Journal of Loss Prevention in the Process Industries xxx (2015) 1–10

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Scaling of dust explosion violence from laboratory scale to full industrial scale – A challenging case history from the past

Rolf K. Eckhoff

University of Bergen, Bergen, Norway

ARTICLE INFO

Article history:
Received 13 August 2014
Received in revised form
22 December 2014
Accepted 29 December 2014
Available online xxx

Keywords:
Dust explosions
Pressure development
Explosion venting
Silo cells
Wheat grain dust
Soya meal

ABSTRACT

The standardized K_{St} parameter still seems to be widely used as a universal criterion for ranking explosion violence to be expected from various dusts in given industrial situations. However, this may not be a generally valid approach. In the case of dust explosion venting, the maximum pressure P_{max} generated in a given vented industrial enclosure is not only influenced by inherent dust parameters (dust chemistry including moisture, and sizes and shapes of individual dust particles). Process-related parameters (degree of dust dispersion, cloud turbulence, and dust concentration) also play key roles. This view seems to be confirmed by some results from a series of large scale vented dust explosion experiments in a 500 m^3 silo conducted in Norway by CMI, (now GexCon AS) during 1980–1982. Therefore, these results have been brought forward again in the present paper. The original purpose of the 500 m^3 silo experiments was to obtain correlations between P_{max} in the vented silo and the vent area in the silo top surface, for two different dusts, viz. a wheat grain dust collected in a Norwegian grain import silo facility, and a soya meal used for production of fish farming food. Both dusts were tested in the standard 20-L-sphere in two independent laboratories, and also in the Hartmann bomb in two independent laboratories. P_{max} and $(dP/dt)_{max}$ were significantly lower for the soya meal than for the wheat grain dust in all laboratory tests. Because the available amount of wheat grain dust was much larger than the quite limited amount of available soya meal, a complete series of 16 vented silo experiments was first performed with the wheat grain dust, starting with the largest vent area and ending with the smallest one. Then, to avoid unnecessary laborious changes of vent areas, the first experiment with soya dust was performed with the smallest area. The dust cloud in the silo was produced in exactly the same way as with the wheat grain dust. However, contrary to expectations based on the laboratory-scale tests, the soya meal exploded more violently in the large silo than the wheat grain dust, and the silo was blown apart in the very first experiment with this material. The probable reason is that the two dusts responded differently to the dust cloud formation process in the silo on the one hand and in the laboratory-scale apparatuses on the other. This re-confirms that a differentiated philosophy for design of dust explosion vents is indeed needed. Appropriate attention must be paid to the influence of the actual dust cloud generation process on the required vent area. The location and type of the ignition source also play important roles. It may seem that tailored design has to become the future solution for tackling this complex reality, not least for large storage silos. It is the view of the present author that the ongoing development of CFD-based computer codes offers the most promising line of attack. This also applies to design of systems for dust explosion isolation and suppression.

1. Background

The research presented in this paper was first presented in the report by Eckhoff et al. (1982). A condensed version was presented by Eckhoff and Fuhre (1984). The project was a joint venture between and sponsored by the following agencies:

- Fire research Station, UK
- Health and Safety Executive, UK
- National Ports Council, UK
- Labour Protection Foundation (Arbetarskyddsfonden), Sweden
- The State Grain Company (Statens Kornforretning), Norway
- Vaksdal Milling Company, Norway

E-mail addresses: rolf.eckhoff@ift.uib.no, amerke@eckhoff.no.

http://dx.doi.org/10.1016/j.jlp.2014.12.020

- Royal Norwegian Council for Scientific and Industrial Research
- Norwegian Fire Insurance Company (Norges Brannkasse)
- Chr. Michelsen Institute, Norway

The technical/scientific justification for conducting this kind of quite demanding large-scale work was given by Eckhoff (1982).

2. Nature of vented dust explosions

2.1. Basic features

The overpressure development with time P(t) in a vented enclosure in which a dust cloud deflagration takes place, is the net result of two simultaneous competing processes:

- Heating of the dust cloud due to the burning of the dust, causing the pressure to increase.
- Flow of unburnt and burning dust cloud, and combustion products through the vent opening, causing the pressure to decrease.

When considering the two competing processes, predicting the rate of heat generation in the enclosure is by far the most demanding task. Appreciation of this fact was the basic motivation for performing the large-scale silo experiments reported in the present paper. During the 33 years that have elapsed since these experiments were performed, much valuable work has been carried out to develop comprehensive computational tools for predicting the course of dust explosion venting processes. But much work still remains to be done.

2.2. Factors influencing the heat generation rate

When trying to assess the instantaneous rate of heat production during a dust explosion in a vented enclosure, several factors play a role:

a) chemical composition of the dust, including moisture
b) distributions of particle sizes and shapes in the dust, determining the specific surface of the dust in the fully dispersed state
c) degree of dust dispersion/agglomeration of the dust particles, determining the effective specific surface relevant to combustion in the dust cloud in the actual industrial situation
d) distribution of the dust concentration in the actual cloud
e) distribution of the initial turbulence in the actual cloud
f) possibility of generation of explosion-induced turbulence in the still unburnt part of the cloud (which also depends on the location of the ignition source).

Whereas factors (a) and (b) can be assessed accurately in laboratory tests using representative dust samples, factors (c) to (f) are determined entirely by the actual industrial dust cloud generation process, the internal geometry of the enclosure, and the location of the ignition source. The influence of the latter factors cannot be easily assessed by current laboratory tests. However, as discussed by Eckhoff (1984), laboratory tests have demonstrated the importance of these factors in semi-quantitative terms.

3. How can explosible dusts clouds be generated and accidentally ignited in large silo cells in practice in industry?

As discussed by Eckhoff (1987) this question certainly has numerous answers, depending on the actual circumstances. If the main material to be stored in the silo is in itself sufficiently fine to give explosible clouds in air, such clouds are most likely to be generated somewhere in the silo whenever new material is discharged into it, whether pneumatically or mechanically. If the main material is coarse, such as grain, explosible clouds may be generated by unburnt dust being blown into the silo by preceding explosions elsewhere in the plant. Dust clouds could, for example, be injected through the various openings close to the silo top. Injection through the hopper exit at the bottom seems a more unlikely scenario. Another process of dust cloud generation could be that dust layers, which have accumulated on the inside of the silo wall and roof, are disturbed and dispersed into a cloud by air blasts or mechanical vibrations induced, for example, by preceding explosions elsewhere in the plant.

The identification of possible ignition sources and their likely locations in silo cells is another central problem. Dust flames from preceding explosions entering the silo through various openings are one possibility. Dispersion of smouldering dust deposits in the silo itself is another. The possible roles of electrical and mechanical sparks remain a topic of discussion. The influence of the location of the ignition source in the silo cell on the explosion development in the cell was discussed specifically by Eckhoff (1987).

4. The dusts used in the silo explosion experiments

Two different dusts were used. The first was a wheat grain dust collected in the bag filters of the largest Norwegian grain import silo, in Stavanger. The second was a soya meal supplied by another Norwegian company and used for production of fish farming food. Measurements of the moisture content of the wheat grain dust showed an average of 10.5% by weight, and of the soya meal 9%. A number of samples of the two dusts were taken from a representative number of bags on site at Boge and transferred to the test laboratory of Chr. Michelsen Institute in Bergen (presently GexCon AS) in sealed containers for determination of particle size distribution, moisture content, and P_{max} and $(dP/dt)_{max}$ (1.2 L Hartmann bomb). Samples were also sent to the Fire Research Station, UK and Ciba–Geigy AG, Switzerland, for independent, parallel determinations of P_{max} and $(dP/dt)_{max}$ in both the Hartmann bomb

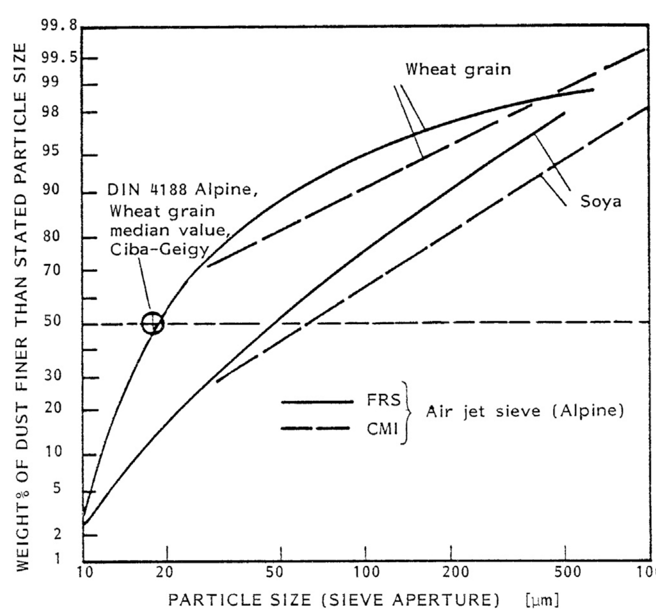

Fig. 1. Particle size distributions of the two test dusts obtained in three different laboratories. From Eckhoff et al. (1982).