

**Keywords:** Explosion, dust, meal, characteristic

## Research campaign into flammability and explosibility parameters of products handled in the animal feed sector

### 1. Background

Table 1 lists the values of explosibility and flammability parameters for the raw materials handled during animal feed manufacture based on a bibliographic study (adapted from the guide to state-of-the-art in the silo sector).

The variability in parameter values can be explained

by the differing particle sizes and moisture contents of the characterised pulverulent products.

Objective use of this data is highly problematic due to insufficient knowledge both of the related experimental methods and equipment, and of the particle sizes and moisture contents of these raw materials.

Product	Pmax (bar)	Kst (bar.m/s)	MIE (mJ)	Minimum ignition temperature (°C)	
				Dust cloud	Dust layer (5 mm)
Wheat	[5 ; 9] (b)	[20 ; 120] (b)	[10 ; 160] (a)	[350 ; 600] (a)	[300 ; 450] (a)
Wheat flour	[7 ; 9] (b)	[30 ; 200] (b)	[10 ; 300] (a)	[400 ; 500] (a)	330(a)
Barley	[5 ; 9] (a)	[10 ; 150] (a)	[10 ; 150] (a)	[400 ; 450] (a)	[300 ; 450] (a)
Maize	[5 ; 9] (b)	[10 ; 130] (b)	[10 ; 300] (a)	[400 ; 450] (a)	[300 ; 450] (a)
Sunflower seeds	[6 ; 8] (b)	[20 ; 90] (b)		[400 ; 500] (a)	350(a)
Alfalfa	7 (c)	90 (c)			
Beet pellets	[5 ; 9] (b)	[20 ; 100] (b)	[10 <sup>3</sup> ; 10 <sup>6</sup> ] (a)	400(a)	270(a)

(a) "Combustion and Explosion characteristics of dust" Berufsgenossenschaftliches Institut für Arbeitssicherheit, BIA-Report, 12/97, HVBG, November 1997  
 (b) BIA and Standard NFPA 61  
 (c) Standard NFPA 61

**Table 1: Explosibility and flammability parameter values for raw materials used in the animal feed sector**

### 2. Focus

In view of the shortage of genuinely usable bibliographic data (see § 1), this study set out to characterise the flammability and explosion severity of products used typically in the animal feed sector, based on empirical scientific experiment.

This study was conducted jointly in 2007 by Tecaliman and the *Laboratoire des Sciences du Génie Chimique* (LSGC), a *Unité Propre de Recherche* (Independent Research Institute) No. 6811 within the CNRS, located at the premises of the *Ecole Nationale Supérieure des Industries Chimiques* in Nancy.

TECALIMAN was responsible for sampling, preparation (division and sifting), packaging and physical characterisation of the tested product samples. The LSGC conducted both physical product characterisations on the samples and experiments used to characterise the products' flammability and explosibility properties. The experimental equipment and apparatus used is described in § 3 of Technical Datasheet No. 69.

### 3. Descriptions of the tested products

#### 3.1. General description

A group of 9 products was selected by a committee of industry representatives. These products were:

5 compound feedstuffs **in meal format**

3 premixes

A particulate deposit taken from the grinder's bag filter.

The main selection criterion was:

- for selected compound feedstuffs, the broadest possible range of raw materials used in meal manufacture.
- for premixes, the composition breakdown in terms of the ratio of mineral/plant materials.

The laboratory equipment used for experimental measurement of flammability and explosibility characteristics cannot be relied on to provide accurate values for particle sizes greater than 800

µm. For this reason, the tested product samples were sifted through a 760-µm screen. Flammability and explosibility properties were therefore characterised using the fine product fraction (fraction that passes through a screen with a mesh size of 760 µm). The particle size of the tested samples placed the products in a higher size category than that of actual industry conditions.

Table 2 And Table 3 list the physical properties of the 5 compound feedstuffs and the 3 premixes that were tested.

### 3.2. Product water activity

The sampled products registered a water activity of between 0.47 and 0.66 (Table 2 and Table 3). The particulate filter deposit registered a water activity of 0.55.

Note that the water activity of these products was

reduced to between 0.1 and 0.3 during the various experiments in order to ensure that:

- the products were all tested under "similar" conditions
- the water activity value selected for the tests lay between standard and industry values.

This experimental water activity placed the products under more stringent conditions than those of actual industry conditions.

### 3.3. Product ash content

The ash content of filter cleaning fines (9.1%) and compound feedstuffs were fairly close (between 9 and 15%). The same did not apply to the 3 premixes (Table 3), which had a far greater mineral matter content than the other 6 products.

Type of compound feedstuff	Grower pig	Dairy cattle	Suckling pig	Rabbit	Finishing poultry
<b>Sampling location</b>	Mixer output	Molasser output	Mixer output	Molasser output	Mixer output
<b>Composition in terms of solid RM</b>	82%: Wheat, Barley and Soyabean cake	84%: Soyabean, Rapeseed and Bran	79%: Wheat, Soyabean and Barley	78%: Sunflower cake, Alfalfa, Bran, Wheat and Beet pulp	81%: Wheat, Sorghum, Soyabean and Rapeseed
<b>Liquid content</b>	4.0%	5.5%	3.5%	1.7%	1.2%
<b>Characteristics of the products sampled at the plant</b>					
<b>Particle size D<sub>50</sub> (Retch method)</b>	530 µm	570 µm	540 µm	540 µm	740 µm
<b>Product characteristics after sifting through a 760 µm-mesh screen</b>					
<b>Particle size - D<sub>50</sub> (Retch method)</b>	280 µm	300 µm	450 µm	290 µm	370 µm
<b>Water activity (aw)</b>	0.66	0.62	0.63	0.64	0.61
<b>Ash content</b>	12.4%	15.3%	12.2%	11.4%	12.2%

Table 2: Characteristics of the tested compound feedstuffs

Type of compound feedstuff	Premix 1	Premix 2	Premix 3
<b>Plant material content</b>	51 to 53%	2 to 4%	20 to 22%
<b>Characteristics of the products sampled at the plant</b>			
<b>Particle size D<sub>50</sub> (Retch method)</b>	220 µm	280 µm	230 µm
<b>Product characteristics after sifting through a 760 µm-mesh screen</b>			
<b>Particle size - D<sub>50</sub> (Retch method)</b>	200 µm	260 µm	220 µm
<b>Water activity (aw)</b>	0.47	0.66	0.61
<b>Ash content</b>	44%	78%	63%

Table 3: Characteristics of the tested premixes

### 3.4. Product particle size

Table 4 gives the particle sizes of tested products in their experimental condition (after sifting). In this table, d50 indicates that the equivalent diameter of 50% of the particles in each characterised sample was below that of the value shown (e.g. 240 µm for grower pig feed), and 50% was above the value shown. The d10 value indicates that 10% of particles had an equivalent diameter below that of the value shown (e.g. 66 µm for grower pig feed). The d10 value represents the finest-grained fraction of each product and, therefore, the fraction most likely to increase their susceptibility to fire and/or explosion. These particle sizes were obtained using a Malvern laser particle size analyser, and cannot be compared against those shown in Table 2 and Table 3, which were obtained using a Retsch sifter

Tested products	Particle size		
	d10 (µm)	d50 (µm)	d90 (µm)
Particulate filter deposit	12	50	155
Grower pig	66	240	610
Dairy cattle	150	410	830
Suckling pig	50	230	580
Rabbit	66	320	805
Finishing poultry	50	270	720
Premix 1	105	260	525
Premix 2	30	115	240
Premix 3	40	200	505

Table 4: Particle size distribution of the tested products

The particle size distributions of the tested products were compared as the particle size of a powdered product may play a key role in a product's susceptibility to fire and/or explosion. These comparisons revealed that:

- Grower Pig and Suckling Pig feeds showed very similar particle size distributions, making the analysis results directly comparable,
- Rabbit and Finishing Poultry feeds also showed comparable particle size distributions,
- Despite their relatively diverse particle size distributions, these 4 compound feedstuffs can be compared as they contain largely similar proportions of fine particulate matter,
- Dairy Cattle feed registered a median particle size distribution of around 500 µm, giving it a lower fines content. Caution should therefore be used when comparing it against the other 4 feedstuffs,
- Premixes 1 and 3 are directly comparable, while caution should be used when comparing premix 2 to the other two premixes, due to its higher ratio of fines,
- Due to its very small particle size, it was not possible to compare the particulate filter

deposit against the other products.

## 4. Experiment results

### 4.1. Minimum Ignition Energy (MIE)

The experiments indicated that the **MIE of the 5 compound feedstuffs and the 3 premixes was above 1 Joule** (which is the upper bound value for the lab-tested MIE).

For the particulate filter deposit taken from the grinder's bag filter, the **MIE was recorded as 180 mJ** (Table 7). The experiments varied the following parameters:

- turbulence of the suspended cloud of particles according to 3 conditions
- water activity of the sample

Water activities	Turbulence condition	MIE (mJ)
0.15	1	610
0.13	2	510
0.28	2	<b>180</b>
0.28	3	740
0.13	3	500

Table 5: Determining the minimum ignition energy of the particulate deposit in the grinder bag filter

This table highlights the extent to which experimental conditions influence the expression of MIE. Here, the recorded MIE gave significantly lower results than those obtained under the other experimental conditions.

### 4.2. Minimum ignition temperatures (MIT) in a dust cloud

The minimum ignition temperature in a dust cloud was determined for a product water activity of between 0.11 and 0.21. The results analysis (given in Table 7) suggests that:

- The MIT in both the animal feed dust clouds and in the particulate filter deposit were fairly similar.
- The expression of the tested products' minimum ignition temperature is influenced by the products' ash content. This influence can be seen clearly in the 3 premixes.

### 4.3. Minimum ignition temperatures (MIT) in a dust layer

The dust layer MIT for the particulate deposit in the grinder bag filter was recorded as 180°C. This test was performed on the particulate filter deposit only, as the lower sensitivity of the other products in this case did not allow measurement of their MIT in a dust layer.

#### 4.4. Minimum explosibility concentration (MEC), Maximum pressure build-up rate $(dP/dt)_{max}$ and maximum pressure $(P_{max})$

Note that these 3 values were characterised during the same experimental phase, and were experimentally tested for each product. Table 7 lists the selected characteristic values, which were determined for a product water activity ranging from 0.11 to 0.25.

The maximum pressure and maximum pressure build-up rate  $(dP/dt)_{max}$  values recorded for each product corresponded to a given air/particle concentration ratio (Table 6). The experiment results suggest that the explosion pressure is "relatively stable" over a given range of concentrations (Table 6).

Figure 1 illustrates the change in the explosion pressure  $(P_{max})$  and pressure build-up rate  $(dP/dt)_{max}$  values recorded during the tests on the grinder's particulate filter deposit. The values for maximum pressure and pressure build-up rate  $(dP/dt)_{max}$  are illustrated by the encircled plot points. The maximum recorded pressure seen on this graph can be identified at a concentration of 1250  $g/m^3$ . On closer inspection, this graph clearly shows that this explosion pressure is virtually identical at concentrations ranging from 750 to 2000  $g/m^3$ .

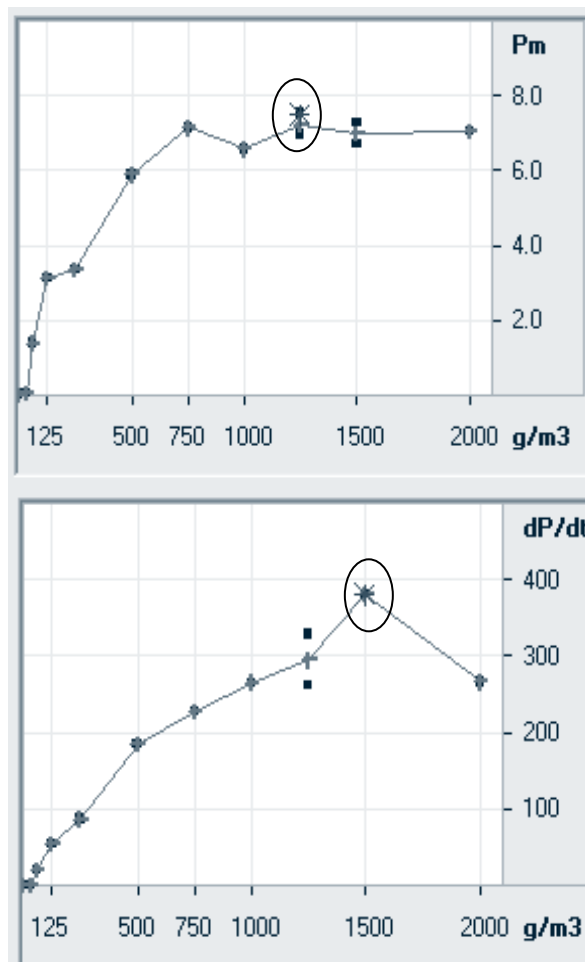


Figure 1: Change in explosion pressure  $(P_{max})$  (on left) and pressure build-up rate  $(dP/dt)_{max}$  (on right) according to the concentration of the particulate deposit on the filter

	Particulate filter deposit	Grower pig	Dairy cattle	Suckling pig	Rabbit	Finishing poultry	Premix 1
$P_{max}$	1250	750	750	1000	750	750	1250
	≈ 750 to 2000	-	≈ 500 to 1250	≈ 500 to 1250	≈ 500 to 1000	≈ 500 to 1500	≈ 1000 to 1500
$(dP/dt)_{max}$	1500	750	750	1250	1000	1000	1250

Table 6: Concentrations ( $g/m^3$ ) with a defined maximum pressure and maximum pressure build-up rate during an explosion

It should be stressed that premix 2 and premix 3 (premix with the highest mineral matter content) did not explode at concentrations ranging from 60 to 1500  $g/m^3$ .

The values for minimum explosibility concentration, maximum pressure and maximum pressure build-up rate were determined experimentally (within the containment chamber) using an ignition source with a developed energy that was significantly higher than the developed energy of an electrostatic discharge in an industrial setting.

## 5. Summary of the findings

While it is always difficult to compare the flammability and explosibility of a range of products, certain general trends and conclusions can nevertheless be drawn. There is an established link between a product's mineral matter content and its flammability and explosibility values; products with a very high ash content (premixes) tend to have lower flammabilities (MIT, MIE and MEC higher than those of the 5 compound animal feeds) and lesser explosive strength ( $P_{max}$  and  $K_{st}$  are lower, or even non-existent).

Despite the differences in raw material composition

and the minor fluctuations in particle size, all 5 compound feedstuff gave fairly similar results: MIT were close to 580°C to 610°C, MIE were higher than 1 Joule, MEC was close to 30 g/m<sup>3</sup>, Maximum overpressure ranged between 6.2 and 7 bars Pressure build-up rates were approx. 160 bars/s, giving a Kst of approx. 40.

The product with the highest sensitivity was filter cleaning fines, which had the highest explosibility rating among all the tested samples (the strongest overpressure and the highest Kst).

In addition to premixes 2 and 3, which did not explode under the experimental conditions of these tests, premix 1 was the least sensitive and least hazardous sample out of all those tested, which exploded within a 20-litre chamber (very low Kst). Premix 1 can be considered the least sensitive product with a minimum explosibility concentration of 125 g/m<sup>3</sup>.

Kst plots generally remained within the interval [0 ;105] corresponding to category St1 pulverulent products.

## 6. Conclusions

All the products were tested under conditions that were more stringent than those found in actual industry conditions.

- All the products had a lower moisture content,
- All the products had a smaller particle size, in particular, for the 5 compound feedstuffs,

- the ignition energies developed during MEC, P<sub>max</sub> and (dP/dt)<sub>max</sub> laboratory tests were higher than those potentially present in an industrial setting.

Note that concerning this last point, some authors have demonstrated that maximum pressure and maximum pressure build-up rate vary according to ignition source where products with low flammabilities are concerned (the general case for the tested products), but virtually no such effect is apparent in highly flammable products.

Analysis of the results highlights the importance of being fully familiar with the experimental methods and equipment used to define the recorded characteristic values.

If the operator does not have a practical, representative value that can be used to characterise the explosibility and flammability of the products used at their site then, as a precautionary measure, it would be advisable to use the values taken from the bibliography that characterise the product's maximum reactivity values.

## 7. Bibliography

i'Doc\_E19, 2005, Guide de l'état de l'art de l'industrie de la Nutrition Animale relatif à la prévention et à la protection des risques d'incendie et d'explosion de poussières

i'Doc\_G10, 2007, SYMPOSIUM TECALIMAN 2007

i'Doc\_G8, December 2007, Matériel et méthode de Caractérisation de l'inflammabilité et de l'explosivité de produits manipulés en alimentation animale

Tested products	Physical characteristics		Flammability characteristics				Explosibility characteristics		
	Ash content (%)	Particle size d10 (µm)	MIT dust cloud (°C)	MIT dust layer (°C)	MIE (mJ)	MEC (g/m <sup>3</sup> )	P <sub>max</sub> (bars)	(dP/dt) <sub>max</sub> (bar/s)	K <sub>max</sub> (bar.m/s)
Particulate filter deposit	9.4	12	180	550	180	> 30 < 60	7.5	381	103
Grower pig	12.4	66	-	600	> 1000	≈ 30	7.0	163	44
Dairy cattle	15.3	150	-	610	> 1000	≈ 30	6.6	159	43
Suckling pig	12.2	50	-	600	> 1000	≈ 30	6.2	122	33
Rabbit	11.4	66	-	580	> 1000	≈ 30	6.8	162	44
Finishing poultry	12.2	50	-	590	> 1000	≈ 60	6.6	144	39
Premix 1	44.4	105	-	620	> 1000	≈ 125	5.2	52	14
Premix 2	78.1	30	-	> 900	> 1000	-	0	0	0
Premix 3	63.2	40	-	710	> 1000	-	0	0	0

Table 7: Summary of selected flammability and explosibility values