

Dust explosion venting and suppression of conventional spray dryers

R. Siwek, FireEx, Giebenach, CH, K. van Wingerden, Kidde-Deugra, Ratingen, DE, O. R. Hansen, GexCon, Bergen, NO, G. Sutter, Chr. Kubainsky, Swiss Saf. Inst. Basel, CH, Chr. Schwartzbach, Niro, Soeborg, DK, G. Giger, Ciba Spec. Chem., Basel R. Meili, MSE Meili, Zurich, CH (0985)

1. Introduction

As already established for e.g. pneumatically filled vessels (Siwek, 1989) and small mills (Barth et al., 1996) dust explosion protection measures taken on the basis of realistic process conditions prevailing in industrial equipment are often less demanding (smaller vent opening, lower strength of industrial equipment, less suppressant to be deployed) than when designed on the basis of turbulence and dust cloud conditions prevailing when applying a dust cloud generation technique for determination of dust explosion properties as prescribed by standards such as ISO 6184-1 (International Organisation of Standardisation (ISO), 1985).

Until now it has been common practice to design explosion protection measures (explosion venting, explosion suppression) for conventional spray dryers on the basis of dust cloud conditions according to the ISO-method (Ott et al, 1993 and Siwek, 2000). The turbulence prevailing in these spray dryers is, however, less intensive than that prevailing in dust clouds generated in accordance with the ISO-standard. The dust cloud is moreover not homogeneous (in the upper part of the dryer the dust particles contain too much inert material (water) to burn, in the middle part the particles contain still so much water that they will burn (if they burn) very slowly and in the bottom part the particles are dry and will burn). One can therefore expect that also explosion protection measures can be chosen to be less stringent than when designed based on the ISO-method for dust cloud properties.

The design of a conventional spray dryer is shown in Figure 1.

The spray dryer has the following features: The drying chamber is cylindrical with a conical bottom. The product (slurry or solution) feed to be dried and the hot drying gas are introduced from the top. The drying gas exits the chamber with a fraction of the dry product and is conveyed to a separation system (cyclone or bag filter). The main part of the dry product exits the chamber from the conical bottom.

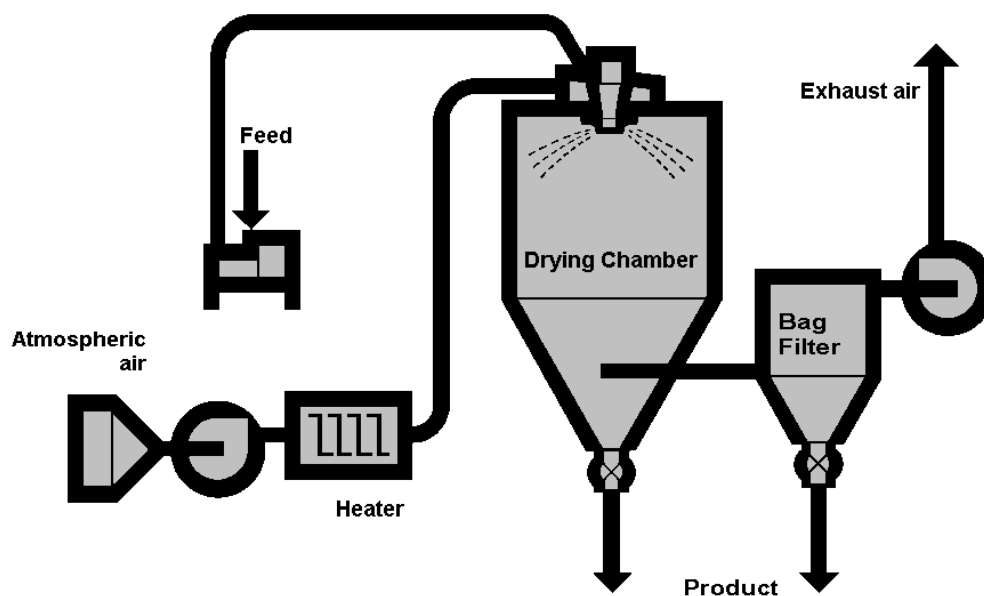


Figure 1 Design of a conventional spray dryer.

In order to investigate how explosion protection measures can be designed in a more optimum way a research project was started aiming at determining how to design venting and suppression systems for spray dryers on the basis of realistic process conditions prevailing in these spray dryers (Van Wingerden and Siwek, 2004).

The main parts of this research project are:

- Dust concentration and turbulence measurements in a number of spray dryers installed in industry
- Reference dust explosion tests in a closed vessel representing a spray dryer
- Explosion tests in the same vessel to investigate the explosion protection method of dust explosion venting
- Explosion tests in the same vessel to investigate the explosion protection method of dust explosion suppression
- The development of a CFD-based tool allowing for extrapolation of the experimental results to larger volumes

This paper describes the main results of the project.

2. Dust concentration and turbulence measurements

Using a laser backscatter measuring system dust concentration and turbulence measurements were performed in various industrial spray dryers. An example of a measured velocity profile as a function of time is shown in Figure 2. Figure 3 shows average dust concentrations measured as a function of height in a 132 m³ spray dryer. The laser back scattering measuring system was compared to other measuring techniques: LDA (Laser Doppler Anemometry) for turbulence and velocity measurements and a system based on the attenuation of light by absorption. The agreement between the laser back scattering system and the other two measuring systems is satisfactory.

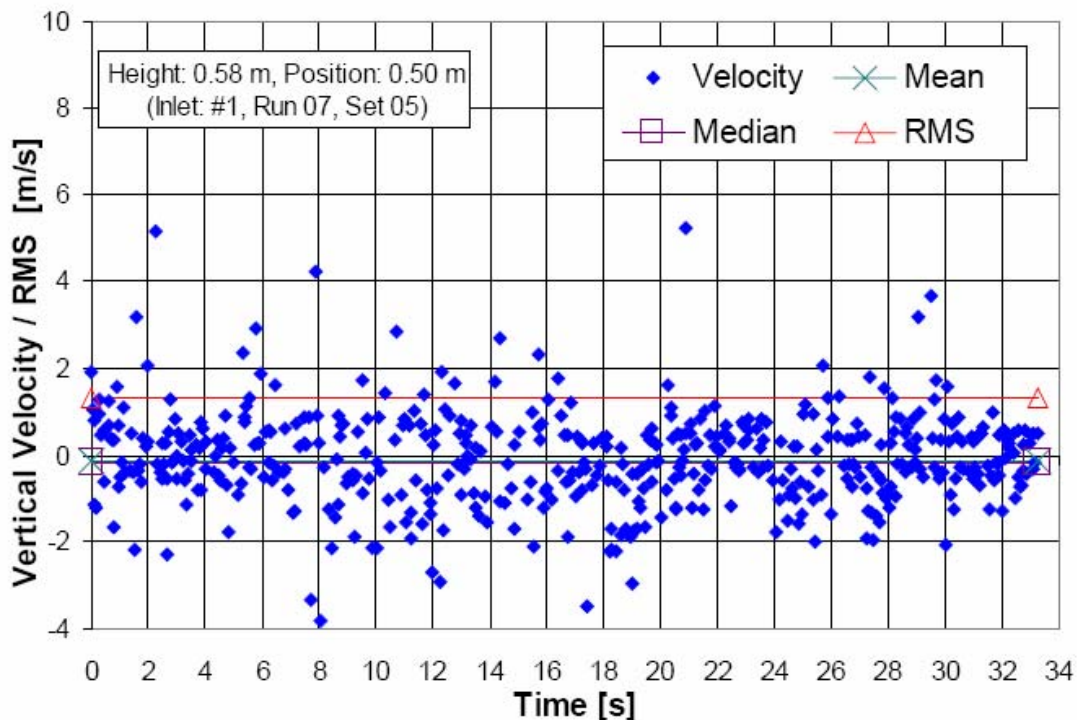


Figure 2 Example of vertical velocity measurement with indicated median, average and Root Mean Square (RMS) velocity measured by a laser backscatter measuring system (spray dryer volume 6 m³, flat bottom).

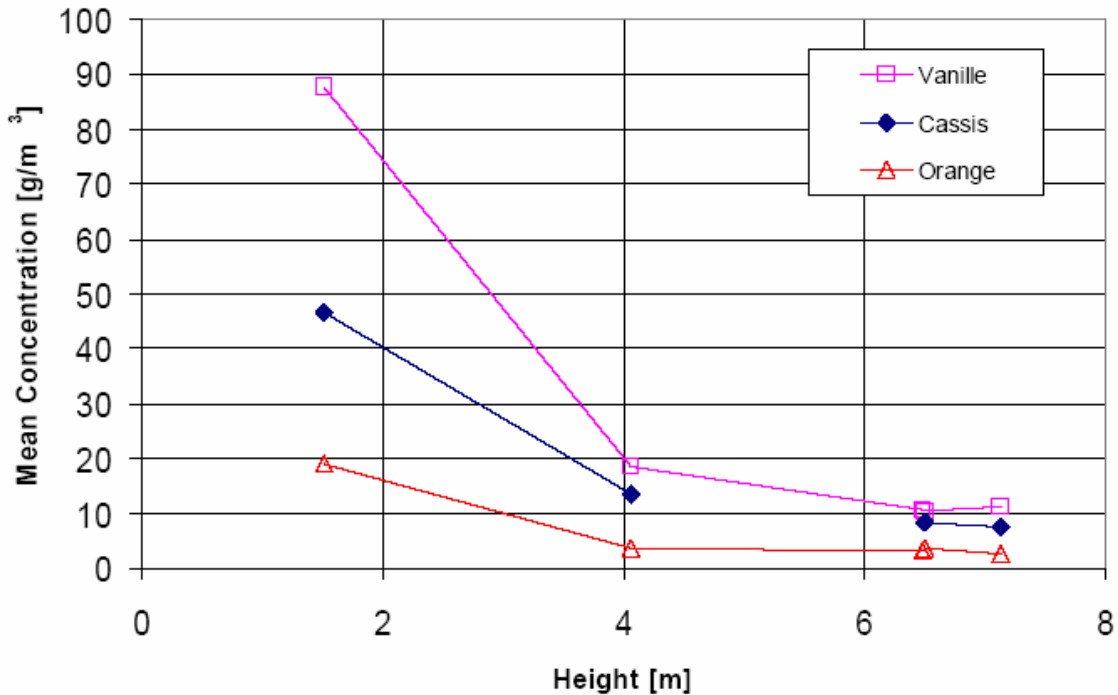


Figure 3 Measured mean concentration values as a function of the height (measured from the bottom) for three different products in a 132 m³ spray dryer (conical bottom).

In total measurements were undertaken in 4 different spray dryers varying in volume from 6 to 310 m³. The production in these spray dryers involved maltodextrine, vanilla flavour, orange flavour, cassis flavour and Elotex dispersion powder.

The conclusion of the concentration and turbulence measurements performed in the industrial spray dryers is:

- Explosive atmospheres in conventional spray dryers only occur in the bottom region of the drying chamber (average concentration < 100 g/m³)
- If explosive atmospheres occur they occur very locally and during a short period of time
- The turbulence intensity seen in the industrial spray dryers is typically 1-2 m.s⁻¹ which is lower than measured when generating dust clouds according to the ISO-method to determine dust explosion properties: 1.5-4 m.s⁻¹ (Hauert et al., 1994)

3. Explosion accidents in spray dryers

A review of explosion accidents in spray dryers show that the by far most common cause of explosions in spray dryers is self-ignition. This self-ignition process causes smouldering material falling down into the conical part of the dryer directly igniting a flammable dust cloud there or whirling up dust and igniting this (Alfert et al., 1988). This observation together with the results of the aforementioned dust concentration and turbulence measurements constitute the basis for the experimental conditions chosen for the explosion experiments.

4. Explosion experiments

The explosion experiments were performed in the 43.3 m³ representation of a spray dryer shown in Figure 4. The vessel is basically a cylinder with end plates. On behalf of the present experiments the cylindrical vessel was provided by a 2.359 m high conical bottom. The vessel has been provided with vent openings of variable sizes (DN200 – DN600): those used in the explosion venting experiments concern one near the top and one on the side just above the conical part. The vessel can withstand a maximum pressure of 6 bars.

Using the ISO-method dust clouds were generated to form dust clouds in the conical part of the drying chamber only (i.e. conservative turbulence conditions compared to those prevailing in spray dryers; dust cloud volume approximately 6 m^3). Ignition was effected by two 5kJ-Sobbe igniters (strong ignition source which is the standard ignition source for dust explosion testing according to the ISO-method (ISO, 1985)).

A dust layer was introduced in the cone to simulate realistic conditions, i.e. the possibility of dust being whirled up by the explosion and contributing to this explosion. The amount of dust used for the dust layer in all experiments was 2,6 kg maize starch: $0,13 \text{ kg.m}^{-2}$ (average number) or 1,65 kg cellulose $0,082 \text{ kg.m}^{-2}$ (average number).

The dusts involved in the experiments concern: maize starch (maximum explosion pressure: 9.0 bar, dust explosion constant: K_{St} : 161 bar.ms^{-1} , median particle size diameter $< 63 \mu\text{m}$) and cellulose (maximum explosion pressure: 8.6 bar; dust explosion constant: K_{St} : 168 bar.m.s^{-1} , median particle size diameter $< 63 \mu\text{m}$).

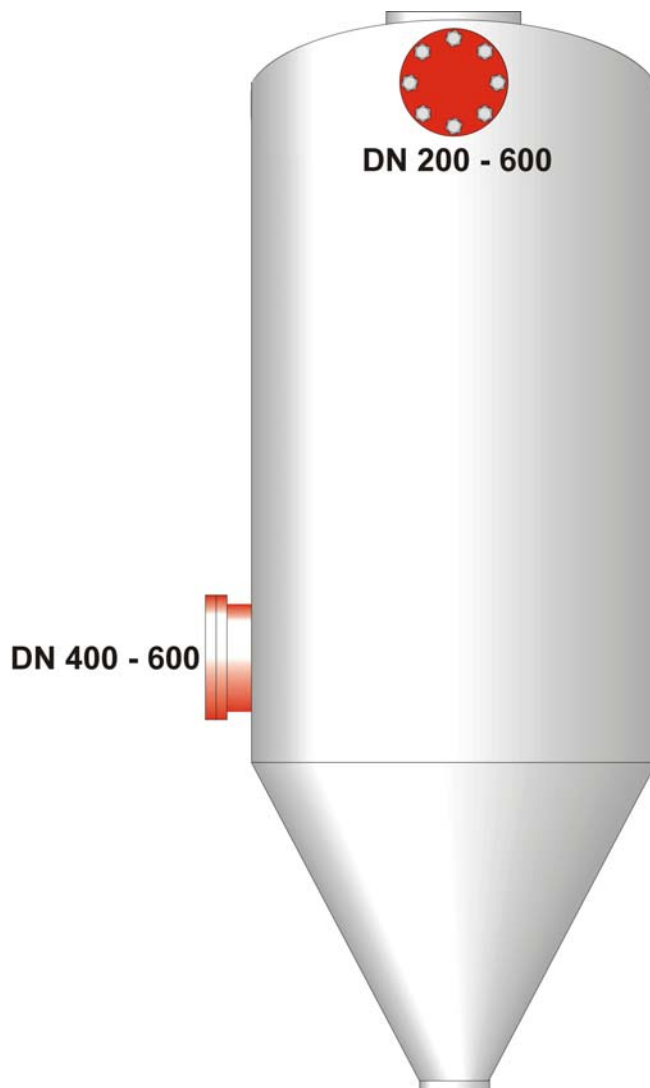


Figure 4 Vessel (43.3 m^3) representing a spray dryer and used for the explosion experiments.

The experiments consisted of three main parts:

- Experiments to find optimal experimental conditions
- Explosion venting experiments
- Explosion suppression experiments

4.1 Finding optimal experimental conditions

Having established the main principles of the spray dryer experiments a series of experiments was carried out to determine the optimum conditions of each of the varied parameters. These experiments were performed in the model spray dryer being fully closed (closed vessel explosion). The parameters that were varied include:

- Dust concentration of dust cloud (with and without dust layer)
- Type of dust in dust layer (cellulose, maize starch)
- Ignition source position

Figure 5 shows results performed with and without a dust layer (dust layer of maize starch and cellulose; dust cloud maize starch) where the concentration of the dust cloud was varied from 100 to 250 g.m⁻³. As reported in section 2 the maximum concentration seen in the industrial spray dryers investigated is 100 g.m⁻³. Ignition was effected at a height of 1.6 m measured from the bottom of the dryer in the centre. In the range investigated, the maximum explosion pressure occurs at the maximum concentration investigated: 250 g.m⁻³. The maximum pressure seen is 0.6 bar. If dust layers are introduced the explosion pressure increases compared to that without the presence of a dust layer. Introducing cellulose dust causes the maximum pressure to increase up to 1.0 bar on average (For this condition the effect of maize starch was only investigated for 100 g.m⁻³). Figure 6 shows examples of measured pressure-time histories.

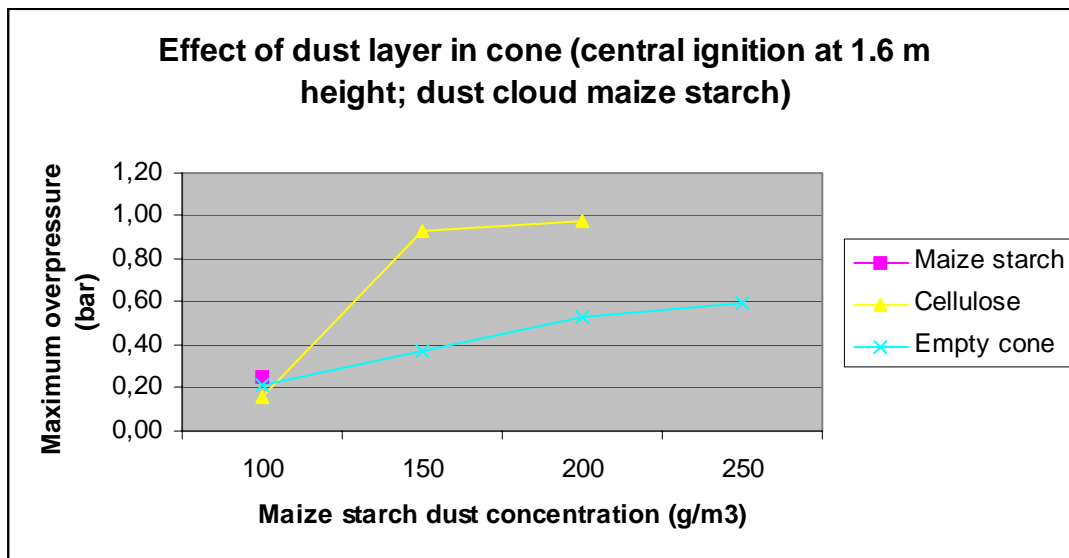


Figure 5 Effect of nominal concentration of maize starch cloud (6 m³) on explosion pressures in 43.3 m³ spray dryer with and without a dust layer in the conical bottom of the dryer (average values of several experiments).

The results shown in Figure 6 clearly demonstrate that dust is whirled up both by the introduction of the maize starch dust as well as by the explosion later demonstrated by the double-peaked pressure-time histories. The maximum pressure is varying strongly depending on the amount of dust taken along by the initial introduction of the maize starch and later by the flows generated by the explosion.

Experiments performed with maize starch as a dust layer in the conical bottom instead of cellulose showed that more dust becomes airborne with cellulose than with maize starch resulting in less contribution to the maximum pressure than when using cellulose.

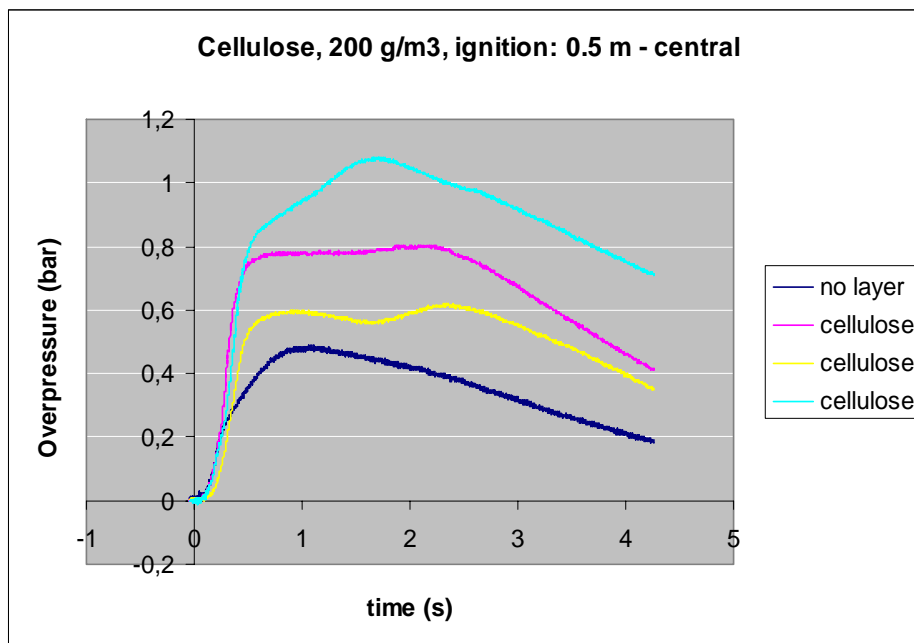


Figure 6 Examples of pressure-time histories of explosions of maize starch dust clouds in the spray dryer with and without cellulose in the conical bottom (ignition source position central at 0.5 m from the bottom of the dryer, $V = 43.3 \text{ m}^3$).

Experiments to determine the optimum ignition source position show that the highest pressures and pressure raise are seen when ignition is effected at a height of 1.6 m from the bottom of the vessel in the centre.

On the basis of these initial experiments the following conditions were used in the majority of the venting and suppression experiments:

- A dust layer of cellulose ($0,082 \text{ kg.m}^{-2}$) onto the conical bottom
- A dust cloud of maize starch in the volume of the conical bottom: concentration 250 g.m^{-3} , turbulence according to ISO 6184/1
- Ignition source position: central at a height of 1.6 m measured from the bottom of the vessel

4.2 Explosion venting experiments

Although the conditions were fixed the effect of the presence of a dust layer and the ignition source position were varied in the venting experiments as well. In addition the size of the vent opening (DN200-DN600), the vent position (near cone and in top of vessel) and the static activation overpressure (0.1-0.2 bar) were varied.

Figure 7 shows the effect of the vent opening size, demonstrating that relatively small vent openings are sufficient to limit the reduced overpressure to values below 0.5 bar (according to VDI-GL-3673, Part 1 (VDI, 2002) one would need a vent area located at the top of the vessel of 2 m^2 or a vent area located near the cone of the vessel of 1.6 m^2 to limit the pressure to 0.5 bar ($P_{\text{stat}} = 0.1 \text{ bar}$)). The Figure demonstrates that the presence of dust layers causes the pressure to increase as seen for the closed vessel explosions. The presence of the dust layer can cause the overpressure to be 3-4 times as high as without a dust layer.

The effect of a higher static activation overpressure P_{stat} without and with dust layer seems to be similar when the vent is located in the top of the vessel. Pressures can be approximately twice as high

when the static activation overpressure is doubled. When the vent is near the cone the effect of the static activation overpressure appears to be negligible. The effect of the ignition source position was found to be limited (in addition to the 1.6 m, central ignition source position, the effect of igniting centrally at 0.5 m from the bottom was investigated).

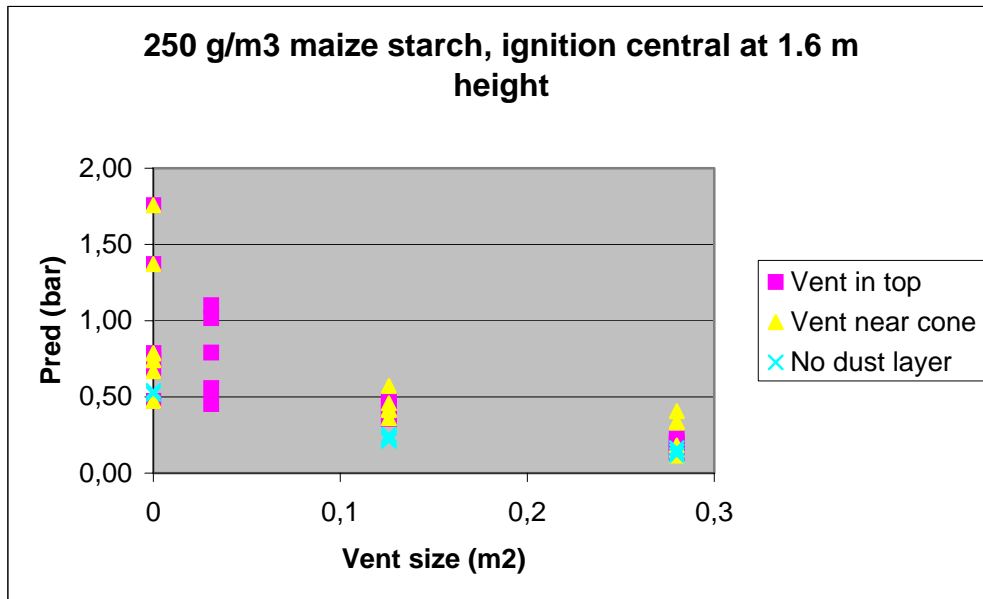


Figure 7 Venting experiments: effect of vent size, vent opening position, presence of dust layer on reduced overpressure in spray dryer (cloud of maize starch 250 g.m⁻³ in cone, ignition at 1.6 m height, static vent opening pressure P_{stat} = 0.1 bar).

4.3 Explosion suppression experiments

A limited number of explosion suppression experiments were performed to investigate the efficacy of these systems under realistic conditions. The system consisted of a pressure detector (activation pressure of suppression system 50 mbar), a control and indicating equipment and suppressors (type Kidde-EHRD). The explosion suppression experiments were performed with both 2 suppressors of 20 l and 2 suppressors of 5 l. As a suppressant KIDDEX was used (a multimodal powder suppressant).

The tests were performed using the optimum experimental conditions. The results of the experiments are summarised in Table 1.

Table 1 Summary results suppression experiments (P_a = 50 mbar)

No suppressors	2 x 5 l suppressors	2 x 20 l suppressors
Maximum reduced overpressure		
0.47 – 1.76 bar	0.18 – 0.41 bar	0.14 – 0.22 bar

The Table shows that a limited number of suppressors is sufficient to reduce the pressure to < 0.5 bar (2 x 5 l suppressors) or < 0.25 bar (2 x 20 l suppressors). Using the same suppression system but the classical ISO-method for generating the dust cloud one would need 13 x 5 l suppressors or 6 x 20 l suppressors to limit the pressure to < 0.5 bar.

5. Explosion simulations

To be able to extrapolate the results of the experiments to other volumes, spray dryer shapes etc. it was foreseen to turn an existing CFD-tool (FLACS= Flame Acceleration Simulator) developed for description of gas explosions in congested environments into a tool able to describe dust explosions (Van Wingerden et al., 2001). To represent dust in the FLACS-tool the particles were assumed to be

infinitely small and the combustion of dust is described by a general theory based on parameters such as the laminar burning velocity, turbulence intensity and length scale. To calibrate the parameters (including thermodynamic parameters), results from 20 l sphere experiments for maize starch were used (as part of the validation process large scale closed vessel dust explosions were successfully simulated; Van Wingerden et al., 2001).

During the first phase of simulations the closed vessel spray dryer experiments were simulated. Simulations of the effect of the dust layer were not finished at the time of writing this paper. The results of some of the simulations performed are shown in Table 2.

Table 2 Comparison simulation results FLACS with experimental results in closed vessel without dust layer in conical bottom (maize starch explosion).

Concentration (g/m ³)	Ignition source position	P _{max} measured (bar)	P _{max} simulated (bar)	(dp/dt) _{max} measured (bar/s)	(dp/dt) _{max} simulated (bar/s)
100	Central, 0.5 m	0.2-0.24	0.25	0.3-0.5	0.53
150	Central, 1.6 m	0.36-0.38	0.38	0.8-1.5	1.47
200	Central, 0.5m	0.49	0.50	1.9-2.2	1.83
200	Wall, 1.6m	0.50-0.51	0.51	1.8	1.29
200	Central, 2.4m	0.45-0.47	0.52	1.8-2.0	0.97
250	Central, 1.6m	0.08- 0.62	0.60	0.1-2.9	2.91
250	Central, 2.4m	0.53-0.70	0.63	1.9-2.2	1.30

The table shows that there is a very good agreement both in maximum pressure and maximum rate of pressure rise.

Similar agreement was seen when simulating the vented explosion experiments with the vent area located on the top or close to the cone of the vessel. Figure 8 shows that FLACS predicts the effect of vent size of the resulting reduced overpressure very well. The calculations with vent opening were carried out prior to the experiments, i.e. the simulations were predictions.

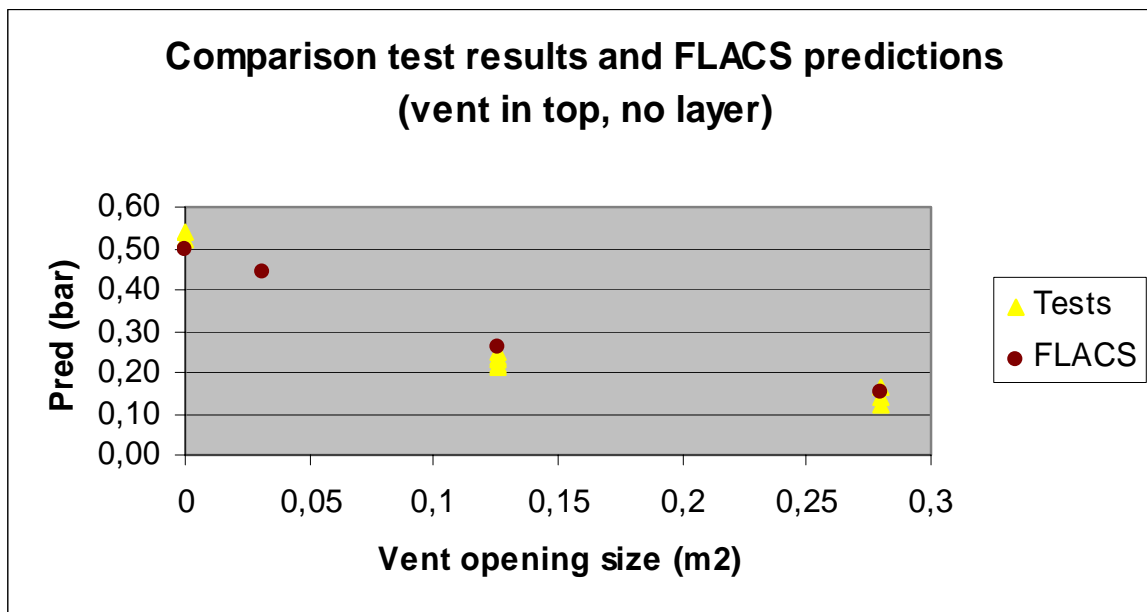


Figure 8 Effect of vent size (located in the top of the dryer) on maximum reduced overpressure. Comparison between predictions with CFD-tool FLACS and experiments (cloud of maize starch 250 g.m⁻³ in cone, ignition at 1.6 m height).

The simulations show that the CFD-tool has good opportunities in extrapolating the results to other vessel volumes, shapes and even process conditions. An ongoing development project, DESC, with 11 partners across Europe and supported by the European Union, aims at improving the capabilities of this tool including the lift of dust layers by explosion-generated flows.

6. Summary and conclusions

The traditional way of protecting conventional spray dryers against the consequences of dust explosions has been assuming that the dust cloud is homogeneous throughout the entire volume of the spray dryer, that the concentration is similar to where the maximum rate of pressure rise will occur and ignition occurs at the worst case location. On the basis of turbulence- and concentration measurements performed in conventional spray dryers ranging from 6 – 310 m³ for several dust types, as well as incident reports one can conclude that this approach was too conservative. On the basis of the results of these studies an experimental set-up was designed and a programme of reference tests, explosion venting and suppression tests was carried out. The experiments were carried out in a 43.3 m³ representation of a spray dryer with conical bottom. On the basis of the experiments a dust cloud was generated in the conical bottom of the dryer only with a concentration of 250 g.m⁻³ maize-starch in air (more than 2.5 times as high as measured in practical conditions). The turbulence intensity in this dust cloud was higher than seen in practice as well. A strong ignition source was applied positioned there where explosion effects seen are highest (on the basis of the reference experiments). Onto the conical bottom of the dryer a dust layer of cellulose dust was introduced (amount of dust also higher than seen in practice: reference tests) being a dust with a very low density resulting in it easily becoming airborne.

The main conclusions of the vented and suppressed experiments which are based on more than 200 individual experiments are as follows:

- Effect of dust layer is very important (pressure increases seen during vented explosions are 3-4 times higher than in the absence of the dust layer). A similar effect was seen during the closed vessel reference tests
- When using explosion venting as the protective measure the vent areas needed to limit the pressure generated in the dryer to safe maximum values are relatively small
- Effect of static activation pressure of the venting device in the presence of a dust layer is smaller or in the worst case similar to that seen without the presence of a dust layer in the conical bottom of the dryer
- When using explosion suppression as the protective measure the amount of suppressant to limit the pressure generated in the dryer to safe maximum values is also considerably smaller than when designing according to the traditional approach
- Simulations performed with a CFD-tool developed for gas explosions and adapted for dust explosions show very good agreement with tests performed without the presence of dust layers (closed vessel and vented vessel experiments). From these conditions extrapolations to other vessel volumes and shapes and process conditions are possible.
- For all conditions mentioned above a new validated design guidance for the calculation of the necessary vent area or the minimum amount of EHRD-suppressors can be developed for conventional spray dryers.

7. Acknowledgement

The paper presented here is a very short summary of the essential findings taken from the final research report “Explosion Protection of Conventional Spray Dryers” (Van Wingerden, K. and Siwek, R., Final Research Report, 2004).

The authors wish to thank the sponsors of the above mentioned project which are:

The Institutions:

The Association of the German Chemical Industry, BG Chemie, Heidelberg, Germany
The Swiss National Accident Insurance Fund, SUVA, Lucerne, Switzerland
The Swiss Safety Institute, Basel, Switzerland

The Companies:

Ciba Specialty Chemical Inc., Basel, Switzerland
Clariant Schweiz AG, Muttenz, Switzerland
Elotex/Claviag AG, Mooslerau, Switzerland
Firmenich SA, Meyrin/Geneva, Switzerland
Nestlé Suisse SA, Vevey, Switzerland
Novartis International AG, Basel, Switzerland

The spray dryer manufacturers:

APV Anhydro AS, Soeborg, Denmark
Niro A/S, Soeborg, Denmark

As well as:

FireEx Consultant GmbH, Switzerland
FSA, Mannheim, Germany
Incom Explosionsschutz AG, Switzerland
Kidde-Deugra Brandschutzsysteme GmbH, Germany
Kidde plc, UK
MSE Meili – Multiphase Systems Engineering, Switzerland

8. References

- Alfert, F., Eckhoff, R.K. and Fuhre, K. (1988) *Zündwirksamkeit von Glimmnestern und heißen Gegenständen in industriellen Anlagen*, VDI-Berichte Nr. 701, pp. 303-319
- Barth, U., Siwek, R., Kubainsky, C. and Suter, G. (1996) *Staubexplosionsschutz für kleine Mahlanlagen*, VDI-Berichte 1272, pp. 493-510
- Huert, F., Vogl, A. and Radandt, S. (1994) *Measurement of turbulence and dust concentration in silos and vessels*, Proceedings of the Sixt Int. Coll. On Dust Explosions, Shenyang, P.R.C., pp. 71-80.
- International Organisation of Standardisation (ISO) (1985) *Explosion Protection Systems. Part 1: Determination of Explosion Indices of Combustible Dusts*, ISO-6184/1
- Ott, R. et al. (1993) *Sicheres und wirtschaftliches Betreiben von Zerstäubungstrocknung in der Nahrungsmittelindustrie unter besonderer Berücksichtigung von Milchprodukten*, Proceedings of the ISSA Symposium, Lugano, Switzerland
- Siwek, R. (1989) *Druckentlastung von Staubexplosionen beim pneumatischen Befüllen von Behältern*, VDI-Berichte 701, pp. 129-140
- Siwek, R. (2000) *Explosionsschutz an Zerstäubungstrocknern*, Gefahrstoffe – Reinhaltung der Luft, Vol. 60, No 3
- Van Wingerden, K., Arntzen, B.J. and Kosinski, P. (2001) *Modelling of dust explosions*, VDI-Berichte No. 1601, pp. 411-421
- Van Wingerden, K. and Siwek, R. (2004) *Explosion Protection of Conventional Spray Dryers*, Final Research Report
- Verein Deutscher Ingenieure (2002) *Pressure venting of dust explosions*, VDI-Guideline 3673, Beuth Verlag GmbH, Berlin