The Explosibility of Flour, Gluten and Wheat Dust

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Summary

Dust explosions require the presence of an explosible dust, air/oxygen and a source of ignition. Flour, wheat and related dusts have explosive qualities - but fall within the category of the least explosible of dusts. Recent research commissioned by **nabim** has presented consistent and logical results for the Kst values (the rate of maximum pressure rise) for a range of dusts to be found in a flour mill; the research confirms that flour is low on the level of explosible dusts. Appendix 2 sets out the three explosion classes and gives examples of each.

The research found Kst values for various flour dusts that ranged from 53-100bar.m/sec; for wheatfeed in the middle of that range; and for various wheat dusts from 105-122bar.m/sec, However, a sample of gluten at 6.7% moisture recorded an unexpectedly high value of 149bar.m/sec. As a result, **nabim** has encouraged flour millers to obtain accurate data from their gluten suppliers.

The minimum ignition energy levels recorded in the research gave no cause for concern, other than that for gluten for which the value was identified as 30-100mJ. However, even this level does not require millers to take any additional precautions.

The information contained in this booklet should provide flour millers with all the data they require to identify the explosibility characteristics of their raw materials and products in the Explosion Protection documents that they will be drawing up in line with the requirements of the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR). The exception is where millers use uncommon processes; for example, producing very dry flours. In such instances, they should carry out their own tests to establish whether there is any additional hazard. Also, millers may use some ingredient dusts which were not tested in this research; companies should seek information on the explosibility of these ingredients from their suppliers.

Responsible milling companies should not find the implications of either DSEAR or the **nabim** research too onerous. However, both should encourage millers to assess risk systematically and to ensure that the proper management procedures are in place.

Introduction

The fact that flour and other wheat products such as gluten, when dispersed in air, are capable in some circumstances of giving rise to a dust explosion has been known for a great number of years. In the UK, **nabim** has always been alive to this hazard and has, since the 1960s, produced several pieces of guidance on the prevention of fire and dust explosions.

In spite of the long-term awareness of the hazard, until the late 1980s relatively little had been published on the explosibility properties of flour and wheat gluten; the data which was in the public arena was generic and unspecific both in terms of substance and test methodology. It was generally accepted that flour fell into the least hazardous class (St1) of explosive dusts but little more was known.

Then within a period of a few years, two programmes of tests aimed at increasing understanding of the subject were undertaken:

1. Measurements of the maximum pressure and maximum rate of pressure rise for a number of types of flour (sponsored by **nabim**);

2. Measurements of the minimum ignition energy of flours, glutens and collector dusts (sponsored by Rank Hovis Ltd).

Both these series of tests were carried out by Chilworth Technology Ltd, Southampton, and some results are shown in tables 2 and 3.

In 2001, prompted by the European ATEX Directive, now implemented in UK law by the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR), **nabim** commissioned further research into the explosive properties of flour, gluten and wheat dusts. This project was undertaken by Burgoyne Consultants Ltd, Runcorn, and was far more extensive than previous research, looking at – initially – twelve different sample dusts.

The results of the tests are contained in table 1 and summarised along with their significance in the following paragraphs. (The full Burgoyne Consultants report is available to **nabim** member companies free of charge on request. Other organisations wishing to purchase a copy (price £500) should contact **nabim**.)

The dusts and the tests

nabim wished its new research project to cover the whole range of wheat-related dusts that might be found in the mill. The costs of testing for explosive characteristics is high; **nabim** therefore sought to ensure that the range of samples chosen provided a complete picture of the milling process. Ten samples were chosen:

1. a high protein white breadmaking flour (no added gluten);
2. a Chorleywood breadmaking flour;
3. a biscuit flour;
4. a heat-treated cake flour;
5. wholemeal;
6. gluten;
7. (mill head end) dust collector stock;
8. wheatfeed;
9. wheat dust;
10. screenroom filter dust.

All the samples were tested for maximum pressure (Pmax), maximum rate of pressure rise (Kst) and minimum ignition energy (MIE).

In order to make the research as relevant as possible to the situation found in a mill, sample 5 was tested 'as received' from the mill whilst samples 1 and 8 were tested both 'as received' and having been sieved in accordance with standard scientific protocol. This meant that twelve sample dusts were tested. Following completion of the project, **nabim** commissioned further tests on a thirteenth sample, a 90:10 mixture of samples 1 and 6.

Other tests

Some of the samples were also tested for other explosive characteristics. Samples 1 and 8 (both as received and sieved) were tested for both minimum ignition temperature (MIT) and layer ignition temperature (LIT). Samples 5 (as received), 6, 9 and 10 were tested for MIT. Sample 1 (as received) was tested for minimum explosive concentration.

Preparation of the samples

All the samples were collected through the generous assistance of Rank Hovis Ltd. Each sample was tested for moisture and protein content before being coded and despatched, in sealed containers, to Burgoyne Consultants, who again tested each sample for moisture and protein. Once the tests had been completed, the remainder of the samples were returned to Rank Hovis for repeat testing to ensure that there could have been no possibility of samples having become misidentified during the research process. (In the event, **nabim** had reservations about the particle sizes, as calculated by Burgoyne Consultants, using mechanical sieving. The check testing carried out by Rank Hovis, using the Malvern apparatus, revealed nothing untoward about the samples.)

The Test Results

Maximum rate of pressure rise

The Kst values for the various flour samples were generally lower than previously published research and confirmed that values substantially above 100 are unlikely. Kst values for wheat dust and all other dusts were a little higher, though still well within the St1 explosion class.

For the various flours, the range was between 53bar.m/sec for wholemeal (sample as received) and 100bar.m/sec for heat-treated cake flour (6.6% moisture). Wheatfeed recorded Kst values of 79 (as received) and 69 (sieved according to standard testing protocol). Samples with higher values were dust collector stock (105); wheat dust (112); screenroom filter dust (122); and gluten at 6.7% moisture (149).

Minimum Ignition Energy

All samples with Kst values of under 100 recorded MIEs in excess of 1000mJ. Samples with Kst vales between 100 and 122 recorded MIEs of between 300 and 1000mJ.

The MIE for gluten was recorded at 30-100mJ because one sample, of 1200mg, was ignited at the tenth attempt at 100mJ. (Samples of 600mg and 900mg did not ignite in ten attempts.) Previous research findings have been highly variable but Cerestar quote 120mJ.

Gluten

nabim raised its concerns over the Kst and MIE results for gluten with Burgoyne Consultants, who stated that "the only conclusion (we) would draw is that the actual MIE ... may lie closer to 100mJ than 30mJ at which no ignitions occurred. However, in practice this is not significant as European guidance on electrostatic hazards does not require any additional control measures for materials with an MIE of 30mJ over materials with an MIE of 100mJ." Burgoynes also stated that "the gluten sample tested is more sensitive (than the other samples tested) to electrostatic sources of ignition but not sufficiently so that additional precautions are required to preclude an electrostatic ignition risk".

Burgoynes saw no practical benefit in conducting further research into either the Kst or MIE of gluten. **nabim** agreed but considered that further MIE and Kst tests should be commissioned on a mix of 90% high protein white breadmaking flour and 10% gluten, both substances being drawn from the original test samples. This new mixed sample had a Kst value of 84 bar.msec; a Pmax of 7.3bar; and a MIE of >1000mJ, so confirming that any likely high protein flour with added gluten would have explosibility characteristics far closer to flour than to gluten.

Maximum Pressure

Readings range from 6.6bar (wheatfeed) to 8.8bar (wheat and screenroom filter dust); similar to previous findings although a little higher for the wheat/filter dusts.

Minimum Ignition Temperature

Lowest amongst any samples was 430C (flour). In line with previous research.

Layer Ignition Temperature

None of the four samples tested gave a LIT of below 450C. This data is new and, though needed, gives little cause for concern.

Minimum Explosible Concentration

Recorded for white breadmaking flour as $50g/m^3$. "This result confirms that a flammable dust cloud will be very dense and is unlikely to occur in the general workplace."

Implications of the Test Results

The risk of explosion from wheat dust and related components of wheat has been understood by the flour milling industry for many years. The evidence presented by the latest research project has strengthened this knowledge. An encouraging aspect of the project's conclusions is that although there are measurable risks, they can be controlled and the likelihood of an explosion is low.

With MIEs in excess of 1000mJ for most of the tested samples, no special arrangements are required other than the earthing of metal containers. There are no further requirements given the MIEs of 300-1000mJ for wheat dusts and filter stock. The finding of a possible MIE for gluten below 100mJ is of concern but still does not require further precautions to be taken. However, increased vigilance of gluten plant is advised.

The Kst values confirm that flour and wheat dusts generally lie around the halfway mark in explosion class St1. There appears to be a correlation between Kst value and moisture content / particle size.

The MIT and LIT values are used in the selection of equipment. The maximum thickness of powder deposits on the surface of equipment should not exceed 5mm. The temperature of the surface: should not exceed two-thirds of the MIT value; and should be at least 75C below the LIT value. The values are used in the selection of the T1 - T6 rating of equipment.

A minimum explosion concentration of $50g/m^3$ confirms that a high density dust cloud is required for there to be a significant risk of a dust explosion.

The figures for maximum pressure rise are of most concern to silo and milling equipment manufacturers; millers should ensure that their suppliers are using the correct HSE-approved formulae to calculate the strength of equipment needed.

Thus, **nabim**'s research demonstrates that there is not a high risk of explosion with wheat dusts, provided there is the proper management of what risk there is. The potential for a dust explosion is present in all mills and, given the appropriate circumstances, can and will occur.

Millers should therefore be vigilant to the problems and consider what is required to prevent dust explosions.

The priorities in turn should be:

1. avoidance of dust clouds;
2. elimination of ignition sources;
3. containment;
4. suppression;
5. venting.

Greatest care should be given to those areas or processes with a higher measurable risk, i.e. drying, filter stocks, bin filling. Good housekeeping within a milling plant are essential, not only for the control of infestation but for the reduction of explosion risk.

Elimination of ignition sources should include consideration of:

- mechanical friction;
- hot work (e.g. welding);
- grinding;
- electrostatic discharge;
- smoking;
- lighting and electrical equipment;
- spontaneous combustion;
- risk of fire.

Training and the provision of information and instruction to all staff are valuable components of an explosion prevention strategy, preventing ignorance from contributing to an incident.

Finally, adherence to the requirement of DSEAR will concentrate activity on the systematic assessment of risk and the provision of safe procedures for milling plant.

APPENDICES

1. Glossary

2. Explosibility Classification

3. 2002 Test Results

4. Previous nabim / Rank Hovis Research

Appendix 1 - 'Glossary'

Kst and Pmax:
measuring the maximum rate of pressure rise should a dust explosion occur, the Kst value is determined in a 20litre sphere, in accordance with ISO 6184/1-1985 (BS 6713 Part 1). The maximum explosion pressure (P_{max}) is also determined as an integral part of this test.

Minimum Ignition Energy (MIE):
is the lowest energy value of a high-voltage capacitor discharge required to ignite the dust cloud at atmospheric pressure and room temperature. The MIE is determined by testing in the MIKE 3 apparatus, expected to be the basis of the European standard.

Minimum Ignition Temperature (MIT):
the minimum temperature at which a dust cloud will explode. The MIT is determined using a Godbert-Greenwald furnace; testing is carried out in accordance with BS EN 50281-2-1: 1999. Note – European standards require that surface temperatures of electrical equipment should not exceed two-thirds of the MIT of the dust cloud which might occur.

Minimum Layer Ignition Temperature (LIT):
the minimum temperature at which a dust layer will ignite when exposed to a heated surface, determined using a 200mm diameter hotplate and 5mm thick dust layer. Testing is carried out in accordance with BS EN 50281-2-1: 1999. Note – European standards require that the surface temperature of electrical equipment should not exceed 75K (=75C) below the LIT.

Appendix 2 - Explosibility Classification

Explosion severity can be characterised by the maximum explosion pressure generated in a closed vessel and the maximum rate at which the pressure increases in the explosion.

Dusts can thus be classified by their explosibility, as defined by their Kst value, i.e. the maximum rate of pressure rise in the event of an explosion. The Kst value is measured in bar.m/s.

The most explosive dusts are classified as St3, applied to those with Kst values in excess of 300bar.m/s; examples are typically metals, aluminium for example.

The next classification is St2, applied to dusts with Kst values of between 201 and 300 bar.m/s; many ‘man-made’ products fall within this classification, as do some coal dusts.

Classification St1 is applied to dusts with Kst values of between 1 and 200 bar.m/s. Examples range from coal dust (c150-220) through wheat, flour and other cereals and cereal products (50-100) to dusts which are barely explosible. Most materials handled ‘in bulk’ fall into the St1 class.

For a dust to be classified as St0, it must have a Kst value of 0 bar.m/s; in other words, it is not explosible.

Appendix 3 - Summary of Testing carried out for Europea

Test Material	Moisture	Protein	Protein	Ash	Particle Size * Median (tested)	MIE	Pmax
	%w/w	% as is	% d.b.	% d.b.	µm	Mj	bar
HP white breadm'g	13.4	12.7	14.8	0.58	(<63)	>1000	6.9
HP white breadm'g (tested as received)	13.4	12.7	14.8	0.58	>63 as received	>1000	6.8
HP white breadm'g (with 10% gluten)	12.1	-	-	-	63-90	>1000	7.3
Chorleywood flour	13.6	9.8	11.4	0.70	>63 (<90)	>1000	7.2
Biscuit flour	13.1	9.5	11.0	0.73	>90 (<90)	>1000	7.5
Heat-treated cake flour	6.6	8.6	9.3	0.60	>63 (<90)	300-1000	7.8
Wholemeal (tested as received)	12.9	14.2	16.4	-	>63 as received	>1000	6.8
Gluten	6.7	71.9	77.5		>38 (<63)	30-100	7.3
Collector stock	12.9				>90 (<125)	300-1000	7.7
Wheatfeed	13.5				(<250)	>1000	7.0
Wheatfeed (tested as received)	13.5				>250 as received	>1000	6.6
Wheat dust	11.5				>63 (<38)	300-1000	8.8
Screenroom filter dust	11.5				>38 (<38)	300-1000	8.8

***** The particle size data from Burgoyne Consultants, quoted above, were obtained using mechanical sieving. Data obtained in the industry for these typical products, using Malvern apparatus, may differ from the above

ting carried out for European Flour Explosibility Project

Pmax	Kst	Explosion Class	MIT	LIT	MEC	Combustion Rating
bar	bar.m/s		C	C	g/m^3	
6.9	65	St1	430	>450		
6.8	68	St1	430	>450	50	1
7.3	84	St1				
7.2	66	St1				
7.5	91	St1				
7.8	100	St1				1
6.8	53	St1	430			
7.3	149	St1	470			
7.7	105	St1				
7.0	69	St1	470	>450		
6.6	79	St1	510	>450		1
8.8	112	St1	470			
8.8	122	St1	450			

btained using mechanical sieving.
paratus, may differ from the above.

Appendix 4 – Previous nabim and Rank Hovis Research Data

(undertaken by Chilworth Technology Ltd c1988-1991)

Type of flour	Moisture Content	Protein Content (14%m.c.)	Median Particle Size	Maximum Pressure	Kst	Minimum Ignition Energy
nabim						
Bakers	13.5	12.3	64	6.6	95	-
Bakers	8.4	12.2	61	6.9	101	-
Bakers	4.3	12.3	62	6.7	112	-
Chorleywood	14.7	10.6	71	7.1	80	-
Chorleywood	7.9	10.5	66	7.0	74	-
Chorleywood	3.6	10.4	72	6.7	107	-
Biscuit	12.6	8.8	46	7.1	108	-
Cracker	13.7	10.3	81	6.3	96	-
Filter	13.7	15.9	21	6.4	108	-
Cake (heat-treated)	4.1	8.9	39	6.6	118	-
Wheat dust	11.8	9.6	45	6.4	89	-
Rank Hovis						
Chorleywood	7.8	-	-	-	-	>500
Dried	1.5	-	-	-	-	250-280
Gluten	7.3	-	-	-	-	400-480
Gluten	8.3	-	-	-	-	450-500
Pneumatic collector dust	5.3	-	-	-	-	200-210
Collector dust	5.5	-	-	-	-	400-450

Produced by **nabim**