Forschungsgesellschaft
für angewandte
Systemsicherheit und
Arbeitsmedizin

FSA- Research Report

Constructional Explosion Protection for Elevators

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Project No.: F-05-0701

Date: 15.06.2010

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Project:	Constructional Explosion Protection for Elevators
Project-No.:	F-05-0701
Experimental investigations:	Test centre of FSA/BGN, Ganseck 4, 77876 Kappelrodeck, Germany
Date of investigation:	18.05.2007 – 26.11.2008 02.09.2008 – 09.10.2008 (malt dust 2) 18.06.2009 – 24.06.2009 (additional test with maize starch)
Test-execution:	W. Fischer, M. Roth, H. Wolf, Dr. Roser

Contents

Abstract

Bucket elevators are widely used for the vertical conveying of combustible bulk materials. Depending on the operational conditions, the occurrence of explosible dust/air mixtures, as well as potential ignition sources, have to be assumed. In many cases measures for the prevention of ignition sources are not sufficient; therefore additional safety design features must be taken.

Due to the fact that there was no sufficient data base to design explosion resistant bucket elevators in combination with explosion venting, large scale tests were carried out on the test site of BGN and FSA in Kappelrodeck, Germany. The test will be described and their results presented.

1 Introduction

Elevators are machines for the vertical conveying of bulk material. There are different types of such elevators, but for conveying bulk material with a powder density below 1 kg/dm^3, (typical for combustible bulk materials) mostly bucket elevators are used. Traction mechanisms are chains or belts, where the buckets are mounted. For bulk material, with a powder density of < $1 kg/dm^3$, usually belts are used.

The available investigations refer to twin-leg bucket elevators (up and down leg) with belts used as traction mechanism. The belt bands are driven by friction connection, over a return pulley in the elevator head. This design is widely used with conveying heights up to 50 m and with conveying capacities up to 600 t/h.

The conveyed bulk materials might be quite different, e.g. granulates, grains or pellets, which can contain more or less fine dust. The fine dust is dispersed by the moving buckets, this way an explosive dust/air mixture can occur inside the elevator. Effective ignition sources are possible from the equipment itself as well as from external e.g. foreign objects [1]. Therefore the dust explosion hazard of buckets elevators (figure 1) must be taken into consideration.

Depending on both, the operational conditions and the explosion characteristics of the bulk material, measures taken to avoid ignition sources are often not sufficient to minimize the risk of a dust explosion. Therefore additional design measures for explosion protection must be taken (e.g. explosion venting), in order to limit the dangerous effects of explosions. However, the technical rules or standards which are available for the layout of explosion pressure venting or explosion suppression [2,3] cannot be used due to the special geometry of bucket elevators.

2 State of the art and objective

It is known from previous investigations [4-6] that an explosion can occur if the bucket elevator is fully loaded with explosible bulk material. Under such operating conditions, the dust concentration is in the range of, or exceeds the upper explosion limit and the explosion pressure is quite low. In general clear below 0.5 bar. However, the highest explosion pressure and maximum flame speed can occur when the elevator is in no-load operation.

In this case dust deposits are swirled up through the fast running buckets and even optimum dust concentrations can occur regarding to the explosion course. Under this condition, depending on the bulk material characteristics, one has to expect high flame velocities and high explosion pressures.

Therefore, former experimental research was carried out with optimum dust concentration from 500 to 1000 g/m³. The explosion tests in general were designed in such a way, that dust chambers were under overpressure (e.g. 20 bar) and a defined amount of dust was blown into the running elevator at the elevator head, boot and both legs.

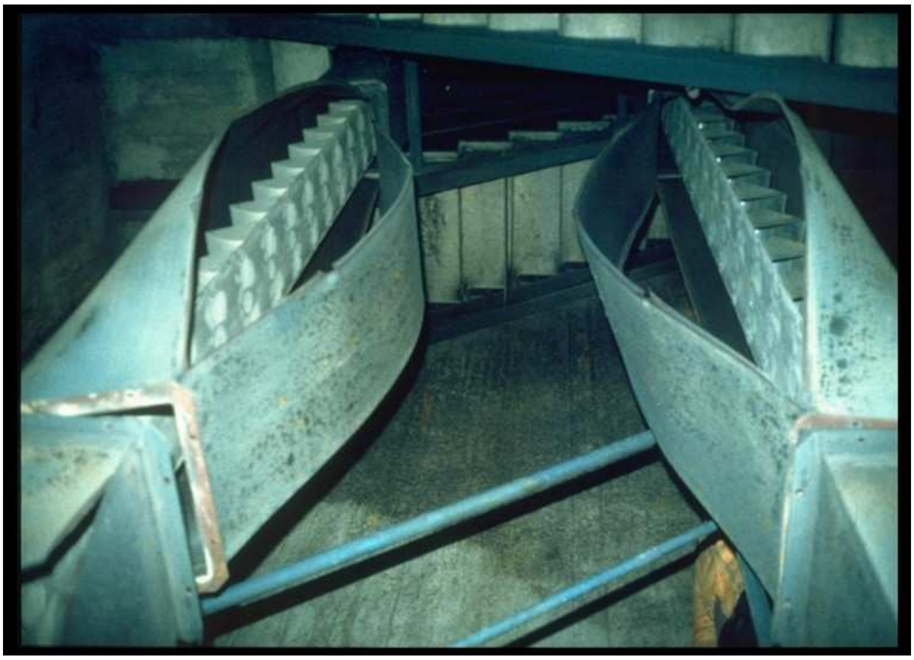

Figure 1: Destroyed twin-leg bucket elevator due to a dust explosion

As a result, Bartknecht [4] requires a pressure shock resistant design of 3 bar if the elevator is protected by extinguishing barriers, when combustible dusts of dust explosion class St1 ($K_{St} \leq 200$ bar·m·s^{-1}) are conveyed. If the conveying height is bigger then 30 m, additional chemical barriers are necessary.

For the calculation of the explosion pressure venting in bucket elevators, numerous explosion experiments were carried out by P. Holbrow and G.A. Lunn [5]. They examined bucket elevators in single and twin leg versions. As test dust, milk powder (K_{St} = 86 bar·m·s^{-1}) and different maize starches were used (K_{St} = 147, 180 and 211 bar·m·s^{-1}).
In principle, the explosion pressure was much higher when a dust injection system was used, in comparison to the tests under practical operating conditions.
An interesting result was that reducing the bucket spacing (bucket spacing ≤ 280 mm) due to the obstruction of the elevator legs damps the explosion course if the dust specific K_{St} value is below 150 bar·m·s^{-1}. However, when maize starch with K_{St} = 211 bar·m·s^{-1} was used, an obvious increase of the flame velocities and the explosion pressures could be observed.
The reason is that the reduction of the bucket spacing increases the turbulent flow conditions inside the elevator legs. Using dust with higher burning velocity and therefore

higher K_{St}-value, could affect the increasing of the explosion violence in a stronger way than the built in parts (buckets) through damping and heat absorption affect the deflagrating combustion.
In general the explosion tests were carried out with vent openings at the elevator head and boot. The size of each venting area was equal to the cross-sectional area of the elevator legs. In dependence on the elevator strength and the K_{St}-values additional vent openings have to be installed in defined distances along the elevator legs. The maximum allowed distances can be taken from a diagram.

The existing results are still an unsatisfactory base for the layout of explosion pressure resistant design in combination with explosion venting. The reason is that most of the tests were conducted with dusts with a K_{St}-value of ~ 200 bar·m·s^{-1} using dust injection systems. This leads to very high requirements regarding the pressure shock resistant design (Bartknecht), which in reality is difficult to fulfil. In fact, the typical bulk materials, which are conveyed in elevators, with few exceptions have K_{St} values below 150 bar·m·s^{-1}
The investigation results from Holbrow and Lunn gave valuable information towards a fundamental understanding of the course of dust explosions in elevators (e.g. influence of the bucket spacing). Looking at the test results of dusts with a Kst = 150 bar·m·s^{-1}, they do not always seem to be plausible. In addition, the explosion tests (pre-tests) of FSA with a dust with low K_{St}-value (wheaten flour type 550 with K_{St} ~ 100 bar·m·s^{-1}) showed higher explosion pressure than comparable tests from Holbrow and Lunn. This could be explained by the different product properties, e.g. dusting number (dispersing) and the different construction form (volume) of the boot of the elevator.

The aim of new experimental investigations was to extend the knowledge of the dimensioning of explosion pressure resistant design in combination with explosion venting of bucket elevators taking into consideration of the existing research results.

Project objective:

- Constructional explosion protection in rectangular twin leg bucket elevators
- Optimization of the layout of explosion pressure resistant design in combination with explosion venting
- Execution of the explosion tests under approximately realistic operation conditions
- Using of bulk material with K_{St} ~ 100, 150 and 200 bar·m·s^{-1}
- Introduction of the results into European standardizations

3 Experimental set-up

For the explosion tests a twin leg bucket elevator with a total height of about 15 m was used. After a violent explosion test in the standard version the test elevator was rebuilt with enhanced pressure resistance of about 3.5 bar. Regarding the flame propagation throughout the elevator legs, the obstruction effects of the bucket installations inside and the cross sectional area of the elevator legs play a very important role. Therefore a typical state of the art bucket elevator was used. The maximal all over wall clearance was less than 70 mm. A bigger wall clearance could encourage the flame acceleration and therefore cause higher explosion pressures as it was measured in the used elevator. The geometrical dimensions and technical data are given in Table 1.

The test elevator could be equipped with pressure venting devices at the elevator boot, head and both legs (about 6 m above the elevator boot). The size of each pressure venting area was equal to the cross sectional area of the elevator legs of 0.105 m². The static activation overpressure of the venting device was p_{stat} = 0.1 bar.

Table 1: Technical data of the twin-leg bucket elevator

Total height	15125 mm
Leg size	270 mm x 390 mm
Cross-sectional area (leg)	0.105 m²
Bucket size	165 mm x 280 mm
Bucket / m	7.5
Bucket volume	~ 3 l (~ 1.8 kg maize starch)
Bucket spacing	130 mm
Wall clearance front	~ 60 mm
Wall clearance side	~ 55 mm
Wall clearance rear	~ 45 mm
Free cross-sectional area	54 %
Sectional obscuration factor	46 %
Conveying capacity	~ 150 t/h grain (bulk weight: 0.75 t/m³)
Conveying velocity	3.5 m/s
Venting area (each)	0.105 m²

The elevator was connected to an extraction system via a dust collecting pipe DN100.
Piezoelectric pressure transducers and infrared sensitive indicators were used for the measurement of the explosion course. They were installed in the boot, head and at defined distances along the up leg and down leg.

A sketch of the twin leg bucket elevator is shown in Figure 2, where the explosion venting areas, the pyrotechnical igniter and the pressure and flame sensors are shown. Figure 3 exemplifies an explosion test in a scaffold elevator, where the pressure venting occurred in the elevator boot, head and in both legs. It was an explosion transfer, with flame front propagation from the bucket elevator, through the dust collecting pipe, diameter DN 100 (length l = 15 m) into the pressure vented cyclone (that can be seen on the right side of the elevator).

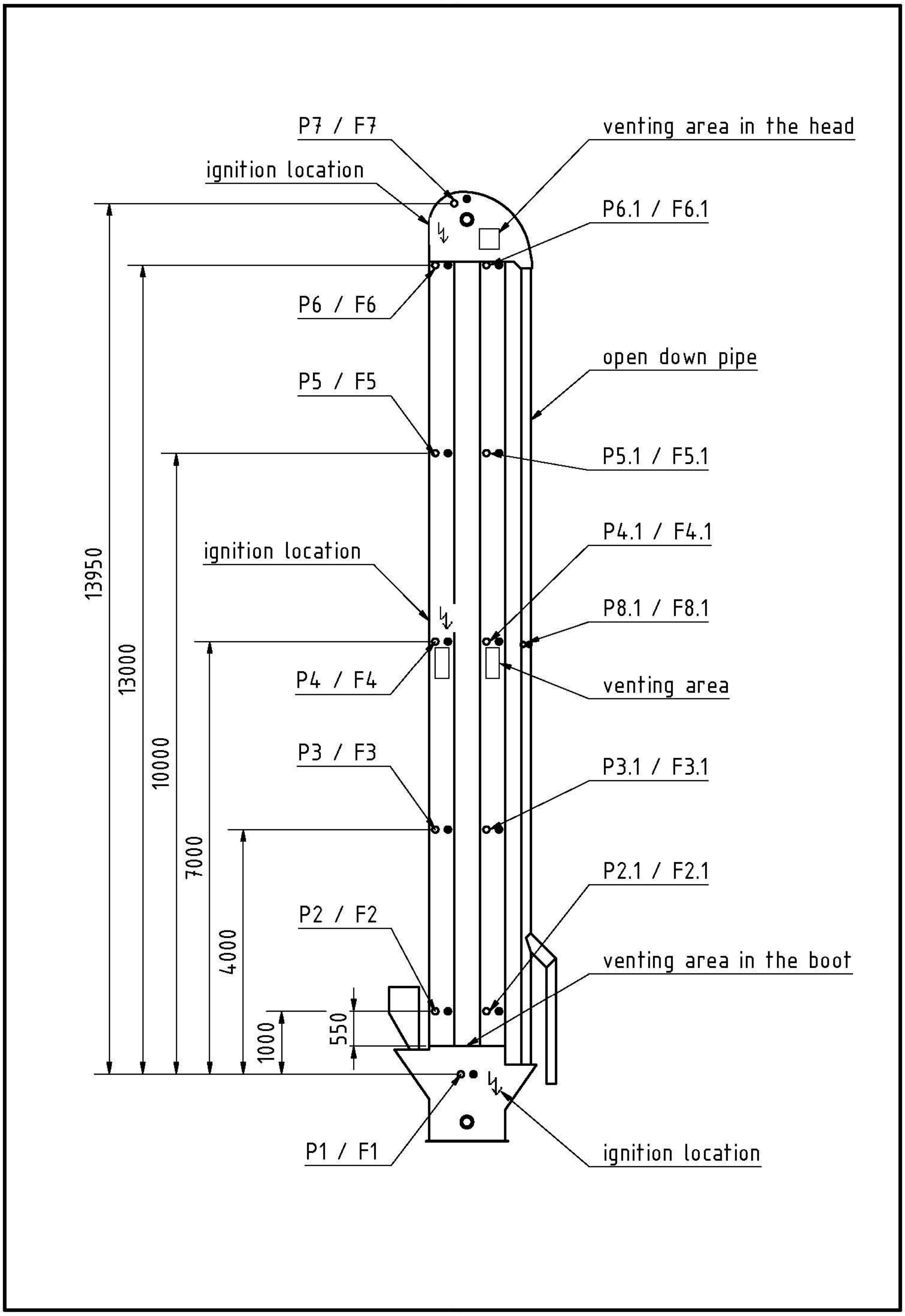

Figure 2: Sketch of the twin leg bucket elevator with the measuring points (P- pressure detector, F- flame (infra red detection), the locations of the possible pressure venting areas and the possible locations of the ignition source

4 Explosion tests

4.1 Explosion characteristics of the used dusts

The explosion characteristics of the used dusts are shown in Table 2. The values were determined by standardized dust samples, according to the relevant standards [8-11]. As additional information, the dimensionless dusting number SN is indicated, which characterizes the ability for dust cloud formation [12].
Information about the particle size distribution and further results of the determination of the dust specific characteristics from the 20 l sphere and 1 m³ vessel can be found in the annex 7.4.

Table 2: Explosion characteristics of the used bulk materials (standardized test sample)

Bulk material	**p_{max} [bar]**	**K_{St} [bar·m·s^{-1}]**	**LEL [g/m³]**	**MIE [mJ]**	**MIT [°C]**	**S_N**
Wheaten flour type 550	6.8	109	60	>10 / ≤ 50	380	0.6
Malt dust 1	7.9	143	60	> 5 / ≤ 10	370	29
Malt dust 2	8.4	159	60	> 5 / ≤ 10	370	13.2
Maize starch	8,7	204	60	> 4 / ≤ 5	380	10.2

p_{max} - Maximum peak explosion over-pressure
K_{St} - Dust specific value
LEL - Lower explosion limit
MIE - Minimum ignition energy (determined with inductivity in the discharge circuit)
MIT - Minimum ignition temperature
S_N - Dusting number as per VDI 2263-Part 9 [17]

4.2 Execution of the tests

For carrying out the explosion tests, two different methods were chosen for the generation of the dust/air-mixture. In addition to a practice oriented method, an injection system with dust from a pressurized dust storage container (20 bar) was used, to be able to compare the results to previous research investigations.

As ignition source two pyrotechnical igniters were used with an ignition energy of 1kJ each. Some tests were carried out with an ignition energy of 5 kJ. The ignition source was varied and was placed either in the elevator head, in the middle of the up leg or in the elevator boot.
The number of the vent openings was systematically varied. The explosion tests were started with 4 vent openings in total (head, 2 x leg, boot). Then they were reduced to three (head, 2 x leg) and finally to only one vent opening in the elevator head. In the case of

weaker explosion courses, (K_{St} ~ 100 bar·m·s^{-1}) with the given pressure shock resistance, it could be done without additional vent openings.
To be able to recognize the influence of the connected dedusting installation on the explosion course, some test were carried out with a switched on/off dedusting. The dedusting installation existed of a 15 m long connecting pipe DN 100, which was connected over a pressure vented cyclone with a radial fan. The flow velocity inside the dedusting pipe was about 20 m/s.

Method A: Explosion tests under practical operating conditions

For this method preliminary tests were studied, to find the ideal settings to reach maximum explosion violence under praxis relevant conditions. For this purpose, the elevator was loaded with 100 to 200 kg of the dust and for a certain period of time driven with a down pipe as a recirculation system. Afterwards the elevator was emptied. Therefore the down pipe was closed by means of a stop valve at the elevator boot and by means of a change- over dumper connected to an open down pipe. After a restart, the elevator was running in no-load operation. Under no-load operation, dust layers were swirled and dispersed inside the casing. After a period of time (about 20 seconds) the dust cloud was ignited. This test method was optimized by a lot of preliminary tests.

Figure 3: Large scale explosion test in a twin-leg bucket elevator at the test site of FSA and BGN in Kappelrodeck (Germany). Explosion transmission via dedusting pipe (pipe diameter: 100 mm; total length: 15 m) into a vented cyclone; – malt dust, ignition location in the elevator head; venting of the boot, legs and head of the elevator

Method B: Explosion tests with the dust injection system

According to this method a defined amount of dust from pressurized (20 bar, 5.4 l dust containers) was dispersed into the elevator. In combination with fast actuated valves, the pressure from the containers could be released and the dust could be blown into the running elevator. One container was located at the elevator boot and head and two containers were placed along the up and down legs. After a defined ignition delay time (t_v = 0.6 s), the dust/air-mixture was ignited by a chemical igniter.
The dispersed amount of dust was varied and so the optimum dust concentration for maximum explosion pressure was found.

4.3 Test results

At first the explosion test were carried out under practical operating conditions, according to method A. Independent form the used dust, the maximum explosion pressure was measured in the area of the ignition source in the elevator head or boot. If there was no explosion venting used at the elevator boot the maximum explosion pressure was measured in the area of the ignition source in the elevator boot.

Influence of the pneumatic extraction system

Additionally tests with and without dust extraction system were carried out. However, with the chosen bulk material, the dust extraction did not show any influence on the explosion course. Therefore, all further tests were carried out while the dust extraction was switched on. During some tests, a flame front propagation through the dust collecting pipe followed by a flame jet ignition and a secondary dust explosion in the vented cyclone occurred (Figure 3). This is mentioned as important information for the necessity of explosion isolation measures towards interconnected plants.

4.3.1 Results with wheaten flour type 550

Wheaten flour type 550 was chosen as representative for dusts with a dust characteristic value of $K_{St} \leq 100$ bar·m·s^{-1}. The used wheaten flour had a moisture of F = 11.7% (particle size distribution as shown at appendix 7.4).
Because of the low K_{St}-value and the experiences of the pre-tests pressure venting in the elevator boot could be set aside. The explosion tests started with pressure venting in the up and the down leg and in the elevator head. During these tests and all following tests with wheaten flour could be observed that the maximum explosion overpressure occurred in the area of the ignition location or in the elevator legs between ignition location and pressure vent arrangement in the elevator leg. In the further explosion course the explosion pressure decreased.
Figure 4 shows the explosion pressures of the most violent tests as a function of the location in dependence of the pressure vent arrangement. The distance of the location corresponds to the measuring point P1 at the elevator boot (as shown in Figure 2). The dotted curve with rectangular symbols shows the explosion overpressure with pressure venting in head and legs while the “open” rectangular symbols represent the pressure in the up leg and the “filled” symbols the pressure in the down leg. Under this conditions the maximum peak explosion overpressure p_{max}= 0.3 bar was measured in the down leg.

Furthermore, one could observe that the explosion course in the up and down leg differed less or more. Under the chosen test conditions the higher pressures were mostly measured in the up leg, but also partly in the down leg.

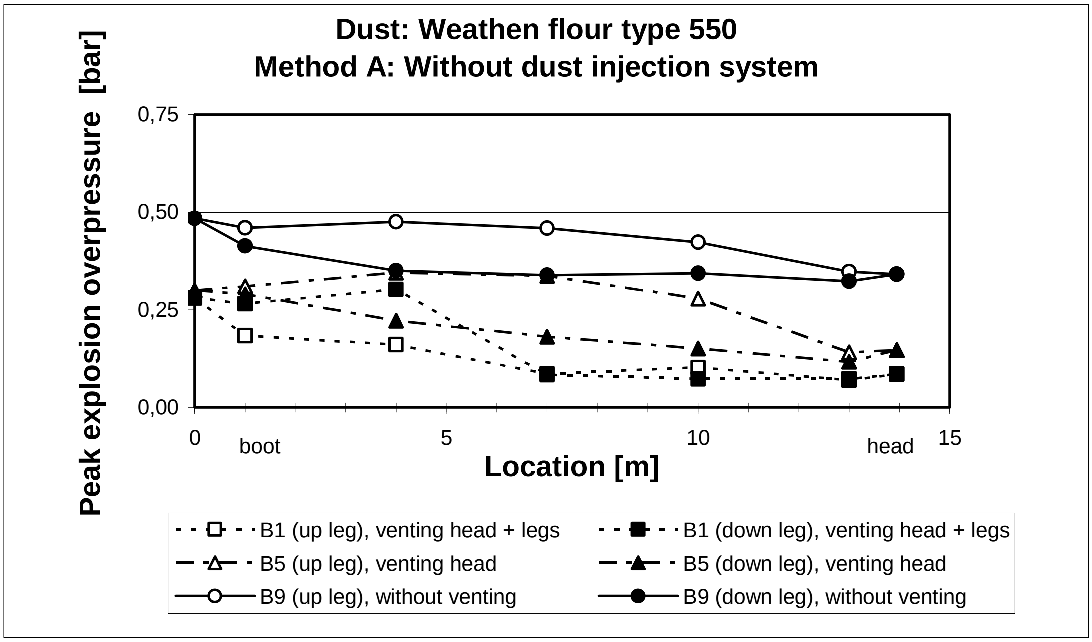

Figure 4: Peak explosion overpressure in the bucket elevator dependent on the measuring points and dependent on the used venting area (venting in head and legs, venting only in the head and without venting); - wheaten flour type 550 with K_{St} = 109 bar·m·s^{-1}

Further tests were carried out with only one pressure venting in the elevator head (triangular symbols). At several measuring points along the legs, the local pressure reached up to 0.25 bar higher values as before. However, the maximum explosion overpressure with 0.35 bar was only slightly higher as with additional pressure venting in the elevator legs.

Due to the fact that relatively low explosion pressures were measured, further tests were conducted without additional pressure vent openings. Figure 4 also shows the explosion overpressures of the most violent test out of the three tests, which were all done under the same conditions. The maximum explosion overpressure rose to nearly 0.5 bar.

Figure 5 shows the results of all tests (Method A) with wheaten flour. As a question of clearness only measuring results of the elevator leg, in which the higher pressures were measured, are shown.

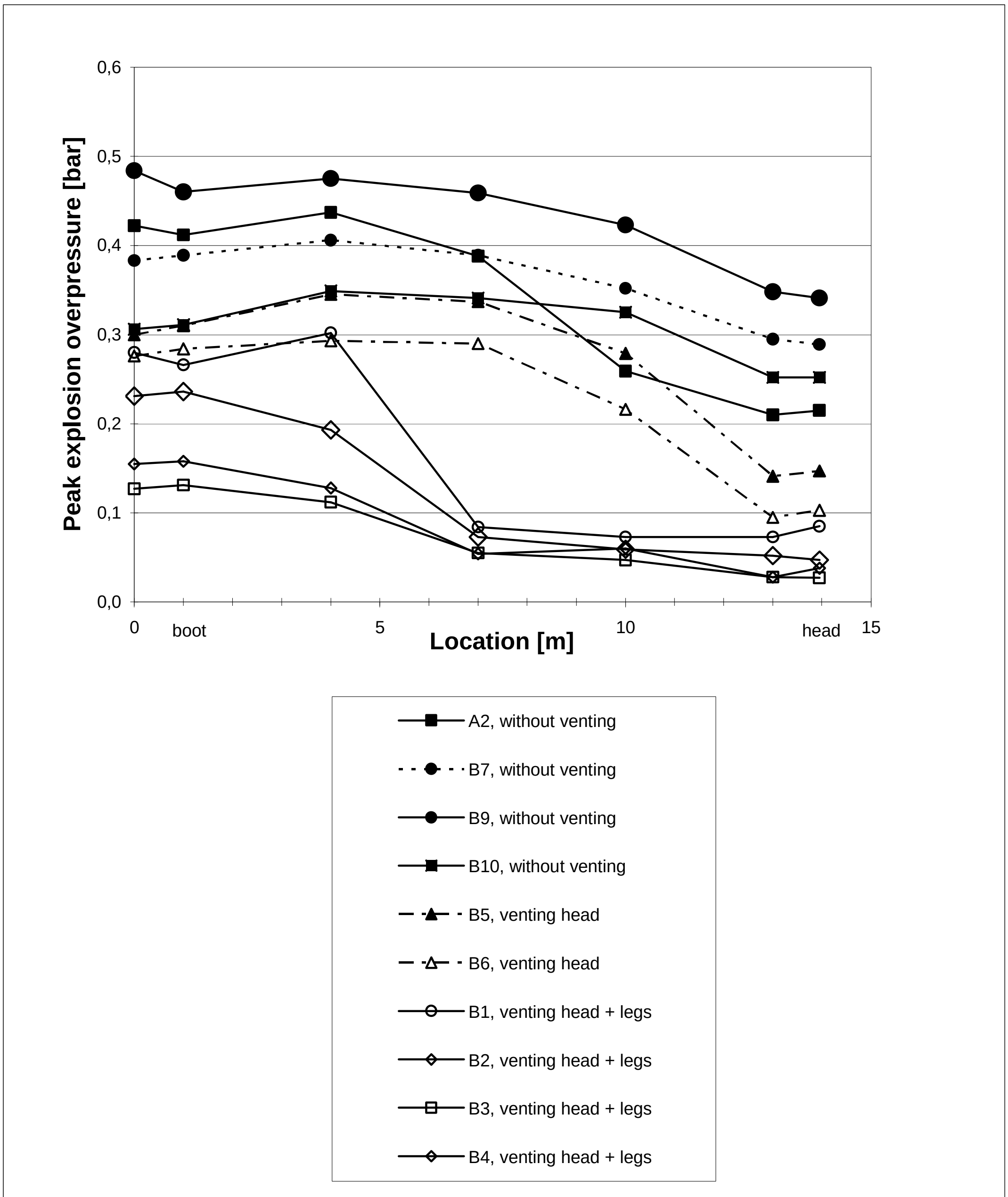

Figure 5: Peak explosion overpressure in the bucket elevator dependent on the used vent opening arrangement following method A (without dust injection); - wheaten flour

It was of great interest to carry out comparative tests with a dust injection system (method B) to guarantee an almost optimum dust distribution inside the elevator. The corresponding results are shown in Figure 6. In the case of pressure venting in the elevator head and at the legs, the maximum explosion overpressure was in three tests only about 0.1 bar. With pressure venting only in the elevator head (triangular symbols) slightly higher pressures were reached as before and without additional pressure venting the maximum peak explosion overpressure increased to p_{max} = 0.6 bar.
Following both methods similar test results were obtained.

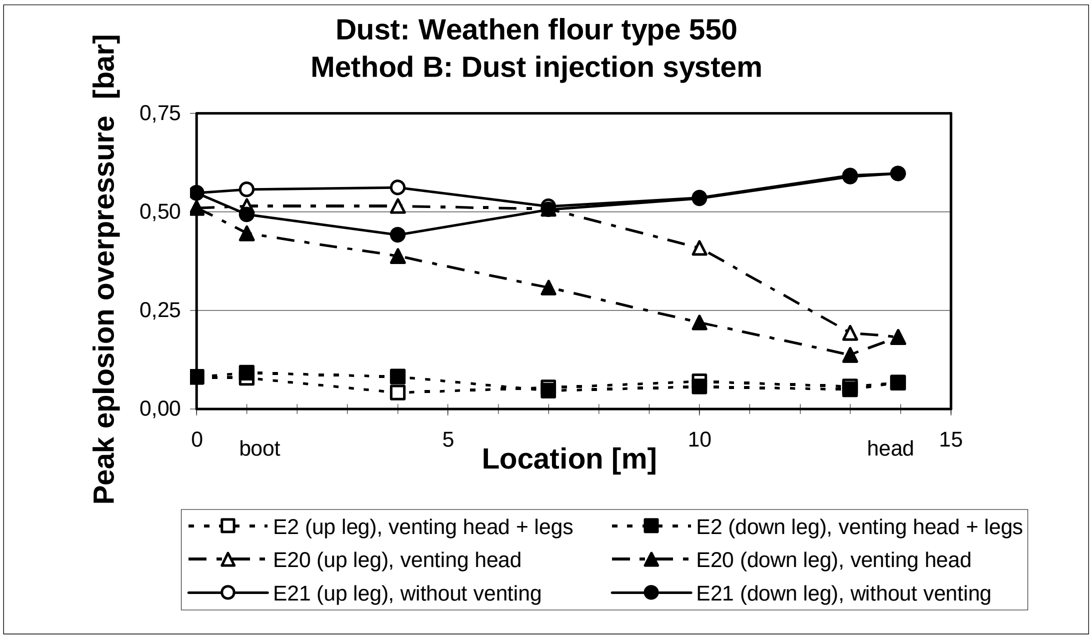

Figure 6: Peak explosion overpressure in the bucket elevator dependent on the measuring points and dependent on the used venting area (venting in head and legs, venting only in the head and without venting); - wheaten flour type 550 with K_{St} = 109 bar·m·s^{-1}

4.3.2 Results with malt dust 1

Under retention of the same procedure, further test series were carried out by using malt dust. The used malt dust, which was originally taken from a dedusting filter of a brewery, could be considered as highly critical representative of combustible dusts in an area up to K_{St} = 150 bar·m·s^{-1} because of its especially high dusting ability. This becomes very visible in the characteristic dusting number SN shown in Table 2. It is more than twice as high as the dusting number of maize starch and more than 40 times higher as the dusting number of wheaten flour type 550. For the tests malt dust was filled into the elevator as in delivered conditions, with a product moisture of F = 5.9 %.
The test series was started with pressure venting in the elevator boot, head and legs. The results can be found in Figure 7.

For clearness reasons, only the measuring results of that elevator leg are indicated, where the highest pressure was measured.
In no-load operation (method A) the maximum explosion overpressure was reached during a test with ignition source at the elevator head. It reached p_{max} = 0.61 bar in the elevator up leg between the elevator head and vent opening in the up leg (test A1). From the location of the vent opening in the legs up to the boot the pressures clearly decreased to values of about 0.2 bar. The test was repeated four times, but could never be repeated with the same violence. In the following tests the peak explosion overpressures reached maximum 0.37 bar.
In a comparable test with additional dust injection (method B) only an overpressure of slightly over 0.1 bar was reached.

The tests, which were carried out without pressure venting of the elevator boot and ignition location at the elevator boot, showed a significant increase of the explosion pressures in the area of the ignition location until the pressure vent openings in the elevator legs. The test results shows a maximum explosion overpressure of p_{max} = 1.23 bar (test A 19). After the pressure venting “leg” in direction to the elevator head the pressure decreases below 0.5 bar.

The five comparative tests with dust injection (method B) showed similar tendencies, but the explosion overpressures with a maximum of p_{max} = 0.81 bar were significantly lower than in the tests, according to method A (without dust injection).
Further increasing of the explosion pressure was measured when only the elevator head was vented. As shown in Figure 7, in this case the explosion courses of both methods were almost identical. The maximum explosion overpressure in the elevator boot area reached p_{max} = 1.37 bar according to method A, and p_{max} = 1.42 bar according to method B (with dust injection system).

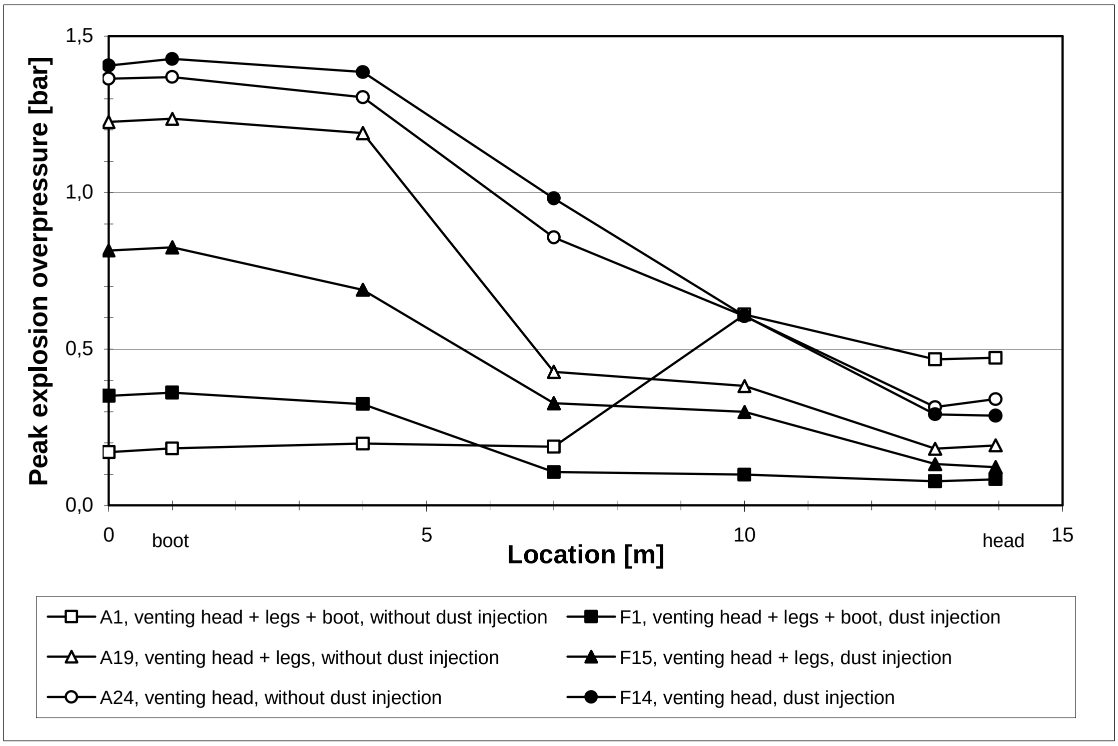

Figure 7: Comparison of the test results according to method A (without dust injection, open symbols) and method B (with dust injection, filled symbols) with malt dust 1;
Ignition location: Test A1 “elevator head”, all others “elevator boot”

4.3.3 Results with malt dust 2

A new batch of malt dust (malt dust 2) had significant higher explosion characteristics than malt dust 1 (see page 9, Table 2). As estimated, much higher explosion overpressures were measured using malt dust 2. Figure 8 shows the comparison of the test results with different malt dust batches with ignition location at the elevator head, according to method A without dust injection.

In this case only the elevator head was vented. In test B7 (malt dust 2), the peak explosion overpressure of 1.753 bar was more than 60 % higher than with malt dust 1 (1,066 bar) in test A26.

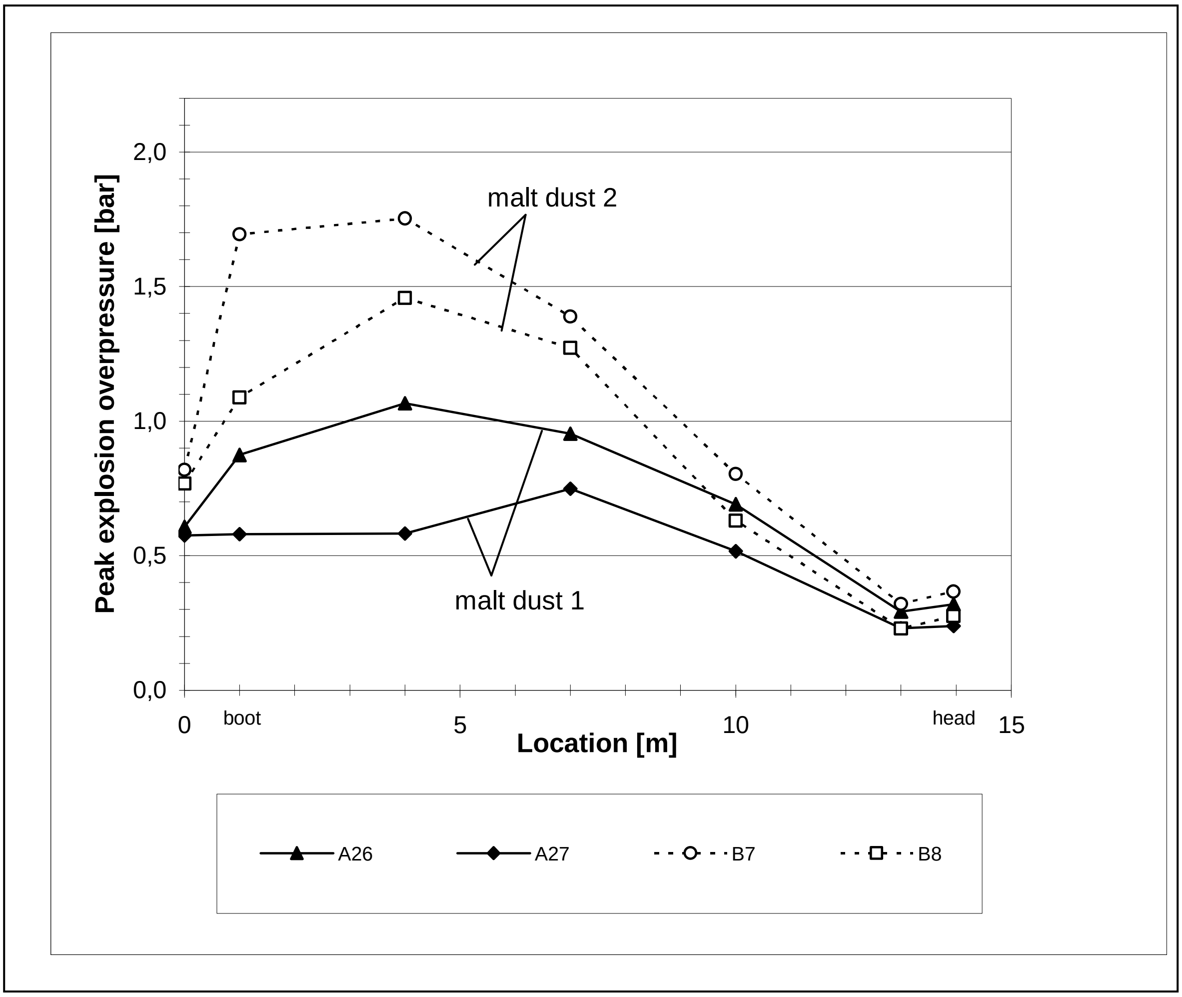

Figure 8: Comparison of the test results, according to method A (without dust injection) between malt dust 1 and 2. Ignition location head, pressure venting only in the head, malt dust 1: Test A26 and A27; malt dust 2: Test B7 and B8

With ignition source in the “boot” and pressure venting only in the head, according to method A, using malt dust 2 performed peak explosion overpressures with just over 2 bar. Comparative tests with malt dust 1 and malt dust 2 are shown in Figure 9. In test B3 (malt dust 2), with 2.08 bar a 51 % higher peak explosion overpressure was measured than with malt dust 1 (1.37 bar) in test A25.

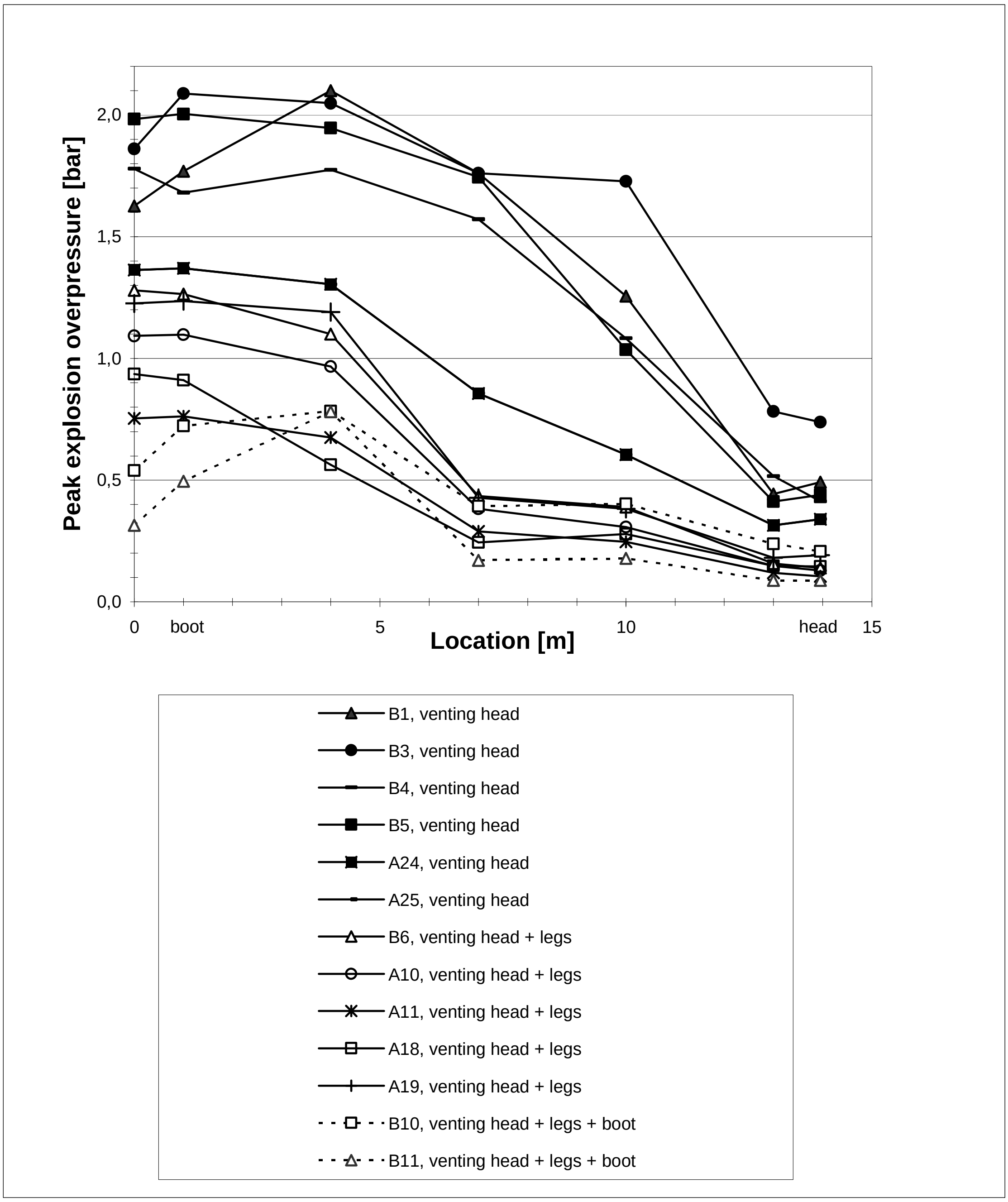

Figure 9: Comparison of the test results according to method A (without dust injection) with malt dust 1 and malt dust 2, ignition source at the boot, malt dust 1: Test A10, A11, A18, A19, A24, A25; malt dust 2: Test B1, B3, B4, B5, B6, B10, B11

4.3.4 Results with maize starch

After the investigations with wheaten flour and malt dust further tests with maize starch were carried out (p_{max} = 8,7 bar; K_{St} = 204 bar·m·s^{-1}).
The tests series was started with method A without dust injection system. With pressure venting in the elevator boot, head and both legs and ignition source at the elevator boot, in the ignition area a maximum explosion overpressure of p_{max} = 0.47 bar was reached.

Without pressure venting at the elevator boot the maximum peak explosion overpressure was increased up to p_{max} = 1.1 bar in the area of the elevator boot and in the beginning of the legs. With pressure venting only at the elevator head a further increase to p_{max} = 1.64 bar was measured.
These results were lower than the measured explosion pressures with malt dust 2 (p_{max} = 8.4 bar, K_{St} = 159 bar·m·s^{-1}). It was supposed that for maize starch the optimum dust concentration and dust distribution (worst case) was not found. In later investigations of explosion suppression inside elevators, pre tests were used to repeat vented explosion tests with this type of maize starch. Using pressure venting at the elevator head, legs and boot, a maximum peak explosion overpressure of 0.71 bar was measured. Pressure venting only at the legs leads to an increase of p_{max} = 1.71 bar.

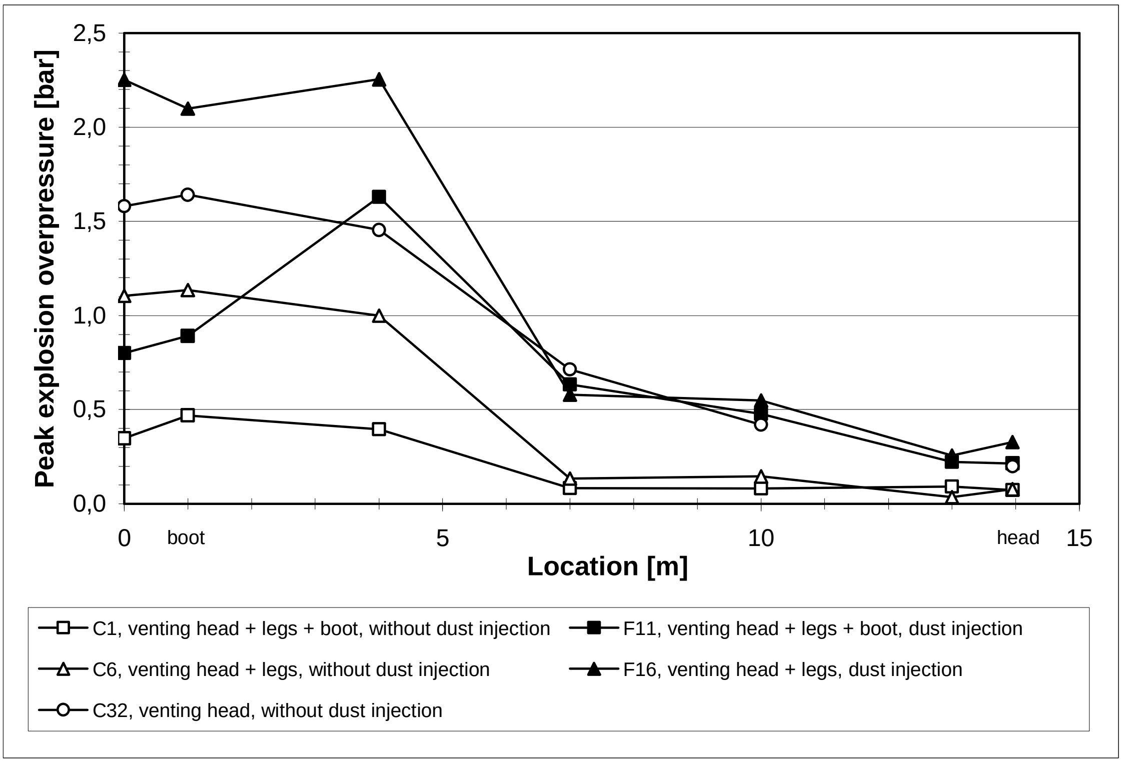

Figure 10: Comparison of the test results according to method A (without dust injection, open symbols) and method B (with dust injection, filled symbols) with maize starch K_{St} = 204 bar·m·s^{-1}

Also with maize starch test series were carried out according to method B, with dust injection. In contrast to wheaten flour and malt dust, the test results with maize starch according to method B showed much higher explosion overpressures. With ignition location in the vented elevator boot, for the first time, a strong flame acceleration was observed, in direction to the pressure venting in the elevator legs (Figure 10, square, “filled” symbols). Directly before this pressure venting, a p_{max} of 1.63 bar was measured, which decreased to approximately 0.6 bar, directly behind the pressure venting in direction to the elevator head.

In further tests the pressure venting at the elevator boot was closed and only the pressure venting in the legs and at the head was used. The consequence was a further increase of the peak explosion overpressure up to p_{max} = 2.26 bar!

The combination of pressure venting only in the elevator head and ignition location in the elevator head resulted in strong flame accelerations and pressure built-up in direction to the elevator boot. This caused the total destruction of the elevator. The elevator legs were ripped open and the elevator boot did not exist any more (see appendix 1, Figure A3 - A5). The estimated peak explosion overpressure was approximately 5 bar. In this test a common version of the elevator was used. Afterwards, the test elevator was re-designed and manufactured in a stiffened version.

Exemplarily from some selected tests, the pressure and flame time history are shown in appendix 7.3.

5 Summary and discussion of the results

The investigations in explosion venting tests on a twin leg bucket elevator were carried out according to two different methods. Following the very praxis relevant method A, the dust layers in the elevator was swirled up and dispersed by the running buckets and then ignited. Similar conditions are given in praxis under no-load operation and possibly under fully load operation in the down leg of the elevator. With this method however, it was not sufficiently guaranteed, that the real optimum conditions regarding dust distribution and dust concentration could be reached. This was the reason for comparative test series according to method B using a dust injection system. The dust concentration was varied until the maximum explosion overpressure occurred.

The disadvantage of method B is the fact that the existing operational flow conditions are disturbed, because the dust is blown in from pressurized dust storage containers and will induce additional turbulences inside the elevator. Due to this fact the burning velocity of the dusts could increases significantly, which could lead to an overestimation of the possible explosion course under realistic operating conditions.

It was surprising that according to both methods wheaten flour (K_{St} = 109 bar·m·s^{-1}) reaches similar peak explosion overpressures. The results from Holbrow and Lunn [5] were validated. That means for dusts with low K_{St}-values the obstruction of the elevator legs leads to a dominating damping affect of the explosion course in stead of an increasing turbulence effect. The reason for that could be the increase of the flow resistance and the heat losses through the buckets. Although flame propagation could be observed along the entire elevator, the average flame velocities, section by section, was with up to 35 m/s relatively low. Using method B (dust injection), the observed partial

flame velocities were between 60 to 120 m/s. However, there was no correlation ascertained between the flame velocity and the explosion pressure.
The maximum peak explosion overpressures occurred in the region of the ignition location and along the first meters in the elevator legs. In general however, the measured results were higher than the results from Holbrow and Lunn.
According to method A (no-load operation) and without additional pressure venting at the elevator, a maximum peak explosion overpressure of p_{max} = 0.49 bar was measured. According to method B, the measured peak explosion overpressure was 0.59 bar. In consideration of the explosion test results, it seems that, when bulk material with a $K_{St} \leq$ 100 $bar \cdot m \cdot s^{-1}$ are conveyed in a twin leg bucket elevator and if the pressure shock resistance [13] of the elevator is $p \geq 1$ bar, without a limit of the elevator linear dimension it is possible to forego the measures of pressure venting. This result however, is only valid for bucket spacing of 280 mm and wall clearances between buckets and legs of 70 mm.
Table 3 gives advice on the dimensioning of explosion pressure venting. The safety margin between the recommended pressure shock resistance of the elevator and the actually measured maximum peak explosion overpressures respects the test accuracy, the small differences in the geometrical ratio and the possible inaccuracies at the determination of the explosion characteristics.

Malt dust was chosen to represent the combustible dust group 100 $bar \cdot m \cdot s^{-1} < K_{St} \leq 150$ $bar \cdot m \cdot s^{-1}$. Malt dust has an extraordinary high dusting number of SN = 29 [12]. From now on, this malt dust will be referred as malt dust 1. This malt dust reached higher peak explosion overpressures as expected after the results from Holbrow and Lunn. It is astounding that in consideration of all the test results except one, the higher peak explosion overpressures only occurred when the tests were carried out according to method A (under no-load operation and with swirled up of dust deposits inside the elevator through the running buckets). On the one hand this confirms the importance of the dusting number (ability for dust cloud formation). On the other hand it confirms the difficulties in case malt dust should be dispersed with high pressure via nozzles (method B). Regarding the dust characteristic determination in the 20 l sphere and in the 1 m^3 standard test vessel, malt dust is showing the same behaviour. The reason could probably be found in the question of the dust morphology. It cannot be foreclosed that the standardized procedure for the determination of dust characteristic values in the 1 m^3 vessel and in the 20 l sphere [7, 8] yield to lower K_{St} - values in the case of malt dust.
The coarser malt dust particles, which are screened out for the standardized procedure for the determination of dust characteristic values have obviously no influence on the development of dust clouds in an elevator during no-load operation. The running buckets disperse preferably the fine particle content of the bulk material.

By using malt dust 1 the mean flame velocity, section by section, reached about 70 m/s, independently whether method A (no-load operation) or method B (dust injection system) was used. There was no correlation between peak explosion overpressure and flame speed observed in this case either. The present investigation shows that pressure shock resistance of the bucket elevator of 1 bar should be enough when bulk material will be conveyed with $K_{St} \leq 150$ $bar \cdot m \cdot s^{-1}$, if the elevator is vented at the boot and at the legs in spacing of maximum every 6 m.

If the pressure shock resistance of the elevator however is 1.5 bar, there is no need for a pressure venting of the elevator boot, if the venting of the elevator legs is in spacing of maximum every 6 m.
At first glance it seems that a pressure shock resistance of 2 bar should be enough, if the elevator head is pressure vented only. However considering the results with malt dust 2, with a K_{St} -value of a little bit more than 150 bar·m·s^{-1}, it is recommended to use additional pressure venting of the elevator legs in spacing of maximum 12 m.
These statements are only valid under the condition that the bucket spacing is 280 mm and the wall clearance between buckets and elevator wall is 70 mm. Table 4 advises on the dimensioning of explosion pressure venting devices.

Malt dust 2 had explosion characteristics (p_{max}, K_{St}), which were about 10 – 15 % higher than the primary used malt dust 1. With the usage of malt dust 2, the peak explosion overpressures suddenly showed an increase of 50 %. The assumption is, that the turbulent burning velocity of malt dust 2 exceeds a certain threshold value, and therefore the induced turbulence effect (caused by the running buckets) is bigger than the blocking effects. The consequence is an increase of the burning velocity and an impressive increase of the peak explosion overpressure. Similar effects were found by Holbrow and Lunn [5] at their elevator investigations. They used different types of maize starch with only slight differences in the explosion characteristic values.

Another behaviour was observed with maize starch with a dust specific value of K_{St} = 204 bar·m·s^{-1}. In this case according method B (dust injection system) at least a 100% higher peak explosion overpressure was measured as according method A (praxis conditions, without dust injection system). Obviously by using a dust with a relatively high Kst-value, the additional turbulence induction through the injection system effected a strong increase of the turbulent burning velocity and to the explosion course. By using method A (without dust injection system) the mean flame velocity (section by section) reaches a maximum of v_F = 75 m/s. In comparison to method A, the flame velocity reaches a maximum of v_F = 180 m/s by using method B (dust injection system). The circumstances existing in reality which could occur in elevator operation will probably be overestimated because of the additional turbulence inductions.

Due to the results of this study, for the conveying of bulk material with a K_{St} -value of $K_{St} \leq$ 210 bar·m·s^{-1} and a pressure shock resistance (strength) of 1.5 bar, it is recommended to use pressure venting at the elevator boot and head and along the legs in spacing of maximum every 6 m.
When the pressure shock resistance of the elevator is 2 bar, there is no pressure venting needed at the elevator boot, if there is pressure venting along the legs in spacing of maximum every 6 m (as shown in Table 5).

Dimensioning of the pressure venting arrangements

Based on the explosions results Table 3 to 5 recommends in practical dimensioning of pressure venting arrangements of bucket elevators, with rectangular up and down legs. Depending on the pressure shock resistance of the bucket elevator and the K_{St} –value of

the bulk material information is given if pressure venting is required at the elevator head and boot and if additional pressure venting is necessary along the elevator legs.
The safety margin between the recommended pressure shock resistance and the actual measured explosion pressures considers test inaccuracies, the inaccuracy of the explosion characteristic values of the balk material and other influences (e.g. dusting number), which were not completely considered during the experimental investigations.
By using bulk material whose fine particulate has a $K_{St} \le 100$ bar·m·s^{-1} there is no need for pressure venting if the pressure shock resistance of p ≥ 1 bar is given (as shown in Table 3).

The specifications in Table 3 to 5 are only valid under the following conditions:

- ignition location inside the elevator (no explosion entry from connected plants)
- organic dusts
- maximum explosion overpressure of the dust $p_{max} \le 10$ bar
- rectangular elevator legs
- free cross sectional area (leg) < 60 %
- bucket spacing ≤ 280 mm with $K_{St} \le 150$ bar·m·s^{-1}
- bucket spacing ≤ 140 mm with $K_{St} \le 210$ bar·m·s^{-1}
- each pressure venting area ≥ free cross sectional area (leg)
- static activation pressure of the venting device $p_{stat} \le 0{,}1$ bar
- free explosion pressure venting without vent ducts
- pressure venting ability of the pressure venting device $E_F = 1$

Table 3: Dimensioning of the explosion pressure venting device for bucket elevators with rectangular legs for bulk material with $K_{St} \le 100$ bar·m·s^{-1}

Pressure shock strength 1)	$K_{St} \le 100$ bar•m•s^{-1}			Measured maximum peak explosion overpressure	
	Elevator boot	Elevator head	Distances legs 2) L [m]	after method A	after method B
p [bar]				p [bar]	p [bar]
0,25	V	V	3		
0,35	NV	V	3		
0,50	NV	V	6	0,31	0,11
1,00	NV	NV	NV	0,49	0,59*

1) overpressure

2) maximum spacing of the explosion venting areas, measured from the elevator boot

* dried wheaten flour reaches a maximum peak explosion overpressure of 0.71 bar (Test No E16)

Table 4: Dimensioning of the explosion pressure venting device for bucket elevators with rectangular legs for bulk material with 100 bar·m·s^{-1} < K_{St} ≤ 150 bar·m·s^{-1}

Pressure shock strength [1)]	100 bar•m•s-1 < K_{St} ≤ 150 bar•m•s^{-1}			Measured maximum peak explosion overpressure	
	Elevator boot	Elevator head	Distances legs [2)] L [m]	after method A	after method B
p [bar]				p [bar]	p [bar]
0,25	Explosion strength insufficient				
0,35					
0,50	V	V	3		
1,00	V	V	6	0,61	0,15
1,50	NV	V	6	1,24	0,82
2,00	NV	V	12	1,37	1,43

[1)] overpressure

[2)] maximum spacing of the explosion venting areas, measured from the elevator boot

Table 5: Dimensioning of the explosion pressure venting device for bucket elevators with rectangular legs for bulk material with K_{St} ≤ 210 bar·m·s^{-1}

Pressure shock strength [1)]	150 bar•m•s-1 < K_{St} ≤ 210 bar•m•s^{-1}			Measured maximum peak explosion overpressure	
	Elevator boot	Elevator head	Distances legs [2)] L [m]	after method A	after method B
p [bar]				p [bar]	p [bar]
0,25	Explosion strength insufficient				
0,35					
0,50					
1,00	V	V	3		
1,50	V	V	6	0,71	1,63
2,00	NV	V	6	1,71	2,26

[1)] overpressure

[2)] maximum spacing of the explosion venting areas, measured from the elevator boot

Note:
Following method A and using pressure venting only at the elevator head resulted in a maximum peak explosion overpressure of 2,1 bar with malt dust 2 (test B1) and according

method B in an explosion overpressure in the elevator boot of up to 5 bar with maize starch (see appendix 1, Figure A3 - A5).

As a final remark about the conveying of coarser bulk material (for e.g. grains), it should be mentioned that is not explosible itself because of its particle size.
However, it is to be considered that through contamination or mechanical abrasion during the conveying process of bulk material, considerable amounts of dust deposits inside the elevator could be generated. That could be enough to create an explosible dust/air-mixture in a no-load operation of bucket elevators.

6 References

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7. Appendix

7. Appendix

7.1 Pictorial documentation

Figure A1: The setup of the test elevator surrounded by scaffolding, front view

Figure A2: The test elevator surrounded by scaffolding, rear view.

Figure A3: Destroyed elevator boot, (after explosion test No D1), product maize starch with dust injection system, ignition location head, pressure venting only in the head, P1 ~ 5 bar, P3 ~ 2.4 bar, P7 ~ 0.5 bar

Figure A4: Ripped open elevator leg (after test No D1)

Figure A5: Jettisoned side parts of the elevator boot (after test No D1)

Figure A6: Dust explosion in a vented bucket elevator with explosion propagation in a vented dedusting chamber via a connecting pipe with an diameter of d = 100 mm (test A3)
Bulk material: malt dust 1; ignition location: elevator boot; pressure venting of the elevator head, boot and legs

7.2 Results of the measurements

without dust injection system, malt dust

Constructional explosion protection for elevators

Project No.: F-05-0701

Test	Date	Load	Ignition	tv	Boot	Peak explosion overpressure up leg					Head	Peak explosion overpressure down leg					Oulet	Boot	Flame arriving time up leg					Head	Flame arriving time down leg					Oulet
No.			energy	[s]	P1	P2 1m	P3 4m	P4 7m	P5 10m	P6 13m	P7 13,95m	P2_1 1m	P3_1 4m	P4_1 7m	P5_1 10m	P6_1 13m	P8	F1	F2 1m	F3 4m	F4 7m	F5 10m	F6 13m	F7 13,95m	F2_1 1m	F3_1 4m	F4_1 7m	F5_1 10m	F6_1 13m	F8
		[kg]	[J]		[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]
Malt dust; ignition location head; aspiration = ON; pressure venting head, legs and boot; no-load operation without dust injection system																														
A 1	18.05.2007	100	1000	22	0,170	0,182	0,198	0,188	0,610	0,467	0,472	0,212	0,305	0,150	0,483	0,428	0,327		1139	1306		709			848	795	735	670	339	744
A 2	21.05.2007	100	1000	22	0,153	0,149	0,140	0,061	0,254	0,230	0,209	0,174	0,209	0,106	0,301	0,196	0,172	1514	1725	1849	1091	522			1542	1700	541	498	336	740
A 3	22.05.2007	100	1000	22	0,141	0,144	0,120	0,066	0,294	0,262	0,230	0,150	0,165	0,106	0,259	0,212	0,267	2547	2266	1929	1212	648			2775	3373	653	612	419	
A 16	05.07.2007	100	1000	22	0,152	0,124	0,137	0,055	0,350	0,167	0,131	0,153	0,118	0,055	0,202	0,144	0,072	1626	1850	2040	1300	231	103		1521	1132	505	241	189	609
A 17	06.07.2007	100	1000	22	0,159	0,163	0,151	0,085	0,370	0,341	0,309	0,145	0,148	0,116	0,339	0,261	0,321		3868	3443	3004	755	771	128			753		438	794
Malt dust; ignition location boot; aspiration = ON; pressure venting head, legs and boot; no-load operation without dust injection system																														
B 10 *	05.09.2008	100	2000	35	0,539	0,723	0,784	0,393	0,403	0,239	0,208	0,488	0,702	0,227	0,234	0,175	0,116													
B 11 *	05.09.2008	100	2000	35	0,314	0,306	0,294	0,149	0,145	0,092	0,088	0,495	0,781	0,171	0,179	0,088	0,051			383	477	540	697	834	325	503		1767	1075	1311
Malt dust; ignition location head; aspiration = ON; pressure venting head and legs; no-load operation without dust injection system																														
A 5	24.05.2007	100	1000	22	0,179	0,194	0,142	0,067	0,285	0,246	0,219	0,167	0,188	0,099	0,316	0,204	0,173	2269	2582		2041	560	54	55	2226	2327	564	527	378	601
A 6	24.05.2007	100	1000	22	0,131	0,129	0,103	0,085	0,372	0,298	0,255	0,117	0,123	0,125	0,257	0,232	0,253	1725	2008	2192	1330	728	698		1606	1177	707		437	754
Malt dust; ignition location head; aspiration = ON; pressure venting only head; no-load operation without dust injection system																														
A 26	13.07.2007	100	1000	22	0,607	0,571	0,441	0,286	0,447	0,363	0,320	0,874	1,066	0,954	0,691	0,292	0,284		2564	2009	1256	552			645	612		573	254	616
A 27	17.07.2007	100	1000	22	0,575	0,509	0,330	0,398	0,494	0,269	0,239	0,580	0,583	0,748	0,516	0,230	0,170	891	1174	1411	1616	315			809	383	344	301	215	469
B 7 *	04.09.2008	100	2000	35	0,819	0,773	0,425	0,736	0,806	0,483	0,367	1,694	1,753	1,389	0,804	0,321	0,277		2753	2053	1295	679			747	732		626	337	
B 8 *	04.09.2008	100	2000	35	0,768	0,914	0,662	1,168	1,120	0,433	0,276	1,088	1,458	1,272	0,630	0,229	0,100		1937	1216	1142				1221	1195	1142	1021	363	926
Malt dust; ignition location head; aspiration = OFF; pressure venting head and legs; no-load operation without dust injection system																														
A 7	24.05.2007	100	1000	22	0,063	0,065	0,072	0,043	0,154	0,139	0,150	0,060	0,076	0,055	0,134	0,116	0,101	1412	1615	1566	1728	914			1330	1102		732	378	
A 8	25.05.2007	100	1000	22	0,185	0,174	0,227	0,115	0,580	0,383	0,339	0,180	0,129	0,088	0,316	0,276	0,346					841					861	750		876

without dust injection system, malt dust

Constructional explosion protection for elevators

Project No.: F-05-0701

Test No.	Date	Load [kg]	Ignition energy [J]	tv [s]	Boot P1 [bar]	Peak explosion overpressure up leg P2 1m [bar]	P3 4m [bar]	P4 7m [bar]	P5 10m [bar]	P6 13m [bar]	Head P7 13,95m [bar]	Peak explosion overpressure down leg P2_1 1m [bar]	P3_1 4m [bar]	P4_1 7m [bar]	P5_1 10m [bar]	P6_1 13m [bar]	Oulet P8 [bar]	Boot F1 [ms]	Flame arriving time up leg F2 1m [ms]	F3 4m [ms]	F4 7m [ms]	F5 10m [ms]	F6 13m [ms]	Head F7 13,95m [ms]	Flame arriving time down leg F2_1 1m [ms]	F3_1 4m [ms]	F4_1 7m [ms]	F5_1 10m [ms]	F6_1 13m [ms]	Oulet F8 [ms]
Malt dust; ignition location boot; aspiration = ON; pressure venting head and legs; no-load operation without dust injection system																														
A 10	31.05.2007	100	1000	22	1,092	1,098	0,966	0,382	0,308	0,149	0,129	1,08	1,044	0,14	0,220	0,131	0,118	332	516	525	563	588			391	451			492	
A 11	31.05.2007	100	1000	22	0,753	0,762	0,675	0,289	0,247	0,119	0,106	0,697	0,618	0,08	0,169	0,077	0,051	640	654	602	665				583	664	627		690	
	the following tetst (A 18 - A 19) have different ignition delay times (tv)																													
A 18	09.07.2007	100	1000	10	0,936	0,911	0,564	0,244	0,279	0,149	0,145	0,907	0,654	0,146	0,168	0,140	0,079		221							260				
A 19	10.07.2007	100	1000	60	1,226	1,236	1,190	0,427	0,382	0,181	0,192	1,038	0,675	0,109	0,191	0,140	0,107		442		592				517	585				
B 6 *	03.09.2008	100	2000	35	1,280	1,265	1,100	0,435	0,390	0,157	0,140	1,173	0,976	0,161	0,250	0,123	0,062		53	241	284					284	195			
Malt dust; ignition location boot; aspiration = ON; pressure venting only head; no-load operation without dust injection system																														
A 24	12.07.2007	100	1000	22	1,364	1,370	1,305	0,857	0,605	0,314	0,340	1,312	1,202	0,632	0,424	0,259	0,158		255	304	485					308				
A 25	12.07.2007	100	1000	22	1,142	1,092	0,803	0,577	0,406	0,215	0,224	1,142	1,019	0,496	0,307	0,170	0,115		240	308						283				
B 1 *	02.09.2008	100	1000	35	1,626	1,769	2,100	1,761	1,256	0,443	0,492	1,526	1,414	1,251	0,689	0,376	0,241		79	393	530	582	624		587	551	603			
B 3 *	03.09.2008	100	2000	35	1,861	2,088	2,048	1,761	1,728	0,782	0,738	1,734	1,544	1,415	0,722	0,463	0,366		84	441	519	566	587		414	514	556			
B 4 *	03.09.2008	100	2000	35	1,779	1,681	1,775	1,571	1,083	0,517	0,413	1,833	1,788	1,874	0,909	0,437	0,237		136	524	703	755	787		498	729	524			
B 5 *	03.09.2008	100	2000	35	1,984	2,004	1,946	1,745	1,036	0,412	0,439	1,797	1,474	0,997	0,626	0,357	0,217		84	288	346				231	351	383			
Malt dust; ignition location in the middle of the up leg; aspiration = ON; pressure venting head and boot; no-load operation without dust injection system																														
A 15	04.06.2007	125	1000	22	0,162	0,215	0,222	0,273	0,415	0,291	0,255	0,397	0,780	0,833	0,537	0,228	0,225					860	1990			3892	3852		3644	
Malt dust; ignition location boot; aspiration = ON; pressure venting head and boot; no-load operation without dust injection system																														
E 3 *	09.10.2008	100	5000	35	0,266	0,335	0,576	0,566	0,358	0,245	0,194	0,291	0,235	0,223	0,208	0,187			41	144	212		3119	3226	131	912	1414		2735	

* Malt dust 2

with dust injection system, malt dust

Constructional explosion protection for elevators

Project No.: F-05-0701

Test No.	Date	Dust concen-tration	Ignition energy	tv	Boot	Peak explosion overpressure up leg					Head	Peak explosion overpressure down leg					Oulet	Boot	Flame arriving time up leg					Head	Flame arriving time down leg					Oulet
					P1	P2 1m	P3 4m	P4 7m	P5 10m	P6 13m	P7 13,95m	P2_1 1m	P3_1 4m	P4_1 7m	P5_1 10m	P6_1 13m	P8	F1	F2 1m	F3 4m	F4 7m	F5 10m	F6 13m	F7 13,95m	F2_1 1m	F3_1 4m	F4_1 7m	F5_1 10m	F6_1 13m	F8
		[g/m³]	[J]	[s]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]
Malt dust; ignition location boot; aspiration = ON; pressure venting head, legs and boot; no-load operation with dust injection system																														
F 1	08.11.2007	750	2000	0.6	0,110	0,115	0,108	0,092	0,080	0,060	0,048	0,112	0,098	0,082	0,070	0,045	0,024	810	952	1077	1231	1253	1293	1315	1013	1536	1889	2059	1395	2215
Malt dust; ignition location boot; aspiration = ON; pressure venting head and legs; no-load operation with dust injection system																														
F 2	08.11.2007	750	2000	0.6	0,351	0,311	0,233	0,120	0,132	0,080	0,084	0,361	0,324	0,107	0,098	0,077	0,047	802	883	974	1015	1070	1103	1121	946	998	1395	1273	1165	1525
F 3	09.11.2007	1000	2000	0.6	0,262	0,257	0,177	0,109	0,111	0,055	0,052	0,268	0,218	0,060	0,068	0,053	0,028	831	942	1031	1114	1142	1182	1203	1010	1150	1726	1518	1282	1737
F 4	12.11.2007	500	2000	0.6	0,198	0,197	0,178	0,113	0,110	0,046	0,056	0,191	0,110	0,075	0,065	0,044	0,036	953	1128	1332		1457	1500	1526	1303	2578	2066	1769	1683	1962
F 15	20.11.2007	750	2000	0.6	0,815	0,825	0,689	0,327	0,299	0,132	0,122	0,810	0,678	0,158	0,166	0,104	0,064	695	788	888					824	927				
Malt dust; ignition location head; aspiration = ON; pressure venting head and legs; no-load operation with dust injection system																														
F 6	12.11.2007	750	2000	0.6	0,091	0,1	0,077	0,053	0,06	0,059	0,054	0,086	0,059	0,061	0,06	0,058	0,043	3094	3180	3234	3312	1346	1135	924	2378	1683	1235	1110	960	
F 7	13.11.2007	750	2000	0.6	0,062	0,064	0,066	0,06	0,066	0,062	0,066	0,062	0,06	0,056	0,061	0,061	0,047	1758	1869	2063	2224	2292	1246		1662	1504	1282	1117	956	1232
Malt dust; ignition location boot; aspiration = ON; pressure venting only head; no-load operation with dust injection system																														
F 13	19.11.2007	750	2000	0.6	0,904	1,041	1,153	1,111	0,814	0,326	0,281	0,743	0,616	0,485	0,395	0,230	0,15		885	999	1081	1110			988	1074				
F 14	20.11.2007	750	2000	0.6	1,406	1,400	1,279	0,916	0,582	0,301	0,287	1,427	1,385	0,982	0,607	0,291	0,114	877	1017	1081					1046	1128				

without dust injection system, wheaten flour

Constructional explosion protection for elevators

Project No.: F-05-0701

Test	Date	Load	Ignition energy	tv	Boot	Peak explosion overpressure up leg					Head	Peak explosion overpressure down leg					Oulet	Boot	Flame arriving time up leg					Head	Flame arriving time down leg					Oulet
No.					P1	P2 1m	P3 4m	P4 7m	P5 10m	P6 13m	P7 13,95m	P2_1 1m	P3_1 4m	P4_1 7m	P5_1 10m	P6_1 13m	P8	F1	F2 1m	F3 4m	F4 7m	F5 10m	F6 13m	F7 13,95m	F2_1 1m	F3_1 4m	F4_1 7m	F5_1 10m	F6_1 13m	F8
		[kg]	[J]	[s]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]
Undried wheathen flour; ignition location boot; aspiration = ON; pressure venting head and legs; no-load operation without dust injection system																														
B 1	05.06.2007	125	2000	22	0,280	0,184	0,161	0,086	0,102	0,070	0,085	0,266	0,302	0,084	0,073	0,073	0,078		1335	1500	1660	1745				1560	2120	1980	1850	2045
B 2	06.06.2007	100	2000	22	0,155	0,158	0,128	0,054	0,060	0,028	0,038	0,148	0,104	0,069	0,051	0,032	0,024	800	945	1125					1083	3625				
Undried wheathen flour; ignition location boot; aspiration = OFF; pressure venting head and legs; no-load operation without dust injection system																														
B 3	06.06.2007	100	2000	22	0,127	0,131	0,112	0,055	0,047	0,028	0,027	0,121	0,084	0,032	0,035	0,029	0,025	250	400	545					490					
B 4	06.06.2007	125	2000	22	0,231	0,226	0,173	0,073	0,063	0,061	0,047	0,236	0,193	0,073	0,059	0,052	0,045	630	795						780	932				
Undried wheathen flour; ignition location boot; aspiration = ON; pressure venting only head; no-load operation without dust injection system																														
B 5	12.06.2007	100	2000	22	0,300	0,310	0,345	0,337	0,279	0,141	0,147	0,290	0,223	0,181	0,151	0,117	0,087	400	609	847	946	1023								
B 6	13.06.2007	100	2000	22	0,276	0,284	0,293	0,290	0,216	0,095	0,103	0,268	0,219	0,186	0,137	0,091	0,072		671	911	1018	1121							1067	
Undried wheathen flour; ignition location boot; aspiration = ON; without pressure venting; no-load operation without dust injection system																														
B 7	13.06.2007	100	2000	22	0,383	0,389	0,406	0,389	0,352	0,295	0,289	0,371	0,348	0,332	0,308	0,280	0,254		433	602	713	806	906	1157		770				
B 9	15.06.2007	100	2000	22	0,484	0,460	0,475	0,459	0,423	0,348	0,341	0,414	0,350	0,339	0,344	0,323	0,279	426	555	967	1092	1192			1053					
B 10	18.06.2007	100	2000	22	0,306	0,311	0,349	0,341	0,325	0,252	0,252	0,251	0,247	0,267	0,247	0,235	0,216		526	824	935	1021			777	902				
A 2	21.08.2008	100	2000	35	0,422	0,412	0,437	0,388	0,259	0,210	0,215	0,409	0,355	0,293	0,256	0,214	0,120		167	370	510	614			587	610				800

with dust injection system, wheaten flour

Constructional explosion protection for elevators

Project No.: F-05-0701

Test No.	Date	Dust concen-tration [g/m³]	Ignition energy [J]	tv [s]	Boot P1 [bar]	Peak explosion overpressure up leg P2 1m [bar]	P3 4m [bar]	P4 7m [bar]	P5 10m [bar]	P6 13m [bar]	Head P7 13,95m [bar]	Peak explosion overpressure down leg P2_1 1m [bar]	P3_1 4m [bar]	P4_1 7m [bar]	P5_1 10m [bar]	P6_1 13m [bar]	Oulet P8 [bar]	Boot F1 [ms]	Flame arriving time up leg F2 1m [ms]	F3 4m [ms]	F4 7m [ms]	F5 10m [ms]	F6 13m [ms]	Head F7 13,95m [ms]	Flame arriving time down leg F2_1 1m [ms]	F3_1 4m [ms]	F4_1 7m [ms]	F5_1 10m [ms]	F6_1 13m [ms]	Oulet F8 [ms]
Undried wheathen flour; ignition location boot; aspiration = ON; pressure venting head and legs; no-load operation with dust injection system																														
E 1	29.10.2007	750	2000	0,6	0,069	0,047	0,045	0,022	0,038	0,040	0,050	0,096	0,109	0,077	0,073	0,039		1021	1189	1465	1676	1787	1880	1912		1737	1937	2023	2066	2346
E 2	30.10.2007	1000	2000	0,6	0,081	0,079	0,042	0,055	0,070	0,057	0,067	0,092	0,082	0,047	0,057	0,050		827	1028	1239	1350	1522	1615	1647	1336	1601	1851	2030	1751	2331
E 3	30.10.2007	1250	2000	0,6	0,066	0,066	0,052	0,034	0,042	0,057	0,053	0,075	0,064	0,044	0,051	0,045		820	963	1089	1160	1225	1325	1357	1114	1318	2489	1955	1372	1952
Undried wheathen flour; ignition location boot; aspiration = ON; pressure venting only head; no-load operation with dust injection system																														
E 4	31.10.2007	750	2000	0,6	0,274	0,293	0,258	0,280	0,200	0,186	0,126	0,291	0,287	0,264	0,208	0,106		831	1028	1250	1379	1400	1436	1450	1282	1389	1679	3624	3835	2038
E 5	31.10.2007	1000	2000	0,6	0,100	0,110	0,097	0,092	0,082	0,030	0,070	0,168	0,174	0,154	0,096	0,062		927	1146	1411	1565	1633	1690	1708	1662	1737	2084	2424	2002	2131
E 6	31.10.2007	1250	2000	0,6	0,299	0,307	0,301	0,296	0,245	0,054	0,133	0,305	0,291	0,247	0,181	0,119		824	974	1103	1210	1235	1293	1314	1121	1422	1873	2195	2389	
E 7	02.11.2007	500	2000	0,6	0,274	0,273	0,258	0,251	0,218	0,107	0,121	0,315	0,279	0,254	0,190	0,116	0,070	902	1128	1343	1429	1465	1497	1515	1400	1425				
E 8	02.11.2007	1500	2000	0,6	0,349	0,350	0,355	0,361	0,281	0,135	0,162	0,359	0,341	0,271	0,236	0,163	0,094	810	923	996	1055	1084	1110	1121	1017	1043	2074	1822	1135	3759
E 9	05.11.2007	2000	2000	0,6	0,267	0,273	0,307	0,305	0,262	0,111	0,104	0,260	0,207	0,164	0,147	0,093	0,044	755	821	908	971	1022	1055	1106	816	2315	2063	1744	1562	2675
E 20	23.11.2007	1500	2000	0,6	0,510	0,515	0,515	0,508	0,409	0,193	0,183	0,446	0,388	0,308	0,220	0,138		874	1046	1203	1325	1361	1407		1301					
Undried wheathen flour; ignition location head; aspiration = ON; pressure venting head and legs; no-load operation with dust injection system																														
E 10	05.11.2007	1500	2000	0,6	0,188	0,187	0,182	0,117	0,083	0,069	0,092	0,082	0,082	0,086	0,087	0,083	0,054	2027	2081	2131	2188	2202	1117		1912	1765	1586	1332	927	1246
Undried wheathen flour; ignition location head; aspiration = ON; pressure venting only head; no-load operation with dust injection system																														
E 11	06.11.2007	1500	2000	0,6	0,056	0,058	0,053	0,048	0,050	0,045	0,051	0,054	0,051	0,046	0,048	0,044	0,032										2084	1407	935	1261
E 12	06.11.2007	1500	2000	0,6	0,226	0,243	0,280	0,278	0,221	0,121	0,137	0,189	0,128	0,113	0,139	0,106	0,064	2553	2611	2697	2761	2797	2825	2840	2363	2084	1722	1318	938	1228
E 13	06.11.2007	1000	2000	0,6	0,052	0,051	0,051	0,041	0,046	0,045	0,046	0,052	0,051	0,049	0,049	0,044	0,039										2260	1415	935	1196
Dried wheathen flour; ignition location boot; aspiration = ON; pressure venting only head; no-load operation with dust injection system																														
E 14	07.11.2007	1500	2000	0,6	0,328	0,335	0,339	0,316	0,241	0,121	0,103	0,324	0,279	0,212	0,168	0,097	0,041	748	838	924	981	1013	1046	1182	788	1984	1801	1615	1404	
E 15	07.11.2007	1500	2000	0,6	0,447	0,471	0,495	0,486	0,386	0,210	0,174	0,401	0,352	0,302	0,254	0,163	0,075	809	885	953	1006	1031	1060	2406	2439	2363	2249	2009	2141	2958
Dried wheathen flour; ignition location boot; aspiration = ON; without pressure venting; no-load operation with dust injection system																														
E 16	19.11.2007	1500	2000	0,6	0,646	0,705	0,705	0,583	0,468	0,401	0,395	0,547	0,507	0,455	0,433	0,378	0,363	698	788	813	867	981	1056	1103	795					

with dust injection system, wheaten flour

Constructional explosion protection for elevators

Project No.: F-05-0701

Test No.	Date	Dust concen-tration [g/m³]	Ignition energy [J]	tv [s]	Boot	Peak explosion overpressure up leg					Head	Peak explosion overpressure down leg					Oulet	Boot	Flame arriving time up leg					Head	Flame arriving time down leg					Oulet
					P1 [bar]	P2 1m [bar]	P3 4m [bar]	P4 7m [bar]	P5 10m [bar]	P6 13m [bar]	P7 13,95m [bar]	P2_1 1m [bar]	P3_1 4m [bar]	P4_1 7m [bar]	P5_1 10m [bar]	P6_1 13m [bar]	P8 [bar]	F1 [ms]	F2 1m [ms]	F3 4m [ms]	F4 7m [ms]	F5 10m [ms]	F6 13m [ms]	F7 13,95m [ms]	F2_1 1m [ms]	F3_1 4m [ms]	F4_1 7m [ms]	F5_1 10m [ms]	F6_1 13m [ms]	F8 [ms]
Undried wheathen flour; ignition location boot; aspiration = ON; without pressure venting; no-load operation with dust injection system																														
E 17	19.11.2007	1500	2000	0,6	0,572	0,584	0,582	0,556	0,509	0,436	0,434	0,560	0,532	0,446	0,428	0,424	0,356	827	917	1060	1164	1261	1368	1483	1035	1207				
E 21	26.11.2007	1500	2000	0,6	0,548	0,557	0,562	0,514	0,536	0,592	0,597	0,493	0,442	0,506	0,534	0,589		845	1056	1150	1232	1257	1300	1329	1074	1203	1626	1504	1440	

without dust injection system, maize starch

Constructional explosion protection for elevators

Project No.: F-05-0701

Test No.	Date	Load	Ignition energy	Boot	Peak explosion overpressure up leg					Head	Peak explosion overpressure down leg					Oulet	Boot	Flame arriving time up leg					Head	Flame arriving time down leg					Oulet
				P1	P2 1m	P3 4m	P4 7m	P5 10m	P6 13m	P7 13,95m	P2_1 1m	P3_1 4m	P4_1 7m	P5_1 10m	P6_1 13m	P8	F1	F2 1m	F3 4m	F4 7m	F5 10m	F6 13m	F7 13,95m	F2_1 1m	F3_1 4m	F4_1 7m	F5_1 10m	F6_1 13m	F8
		[kg]	[J]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]
Dried maize starch; ignition location boot; aspiration = ON; pressure venting head, legs and boot; no-load operation without dust injection system																													
C 1	20.06.2007	100	1000	0,348	0,332	0,351	0,145	0,137	0,088	0,073	0,470	0,395	0,084	0,082	0,091	0,047			443	722	846	967	1048		445	753	1354	1154	1733
C 2	20.06.2007	100	2000	0,339	0,367	0,251	0,067	0,060	0,050	0,042	0,395	0,177	0,025	0,036	0,062	0,043			502	1051	1245	1414	1484		1403	1161	1577	1633	2253
C 3	25.06.2007	225	2000	0,279	0,339	0,267	0,118	0,104	0,081	0,082	0,306	0,106	0,046	0,064	0,096	0,067		301	383	910	1124	1339	1432		2084	1758	1586	1490	1995
G 1	18.06.2009	100	5000	0,530	0,550	0,420	0,150	0,180	0,110	0,110	0,660	-	0,290	0,260	0,120	0,060		50	143	269	648	941	1019	80	126	216	-	-	-
G 2	19.06.2009	100	5000	-	0,490	0,470	0,190	0,210	0,150	0,140	0,540	-	0,210	0,180	0,110	0,060		100	114	236	395	571	634	90	114	255	1075	809	1910
G 3	23.06.2009	100	2000	0,470	0,460	0,330	0,110	-	0,070	0,060	0,580	-	0,140	0,110	0,060	0,030		100	148	291	702	1065	1156	119	148	315	1566		1670
G 4	23.06.2009	100	2000	0,640	0,650	0,600	0,170	0,170	0,120	0,100	0,710	-	0,240	0,200	0,100	0,045		119	157	271	-	1067	1152	119	157	295	2205		-
Dried maize starch; ignition location boot; aspiration = ON; pressure venting head and legs; no-load operation without dust injection system																													
C 6	28.06.2007	225	2000	1,104	0,682	0,329	0,135		0,084	0,077	1,135	1,000	0,135	0,146	0,035	0,044									189				
C 7	29.06.2007	100	2000	1,172	0,780	0,387	0,165		0,083	0,082	1,096	0,530	0,091	0,075		0,052		172											
G 5	24.06.2009	100	2000	1,210	1,040	0,550	0,170	0,060	0,120	0,100	0,110	0,210	0,290	1,430	1,170	0,060		81	107						106	81			
G 6	24.06.2009	100	2000	1,710	1,410	1,180	0,250	0,270	0,180	0,150	0,210	0,420	0,510	2,190	1,670			81	141						155	125			
Dried maize starch; ignition location head; aspiration = ON; pressure venting only head; no-load operation without dust injection system																													
C 28	18.07.2007	225	2000	0,573	0,406	0,418	0,494	0,975	0,723	0,659	0,625	1,134	1,202	0,923	0,607	0,486					2207				2213	2073	1253	2174	
C 29	18.07.2007	100	2000	0,320	0,282	0,230	0,378	0,707	0,510	0,429	0,314	0,277	0,311	0,422	0,480	0,398	2154	2546	2794	1507	294			1998	1389	731	297		881
C 30	19.07.2007	100	2000	0,359	0,323	0,225	0,331	0,779	0,466	0,399	0,352	0,355	0,470	0,712	0,522	0,306	1676	2009	2363	2564	180			1454	970	519	183		523
Dried maize starch; ignition location boot; aspiration = ON; pressure venting only head; no-load operation without dust injection system																													
C 32	19.07.2007	0	2000	1,581	1,418	0,791	0,629	0,505	0,212	0,200	1,641	1,454	0,714	0,420		0,088									263				
C 33	20.07.2007	100	2000	0,946	0,791	0,394	0,331	0,249	0,123	0,126	0,861	0,404	0,236	0,144		0,083			571	1088	1278	1429	1604		2330	2074	1800	1692	2590
C 34	20.07.2007	0	2000	1,324	1,222	1,324	0,930	0,568	0,301	0,325	1,322	1,250	0,623	0,355		0,148			560	601					583				

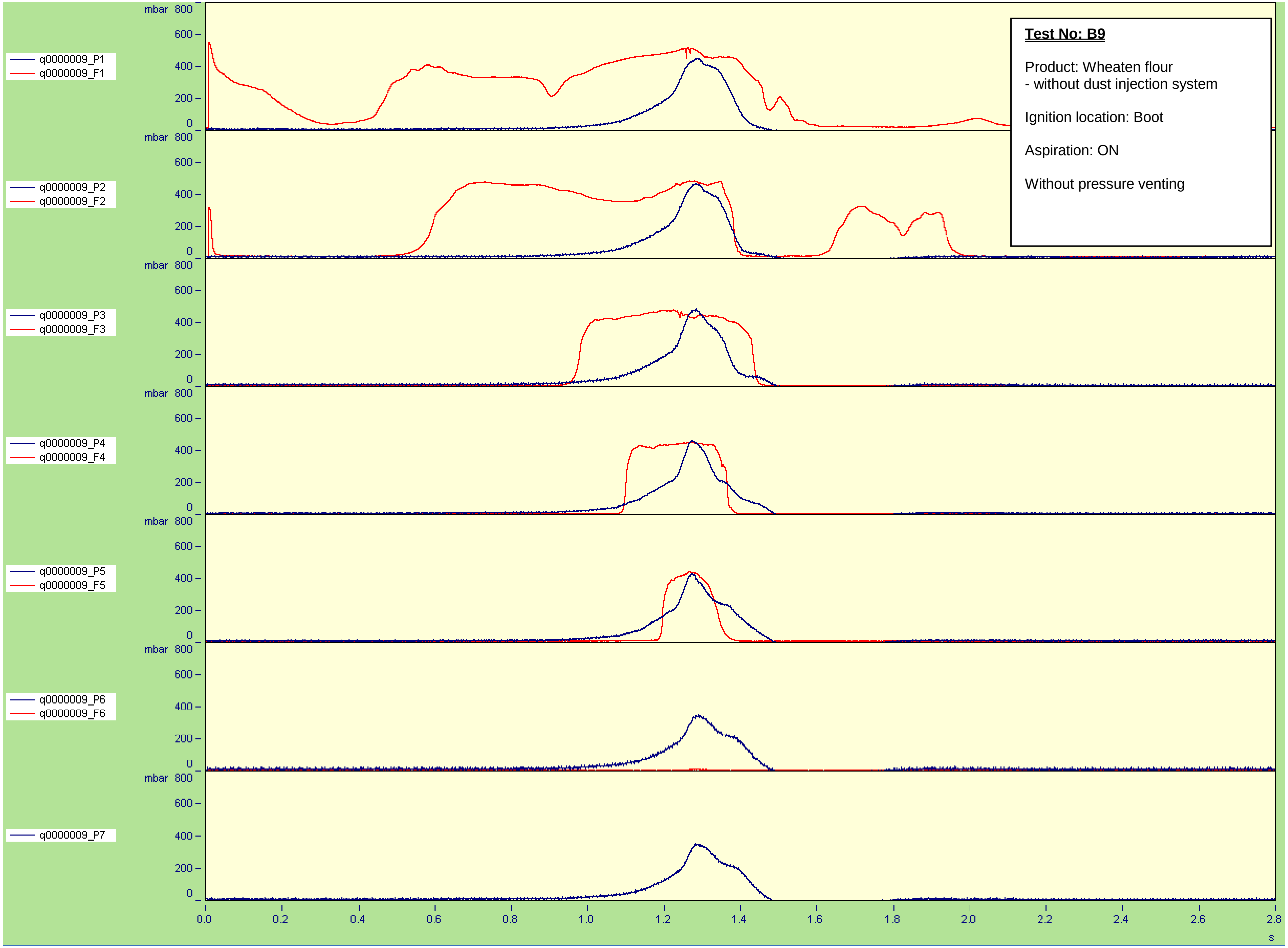
with dust injection system, maize starch

Constructional explosion protection for elevators

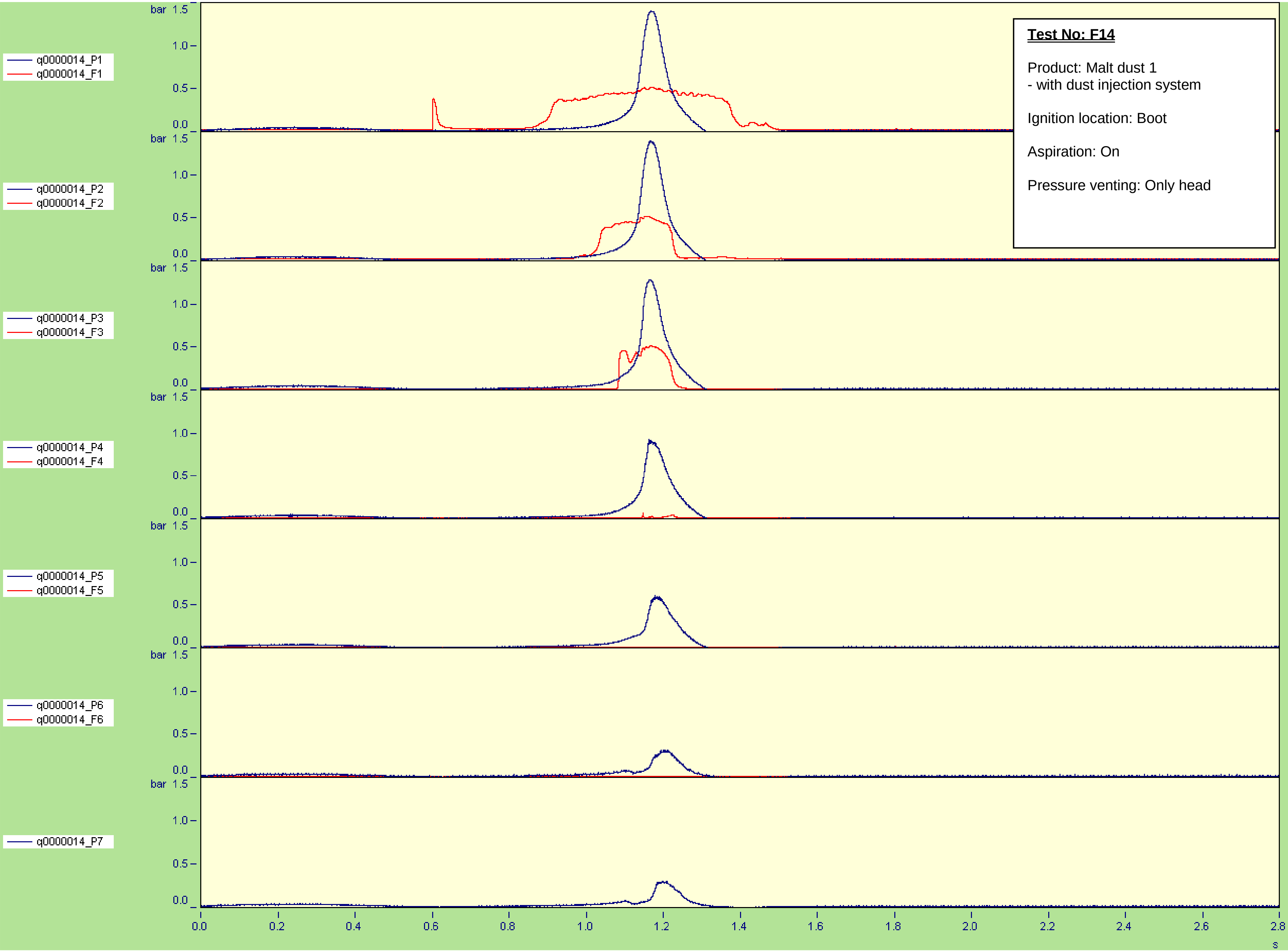
Project No.: F-05-0701

Test No.	Date	Dust concen-tration	Ignition energy	Boot P1	Peak explosion overpressure up leg P2 1m	P3 4m	P4 7m	P5 10m	P6 13m	Head P7 13,95m	Peak explosion overpressure down leg P2_1 1m	P3_1 4m	P4_1 7m	P5_1 10m	P6_1 13m	Oulet P8	Boot F1	Flame arriving time up leg F2 1m	F3 4m	F4 7m	F5 10m	F6 13m	Head F7 13,95m	Flame arriving time down leg F2_1 1m	F3_1 4m	F4_1 7m	F5_1 10m	F6_1 13m	Oulet F8
		[g/m³]	[J]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[bar]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]	[ms]
Dried maize starch; ignition location head; aspiration = ON; pressure venting only head; no-load operation with dust injection system																													
D 1	25.07.2007	1000	2000	~ 5	~ 3,5	~2,4	1,920	1,110	0,504	0,498	~3,5	~2,4	1,640	1,140	0,523	0,566	169	178	174	148	140			169	154	141	125	83	174
Dried maize starch; ignition location boot; aspiration = ON; pressure venting head, legs and boot; no-load operation with dust injection system																													
F 8	13.11.2007	1000	2000	0,910	0,950	1,000	0,496	0,424	0,180	0,185	0,878	1,479	0,340	0,317	0,140	0,074		709	759	795				723	784				
F 9	14.11.2007	750	2000	0,616	0,650	0,679	0,279	0,277	0,215	0,201	0,619	0,786	0,232	0,272	0,212	0,164	759	796	873	916	1083	1184	1244	839	948	1253	1294	1271	1486
F 10	14.11.2007	1250	2000	0,888	0,943	0,981	0,549	0,426	0,432	0,422	0,976	1,553	0,340	0,554	0,446	0,293	673	727	770	791	920	978	1006	727	791	1092	1035	1017	1343
F 11	15.11.2007	1500	2000	0,801	0,852	0,833	0,516	0,386	0,197	0,215	0,891	1,630	0,633	0,478	0,222	0,119		734	774	809	852	902	931	741	791	1114	1049	974	1239
F 12	15.11.2007	1750	2000	0,585	0,608	0,673	0,332	0,489	0,504	0,470	0,602	0,490	0,355	0,952	0,506	0,382	713	728	777	813	953	1074	1109	738	795	1157	1128	1110	1389
Dried maize starch; ignition location boot; aspiration = ON; pressure venting head and legs; no-load operation with dust injection system																													
F 16	21.11.2007	1500	2000	2,251	2,216	1,859	0,833	0,600	0,424	0,327	2,099	2,254	0,580	0,549	0,257	0,127	662	695	723	752				695	734				
Dried maize starch; ignition location heat; aspiration = ON; pressure venting head and legs; no-load operation with dust injection system																													
F 17	21.11.2007	1500	2000	1,039	1,055	1,034	0,478	0,264	0,301	0,205	0,748	0,402	0,259	0,610	0,263	0,145	1067	1074	1107	1124	813	709		1017	806	763	731	709	

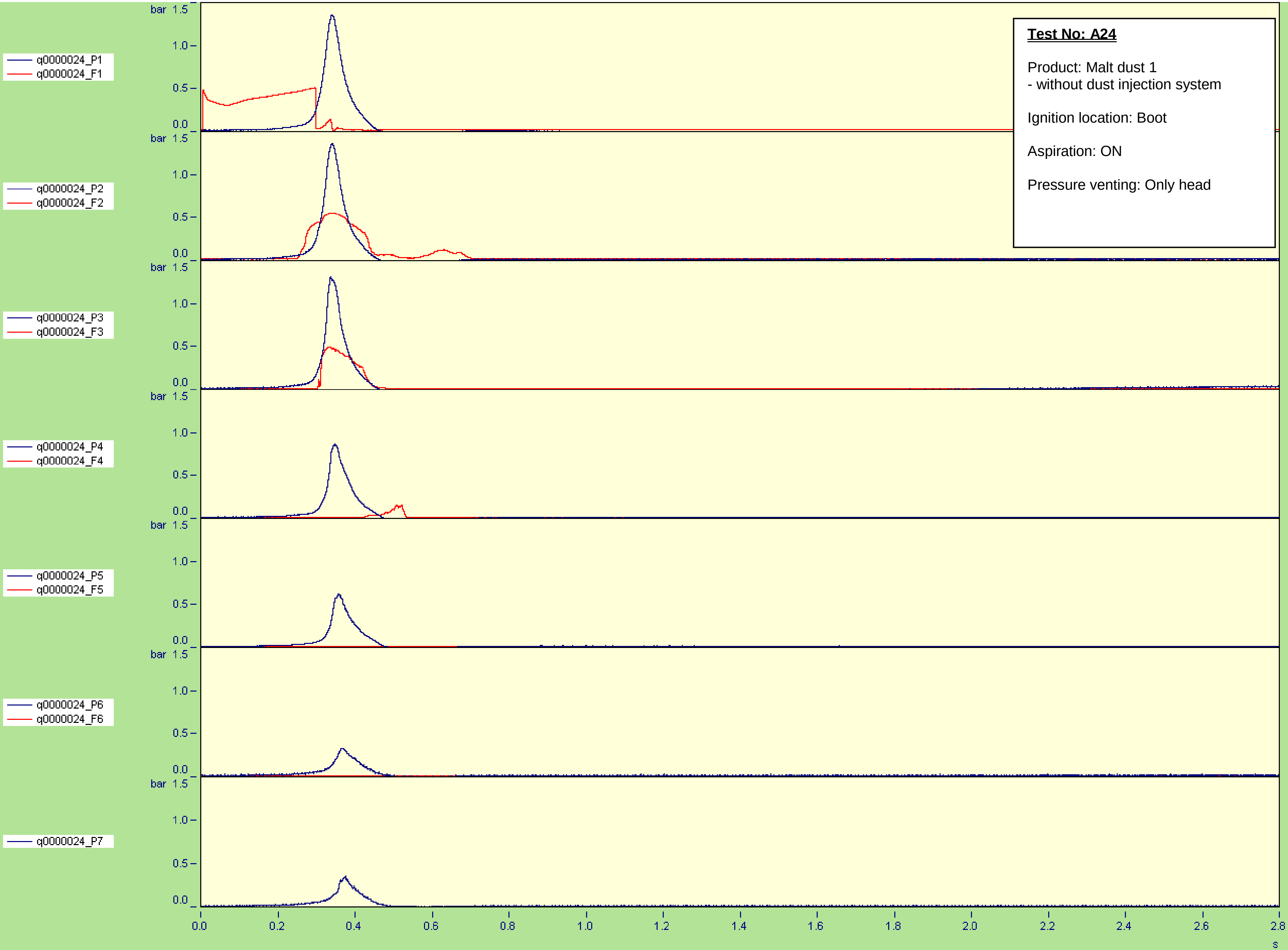
7.3 Pressure- and flame-time histories of selected tests



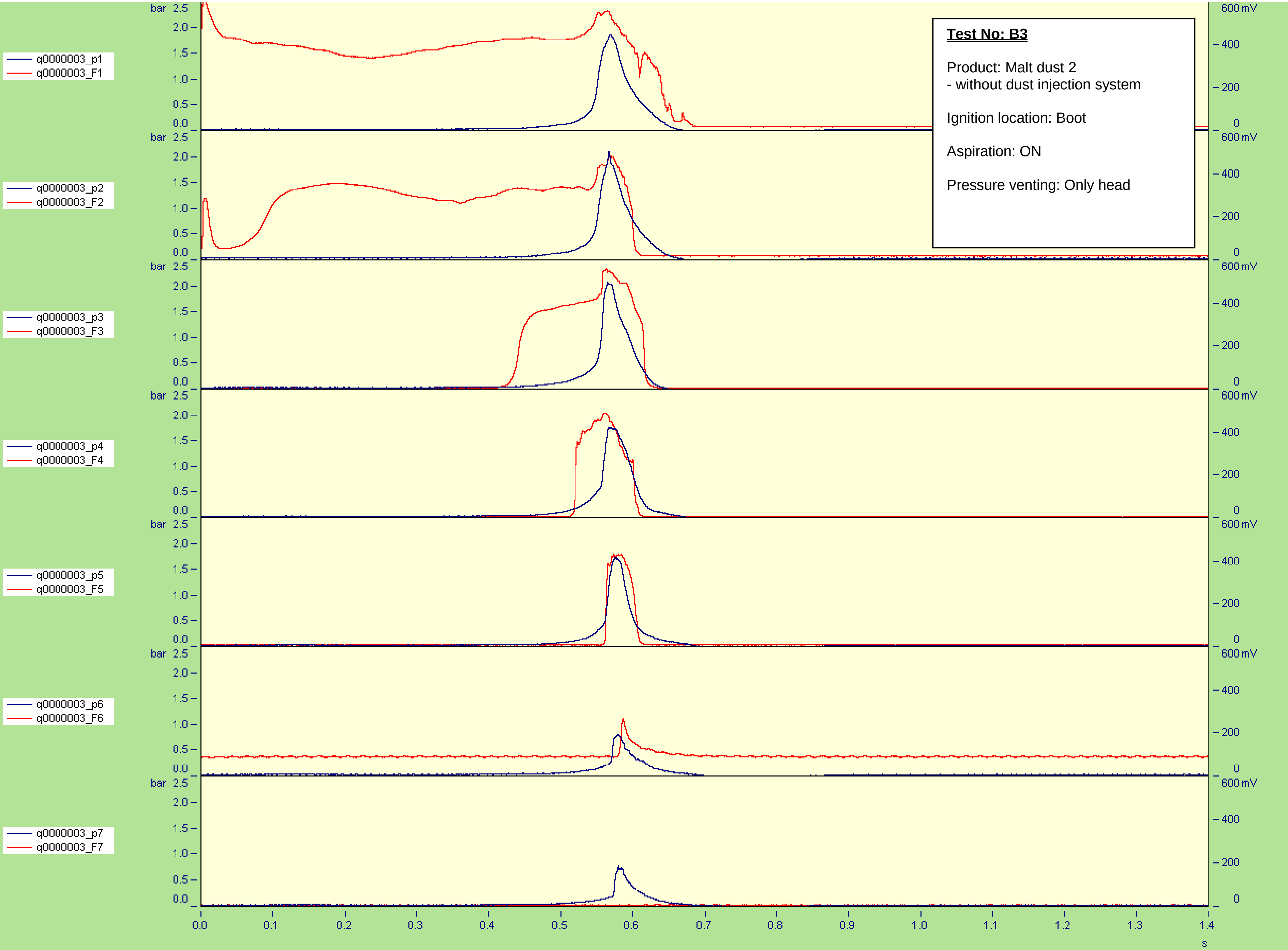
Test No: B9
Product: Wheaten flour
- without dust injection system
Ignition location: Boot
Aspiration: ON
Without pressure venting
q0000009_P1
q0000009_F1
q0000009_P2
q0000009_F2
q0000009_P3
q0000009_F3
q0000009_P4
q0000009_F4
q0000009_P5
q0000009_F5
q0000009_P6
q0000009_F6
q0000009_P7
mbar
s



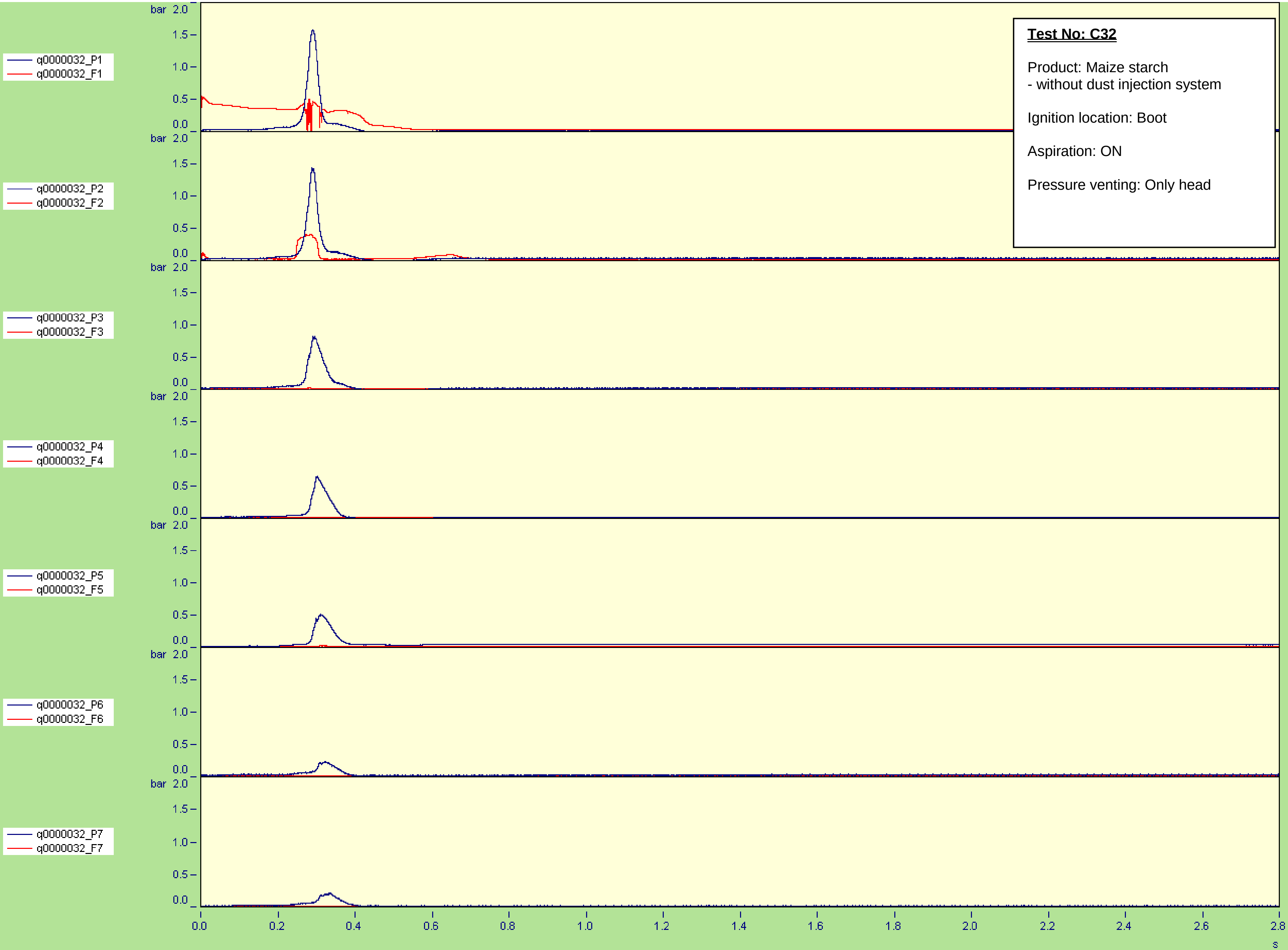
Test No: F14
Product: Malt dust 1
- with dust injection system
Ignition location: Boot
Aspiration: On
Pressure venting: Only head
q0000014_P1
q0000014_F1
q0000014_P2
q0000014_F2
q0000014_P3
q0000014_F3
q0000014_P4
q0000014_F4
q0000014_P5
q0000014_F5
q0000014_P6
q0000014_F6
q0000014_P7
bar
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
s



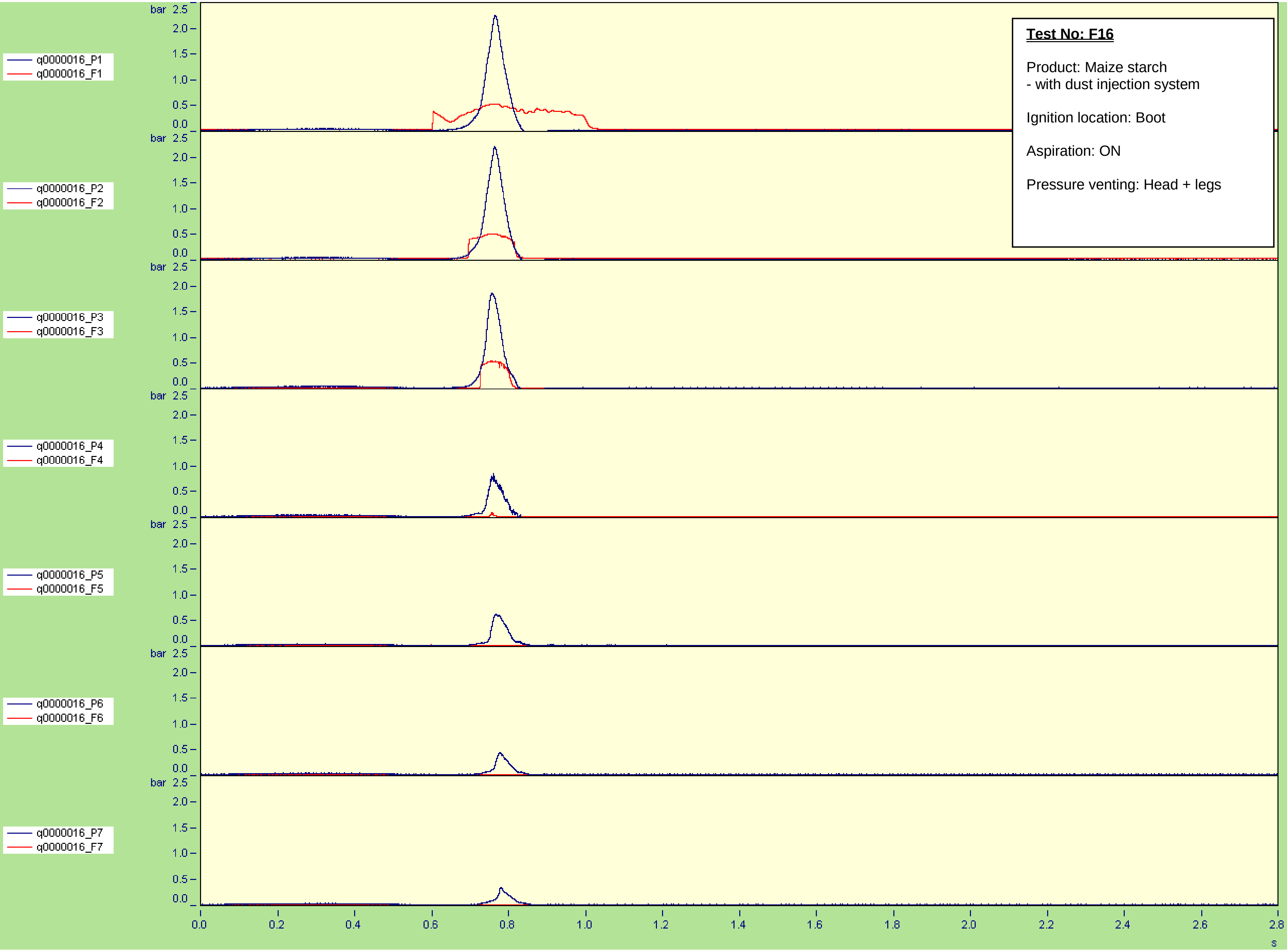
Test No: A24
Product: Malt dust 1
- without dust injection system
Ignition location: Boot
Aspiration: ON
Pressure venting: Only head
q0000024_P1
q0000024_F1
q0000024_P2
q0000024_F2
q0000024_P3
q0000024_F3
q0000024_P4
q0000024_F4
q0000024_P5
q0000024_F5
q0000024_P6
q0000024_F6
q0000024_P7
bar
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
s



Test No: B3
Product: Malt dust 2
- without dust injection system
Ignition location: Boot
Aspiration: ON
Pressure venting: Only head
q0000003_p1
q0000003_F1
q0000003_p2
q0000003_F2
q0000003_p3
q0000003_F3
q0000003_p4
q0000003_F4
q0000003_p5
q0000003_F5
q0000003_p6
q0000003_F6
q0000003_p7
q0000003_F7
bar
600 mV
s



Test No: C32
Product: Maize starch
- without dust injection system
Ignition location: Boot
Aspiration: ON
Pressure venting: Only head
q0000032_P1
q0000032_F1
q0000032_P2
q0000032_F2
q0000032_P3
q0000032_F3
q0000032_P4
q0000032_F4
q0000032_P5
q0000032_F5
q0000032_P6
q0000032_F6
q0000032_P7
q0000032_F7
bar
s


Test No: F16
Product: Maize starch
- with dust injection system
Ignition location: Boot
Aspiration: ON
Pressure venting: Head + legs
q0000016_P1
q0000016_F1
q0000016_P2
q0000016_F2
q0000016_P3
q0000016_F3
q0000016_P4
q0000016_F4
q0000016_P5
q0000016_F5
q0000016_P6
q0000016_F6
q0000016_P7
q0000016_F7
bar
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.2
1.4
1.6
1.8
2.2
2.4
2.6
2.8
s


Test No: D1
Product: Maize starch
- with dust injection system
Ignition location: Head
Aspiration: ON
Pressure venting: Only head
Elevator was destroyed
P1 ~ 5 bar; P3 ~ 2,4 bar;
P7 = 0,5 bar
q0000001_P1
q0000001_F1
q0000001_P2
q0000001_F2
q0000001_P3
q0000001_F3
q0000001_P4
q0000001_F4
q0000001_P5
q0000001_F5
q0000001_P6
q0000001_F6
q0000001_P7
q0000001_F7
bar
mV
s

7.4 Additional information about the dust properties

Table: Explosion Characteristics of the used Dusts

OT - original test sample

ST - standardized test sample (<63 µm; dried)

Product		Particle size distribution [%] (air.)					Moist. [%]	MIE with ind. [mJ]	MIE w.o. ind. [mJ]	IT [°C]	GT [°C]	Flam
		<500	<250	<125	<63	<32						
Maize starch dried (03411)	OT				100	99,7	2,1	4 < MZE ≤ 5	100 < MZE ≤ 500	380	520	5
	ST				100			4 < MZE ≤ 5	50 < MZE ≤ 100	380	520	5
Wheaten flour typ 550	OT		100	94,2	52,5	28,4	11,7	100 < MZE ≤ 500		380	410	2
	ST				100			10 < MZE ≤ 50		380	350	2
Malt dust 1 (rough pre-screened)	OT	85,3	74,2	59,7	46,9	38,6	5,9	5 < MZE ≤ 10	100 < MZE ≤ 500	380	290	2
	ST				100			5 < MZE ≤ 10	100 < MZE ≤ 500	370	290	2
Malt dust 2 (rough pre-screened)	OT	86,4	78	62,9	48,6	39,1	6,4	< MZE ≤	< MZE ≤			
	ST				100			5 < MZE ≤ 10	100 < MZE ≤ 500	370		

Product		Dusting ability	
		Dusting number	Group
Maize starch dried (03411)	OT	10,2	4
	ST		
Wheaten flour typ 550	OT	0,6	1
	ST		
Malt dust 1 (rough pre-screened)	OT	29	5
	ST		
Malt dust 2 (rough pre-screened)	OT	13,2	4
	ST		

Product		Test vessel	P_{max} [bar]	K_{St} [bar·m·s^{-1}]	Comments
Maize starch dried (03411)	OT	1 m³	8,7	204	Maize starch: Original test sample and standardized test sample are nearly identical
	ST	1 m³	8,7	204	
Wheaten flour typ 550	OT	1 m³	7,5	88	
	ST	1 m³ (20 l-Kugel)	8,2 (6,8)	133 (109)	
Malt dust 1 (rough pre-screened)	OT	20 l-Kugel (1 m³)	6,4 (8,2)	133 (119)	1 m³, blocked fast opening valve ever!
	ST	20 l-Kugel	7,9	143	
Malt dust 2 (rough pre-screened)	OT				
	ST	20 l-Kugel	8,4	159	

Berufsgenossenschaft
Nahrungsmittel und Gaststätten
Dynamostr. 7 - 11; 68165 Mannheim

Zentrallabor

BGN
Berufsgenossenschaft
Nahrungsmittel
und Gaststätten

Analysenbericht Nr.

zu Messbericht Nr.	
Auftraggeber	
Betrieb	
Datum der Analyse	20.02.08
Analyse durchgeführt von	Nic

Korngrößenanalyse

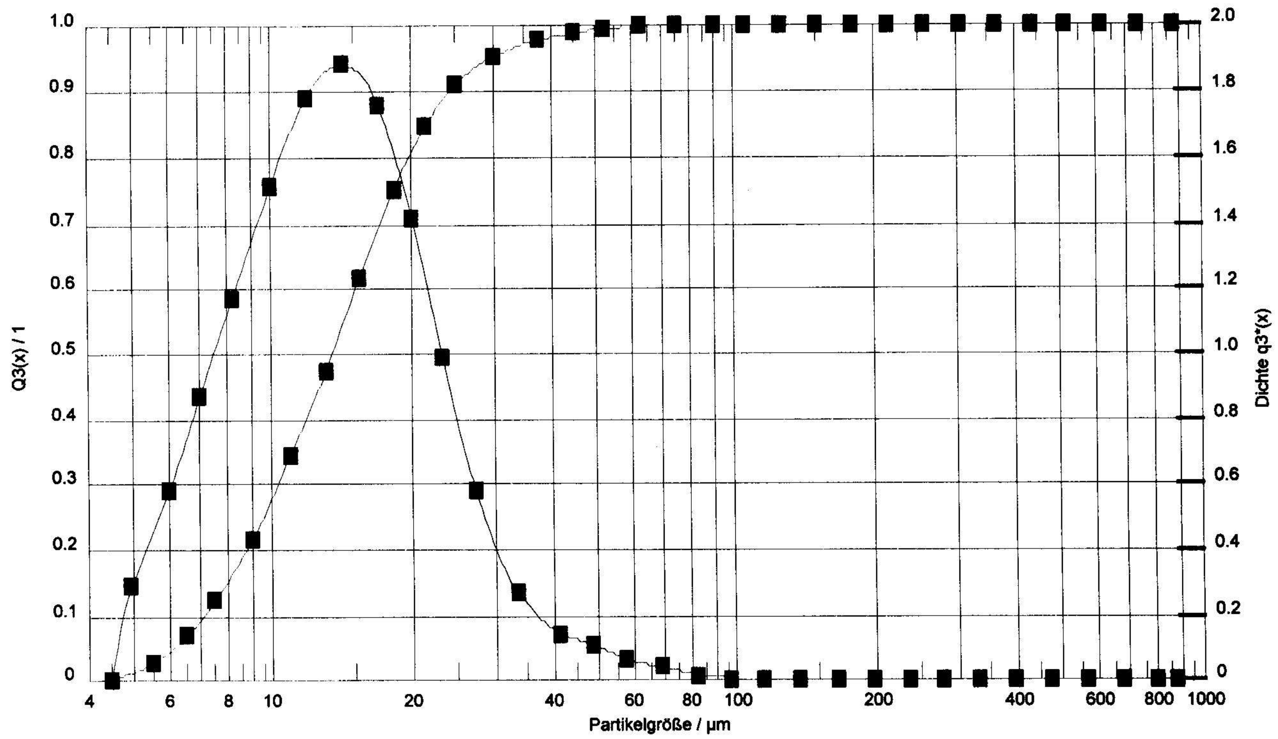
Kennzeichnung der Probe

Bezeichnung Maisstärke, getrocknet
Probenahmedatum HELOS/DOS Dateiname

Analysenparameter

System	Sympatec HELOS (H0872)			
Dipergierer	RODOS		Messbedingung	Nicklisch
Dosierer	VIBRI		Messbereich	R5: 0.5/4.5...875µm
Druck	2,00	bar	Messzeit	09:12:21
Unterdruck	0,00	mbar	Messdauer	30,32 s
Förderrate	80,00	%	Zykluszeit	500 ms
Betthöhe	1,50	mm	Start bei	1,00% auf C.Opt
Drehzahl	0,00	%	Referenzmessung	00:00:23, 0,00 %
c_opt =	4,95	%	Auswertung	LD (V 3.4 Rel.1)

Diagramm



Volumenverteilung

x0/µm	Q3/	x0/µm	Q3/	x0/µm	Q3/	x0/µm	Q3/
4,50	0,00	18,50	74,80	75,00	99,93	305,00	100,00
5,50	2,45	21,50	84,01	90,00	100,00	365,00	100,00
6,50	6,59	25,00	90,44	105,00	100,00	435,00	100,00
7,50	11,91	30,00	94,96	125,00	100,00	515,00	100,00
9,00	21,10	37,50	97,47	150,00	100,00	615,00	100,00
11,00	34,18	45,00	98,56	180,00	100,00	735,00	100,00
13,00	47,01	52,50	99,22	215,00	100,00	875,00	100,00
15,50	61,33	62,50	99,67	255,00	100,00		

Umrechnung in eine Siebanalyse

< 4µm:	0,00	< 10µm:	27,64				
< 20µm:	79,41	< 32µm:	95,63	< 63µm:	99,68	< 71µm:	99,85
<125µm:	100,00	<250µm:	100,00	<500µm:	100,00		

Partikelgröße / µm, interpoliert bei Q3 = nn %

x10 = 7,14 µm	x50 = 13,52 µm	x90 = 24,76 µm
x16 = 8,17 µm	x84 = 21,50 µm	x99 = 50,04 µm

Moment der Verteilung

M1,3 = 15,4 µm

Kommentar:

Mannheim, 20.02.08

Malt dust: The original dust sample

Malt dust: On the right hand the rough pre-screened malt dust sample. The oversize material (hull) is shown on the left side.