a straight-line basis in the operating range [20°C - 1000°C] in order to ensure temperature measurements above 500°C at ± 1% and measurements below 300°C at ± 3%.

There are two types of standardised furnace that can be used to conduct dust cloud MIT tests: the vertical Godbert-Greenwald furnace (GG furnace) and the horizontal BAM furnace (Bundes Anstalt für Materialprüfung). Our studies used the GG furnace only. The dust cloud MIT values obtained using one or other of the furnaces are not directly comparable. The bibliography (mainly German) indicates the data obtained most frequently using the BAM furnace.

3.2.5. Method

Based on international standard CEI/IEC 1241-2-1 of 1994, the minimum ignition temperature is determined experimentally by increasing the furnace temperature in successive steps of 50°C until ignition, and then decreasing the furnace temperature in steps of 20°C until no ignition is observed over the last ten tests. The temperature of the first test is set at 500°C. The appearance of glowing, incandescent particles is not considered an ignition. The resulting minimum ignition temperature is corrected by a 20°C reduction for furnace temperatures above 300°C and a 10°C reduction for furnace temperatures below or equal to 300°C. This temperature reduction corresponds to the safety margin applied when working in an explosive atmosphere.

3.3. Minimum Ignition Temperatures (MIT) in a dust layer

3.3.1. Definition

According to standard NF EN 1127, under specified test conditions, this is the lowest temperature of a hot surface that ignites a layer of pulverulent product. Note that for a given product, the dust layer MIT is always lower than the dust cloud MIT. This energy is expressed in degrees Celsius (°C).

3.3.2. Influence factors

Dust layer MIT mainly depends on the type of product involved, its particle size distribution and its moisture content.

3.3.3. Using the parameter

This parameter is used to define the maximum permissible surface temperatures of heated bodies or system processes and procedures.

3.3.4. Equipment and apparatus

The test apparatus comprised a hotplate and a control device. The apparatus must meet a certain number of conditions concerning temperature uniformity and consistency, and calibration of the control device and measuring devices. The ambient temperature, measured by a thermometer placed less than one centimetre from the hotplate, must be between 15 and 35°C.

3.3.5. Method

The measurement was taken according to international standard CEI/IEC 1241-2-1 of 1994. This states that a layer of product with a thickness of 5.0 mm is considered to have ignited if the material starts to glow, or if flames appear, or if a temperature of 450°C or more is measured, or if the temperature increases by 250°C or more in relation to the surface temperature. This temperature is high enough to cause ignition or self-heating, but is no more than 10°C above the temperature that does not cause either ignition or self-heating. This temperature is rounded to the lower multiple of 10°C.

3.4. Minimum Explosibility Concentration (MEC)

3.4.1. Definition

This is the concentration with the lowest combustible substance content that is capable of propagating a flame in a uniform cloud of airborne particles. It is expressed in grams per cubic metre (g/m³).

3.4.2. Influence factors

MEC mainly depends on a product's particle size and moisture content, its ignition energy, and the volume and shape of the chamber.

3.4.3. Using the parameter

Knowledge of the MEC provides insight into whether a given atmosphere may or may not have a concentration that could be considered potentially explosive, or could cause an explosion if a combustion agent and a high enough energy were also present. This is a complicated and fairly challenging parameter to use in an industrial setting as, at present, there is no confirmed technical means capable of taking a reliable and accurate measurement of the concentration of a cloud of suspended particles in:

- a closed, continuous-operation industrial production circuit, with a dense product flow (conveyor belt, elevator, etc.)
- a closed industrial volume (cell, silo, etc.).

3.4.4. Equipment and apparatus

This parameter is characterised on the basis of a 20-litre containment chamber.

3.4.5. Method

This parameter is characterised at the same time as characterising the maximum pressure build-up rate and maximum pressure values obtained during an explosion.

3.5. Maximum pressure build-up rate and maximum pressure obtained during an explosion

3.5.1. Definition

Maximum pressure, expressed as P_{max}:

- According to standard NF EN 1127-1, under specified test conditions, this is the maximum pressure obtained in a closed vessel during the explosion of an explosive atmosphere (Figure 2). The unit is the bar.

Maximum pressure build-up rate, expressed as (dP/dt)_{max}:

- According to standard NF EN 1127-1, under specified test conditions, this is the maximum pressure build-up rate per unit of time obtained in a closed vessel, during explosions of all sorts of explosive atmospheres within the explosibility range of the combustible

substance. The unit is the bar per second (bar/s).

- In a confined chamber, where the maximum explosion pressure is virtually independent of the volume; the maximum pressure build-up rate varies according to volume based on the "cubic law" equation:

$$(dP/dt)_{\max} = K_{St} V^{-1/3}$$

where K_{St} is a constant that is characteristic of the airborne suspension of particles of a pulverulent product. The unit is the bar.m/s.

This relationship was established by experiment - using chambers with volumes that ranged between 0.020 m³ and 60 m³, and shapes that were defined according to a length or height to diameter ratio of less than 5, and has been verified for a 100 m³ chamber.

English language scientific literature suggests four classes of pulverulent product explosion according to K_{St} . The most simple presentation is given below:

Explosion classes	K_{St} values (bar.m/s)
St 0	0
St 1	1 to 200
St 2	200 to 300
St 3	> 300

Table 1: Explosion classes

3.5.2. Influence factors

These parameters mainly depend on the type of product involved, its particle size distribution and moisture content, the initial turbulence of the cloud of airborne suspended particles, the energy of the ignition source, and even the test vessel.

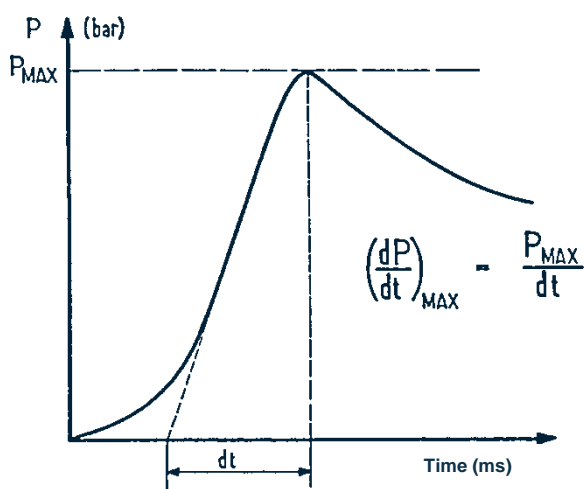


Figure 2: Principle of the variation in explosion pressure according to time for a given concentration of a cloud of suspended particles

3.5.3. Using the parameters

These parameters characterise the force of the explosion and are used to dimension explosion protection measures (vent, etc.).

3.5.4. Equipment and apparatus

These parameters are characterised using a 20-litre containment chamber. The ignition source that may or may not cause an explosion in the chamber develops a total energy of 10 kJ. Note that the energy of this ignition source is significantly higher (and may therefore act as an amplification factor) than the energy emitted by the ignition sources generally found on an industrial site.

3.5.5. Method

For a given product, the maximum pressure and maximum pressure build-up rate are determined by varying the concentration of the cloud of suspended particles. The maximum pressure and maximum pressure build-up rate are not always reached for a given concentration,

4. Conclusion

The laboratory equipment, apparatus and methods described briefly in this datasheet are those that are used to conduct characterisation studies into the flammability and explosion severity of products used in the animal feed manufacture sector.

5. Bibliography

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