

Gas and Dust Explosions Caused by Smoldering Combustion in Powder Layers and Deposits

4.1 Combustion Velocities/Rates in Powder Layers/ Deposits

4.1.1 Dust Layers

Propagation of combustion through layers and deposits of most dusts will occur very slowly compared with the propagation of a flame through an explosive gas/vapor cloud. This is because the ratio of combustible material/oxygen in a dust layer/deposit is about two orders of magnitude larger than the stoichiometric ratio. Very limited supply of oxygen to support the combustion process, and the heat sink effect of all the excess material that does not take part in the combustion, will limit both the rate of propagation of the combustion process, and the temperature in the reaction zone. Therefore, for most dusts the combustion zone will normally be a smolder or glow rather than an open flame, and typical velocities of the combustion wave will be several orders of magnitude lower than laminar burning velocities in pre-mixed gases and dust clouds.

Figure 4–1 shows some data reported by Palmer (1973) from experiments with glowing/smoldering combustion in horizontal layers of beech dust.

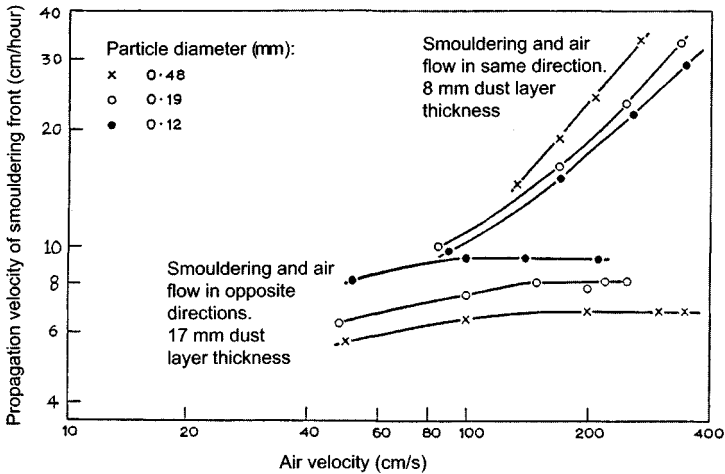


Figure 4–1 Influence of the air velocity along a layer of beech saw dust on the rate of smoldering front propagation along the layer. From Palmer (1973).

The layers, of various thicknesses, were ignited at one end and the velocity of the propagating smolder/glow front along the layer was measured as a function of layer thickness, particle size, and the velocity of a horizontal air flow along the surface of the layer. Figure 4–1 exhibits the following trends:

- The observed smolder/glow velocities were in the range of 0.05–0.5 m/hour, as opposed to the order of 0.5 m/s for laminar burning velocities of clouds of organic dust in air (see Chapter 5), i.e. a difference by a factor of the order of 10^4 .
- The smolder/glow velocity along the layer increased markedly if an air flow of velocity of some m/s was passed across the layer in the same direction as the propagation of the smolder/glow.
- If the direction of the air flow was opposite to that of the propagation of the smolder/glow, there was no significant influence of the air flow in the velocity range 0.4–4 m/s investigated.

- The influence of particle size on the effect of the air flow was somewhat complex. With the air flow in the same direction as the smolder glow propagation, the latter increased with increasing particle size, whereas with the air flow in the opposite direction the highest smolder/glow velocities was found for the smallest particles. However, in the range investigated the influence of particle size was only modest.
- With high air velocities across the layers, in the direction of the propagation of the glow/smolder, the temperatures in the reaction zone inside the layers were quite high, approaching 1,000°C.
- However, in the absence of an air flow across the layer, there was no visible sign of smolder or glow at the surface of the layer, and the temperature of the smoldering/glowing reaction zone inside the layer was in the range 550–620°C.
- There was little influence of the material of the surface on which the dust layer was resting (asbestos, metal, wood), on the velocity of propagation of the smolder/glow in the layer.

Figure 4–2 illustrates a standardized method for characterizing the ability of layers of powders/dusts to propagate smolder, glow, and in some cases even an open flame.

The foundation of this method was laid by Lütolf (1971). A complete description was given by Verein deutscher Ingenieure (1988). For tests at ambient temperature, a ridge of the dust of triangular cross-section is placed on a ceramic plate, as shown in Figure 4–2(a). The test sample is a 2 cm wide and 20 cm long. For tests at elevated temperatures the sample holder shown in Figure 4–2(b) is used. The sample is then placed in a glass tube heated to the desired temperature. A small air flow of about 0.2 m/s through the glass tube must be ensured.

The dusts are classified according to their ability to propagate combustion at one end of the ridge. Ignition along the ridge tested is accomplished using either a gas flame or a glowing platinum wire at 1,000°C. The definitions of the various flammability classes are:

Class 1: No self-sustained combustion

Class 2: Local combustion of short duration

Class 3: Local sustained combustion, but no propagation

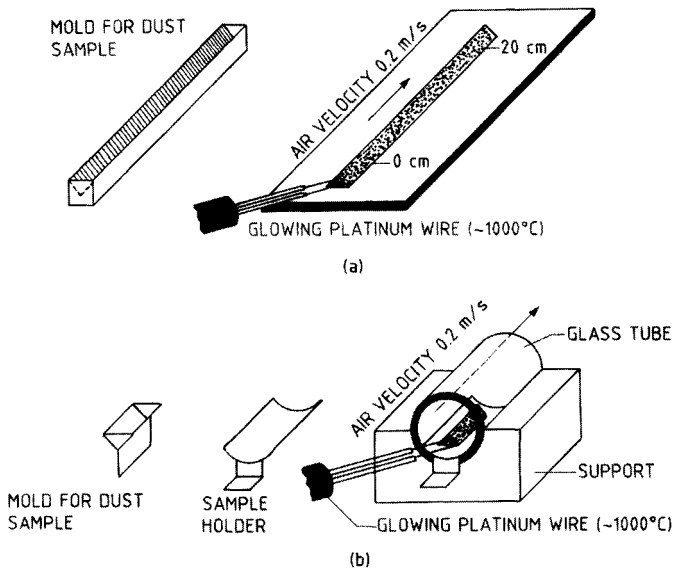


Figure 4-2 Semi-quantitative laboratory method for testing the ability of a horizontal ridge of a given powder/dust to propagate combustion. From Eckhoff (2003).

Class 4: Propagating smoldering combustion

Class 5: Propagating open flame

Class 6: Explosive combustion

4.1.2 Deep Dust Deposits

Figure 4-3 gives the results from investigation of smoldering/glow propagation in deep deposits of beech dusts, also reported by Palmer (1973).

In this case the thickness of the dust deposits was much larger than of the layers discussed above, ranging from 4 cm to nearly 100 cm. The main measurement taken was the time from initiation of the smolder/glow at the bottom of the deposit, till the smolder/glow front reached the deposit top. The following was found:

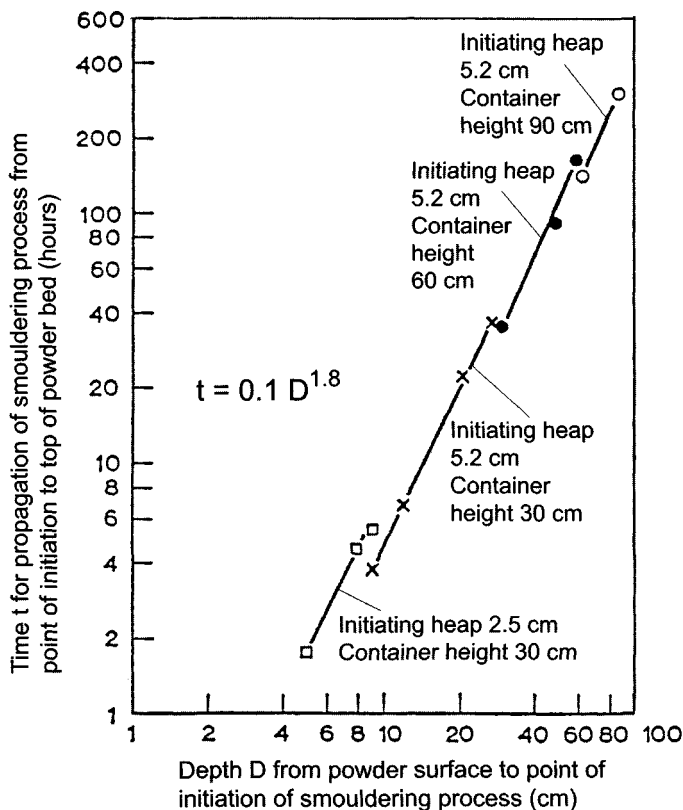


Figure 4-3 Influence of the depth from the top of a deposit of wood saw dust to the point of initiation of smoldering/glow inside the deposit, on the time from initiation to arrival of the smoldering/glow front at the deposit top. From Palmer (1973).

- The average velocity of propagation of the smolder/glow front, from initiation at the bed bottom, to arrival at the bed top, decreased systematically with increasing bed height, according to the approximate relation: $t = 0.1H^{1.8}$, where t is in hours and H is in cm.
- With a deposit height of 85 cm, the propagation of the smolder/glow front from the bottom to the top of the deposit took about 350 hours, i.e. 14–15 days. The average rate of propagation was about 2.5 mm/hour, which is about twenty times less than the lowest layer propagation velocities of about 5 cm/hour given in Figure 4-1.

- As soon as the smolder/glow has reached the bed top, it will start to propagate sideways at the higher velocities typical of horizontal propagation in thin layers.

Smolder/glow processes can propagate inside dust deposits of considerably larger dimensions than about 1 m. The propagation velocities will then be even lower than those typical of the experiment leading to the data in Figure 4–3. In extreme cases, e.g. in huge outdoor storages of coal the times needed for the smolder/glow front to reach the borders of the powder/dust deposit can be up to several years.

The main reason why smolder/glow processes inside large powder/dust deposits are so slow is lack of supply of oxygen to the exothermal chemical reaction. The oxygen has to be transported to the reaction zone by diffusion through the narrow channels between the particles in the deposit. The exothermal process is nevertheless maintained because of the inherent thermal insulation capability of the powder/dust deposit. The very limited amount of heat generated per unit time in the chemical reaction is used effectively for heating the next layer of dust, adjacent to the combustion zone, without being drained into the farther surroundings. The basic principle is the same as that of the general theory of ignition discussed in Section 2.2.2 and illustrated in Figure 2–13.

Besides promoting the development and sustainment of smolder/glow in powder/dust deposits, the high thermal insulation power of the powder/dust creates substantial problems in the efforts to extinguish smoldering/glow processes in large powder/dust deposits, e.g. in silos. Often the main problem is not to extinguish, i.e. to stop the exothermal reaction, but to cool down the hot material to normal temperatures.

Figure 4–10 illustrates a more complex scenario, whereby the smolder/glow process in a silo generates CO, which diffuses upwards through the powder/dust bed and mixes with the air in the empty space above the bed to form an explosive mixture. This mixture is then, in turn, ignited by the glow front as soon as it reaches the top of the powder/dust bed. Further escalation to a secondary dust explosion can occur if dust layers have accumulated in area above silo top.

4.2 Initiation of Combustion in Powder/Dust Layers and Deposits

4.2.1 Minimum Ignition Temperature of Dust Layers

The apparatus shown in Figure 4–4 is often used for determining minimum ignition temperatures of dust layers. It consists of an electric hot plate, a temperature control unit, three thermocouples and a 2-channel recorder.

The hot plate is kept at a given temperature, which is read by one of the thermocouples and displayed on one of the recorder channels. The second thermocouple is used for regulating the plate temperature. When conducting a test, a metal ring of internal diameter 100 mm and height either 5 mm or 15 mm is first placed on the surface of the plate. The powder/dust sample to be tested is then placed on the part of the hot plate that is inside the metal ring and carefully leveled off to the height of the ring. The third thermocouple is placed in the sample through holes in the metal ring. The sample temperature is displayed on the second recorder channel.

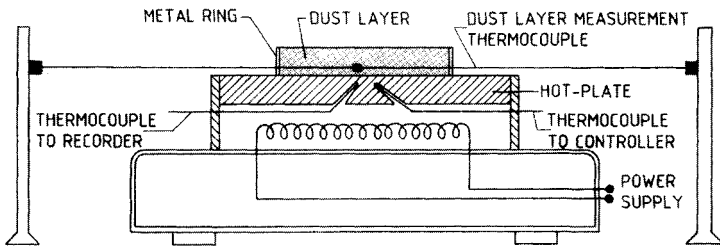


Figure 4–4 Internationally standardized method for determining the minimum hot-plate temperature required for initiating smoldering or flaming combustion of layers of combustible powders/dusts. From Eckhoff (2003).

Typical outcomes of a test are illustrated in Figure 4–5.

Originally it was proposed that the maximum temperature in the dust sample had to exceed the hot plate temperature by more than 20°C for the test to be recorded as ignition. However, it was later decided that a considerably higher temperature rise was required. In order to determine the minimum ignition temperature for the layer thickness tested, repeated

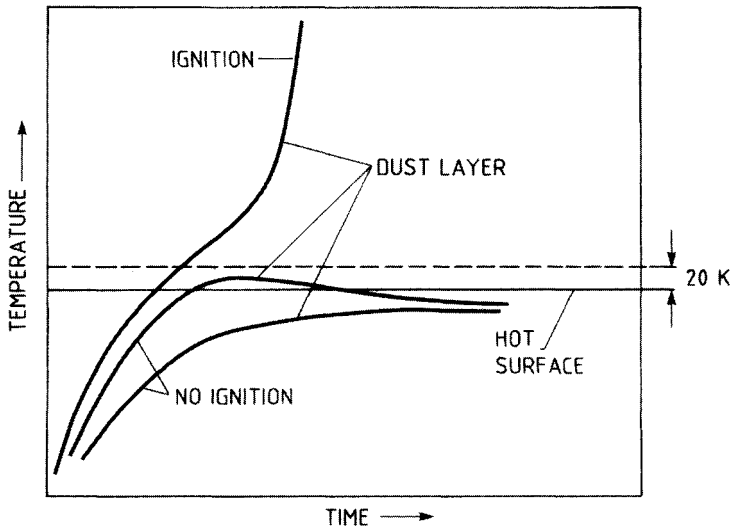


Figure 4-5 Illustration of the three possible outcomes of the test illustrated in Figure 4-4. From Eckhoff (2003).

tests are conducted at different hot plate temperatures until the minimum temperature for ignition has been identified. It is important to note that the minimum hot plate ignition temperature decreases systematically with increasing dust layer thickness. If the values for two different layer thicknesses have been determined, simplified theory enables estimation of the values for other thicknesses.

4.2.2 Minimum Ignition Temperature of Dust Deposits

In this case one considers a powder/dust deposit completely surrounded by air, and the question asked is “what minimum temperature of the air surrounding the deposit is required for self-heating/self-ignition to develop inside the deposit?” The type of apparatus used for determining the minimum ignition temperature in this case is illustrated in Figure 4-6.

The powder/dust sample is suspended in a metal gauze basket inside a heating chamber through which a given flow of pre-heated air is circulated. The air temperature and the temperature inside the powder sample

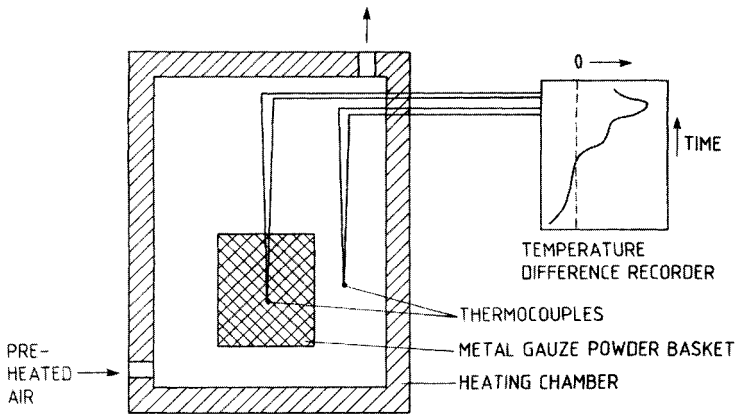


Figure 4-6 Illustration of method for determining the minimum temperature of the surrounding air for initiation of smoldering combustion in a dust sample contained in a wire net basket. From Eckhoff (2003).

are measured and the difference recorded. If the temperature in the powder sample raises beyond that of the air, but not higher than $400\text{ }^{\circ}\text{C}$, the phenomenon is called “self heating.” Temperature rises beyond $400\text{ }^{\circ}\text{C}$ are named “self ignition.” Figure 4-7 illustrates the typical linear relationship between the minimum ignition temperature and the sample size resulting from plotting the experimental data in a double-logarithmic form. This enables extrapolation to larger volumes than those tested. More sophisticated instruments for detailed studies of the rate of reaction as a function of temperature, under adiabatic conditions, are also available, including *Accelerating Rate Calorimeters* (ARC), which are essentially highly computerized adiabatic calorimeters. During an ARC experiment, the sample is maintained in a near to perfect adiabatic condition, while time, temperature and pressure data are automatically collected and stored. The data can then be processed by computers. In addition to ARC, *Differential Scanning Calorimeters* (DSC) are also in use. In a DSC the rate at which heat must be transferred to or from the test sample in order to maintain it at the same temperature as an inert reference sample, is measured.

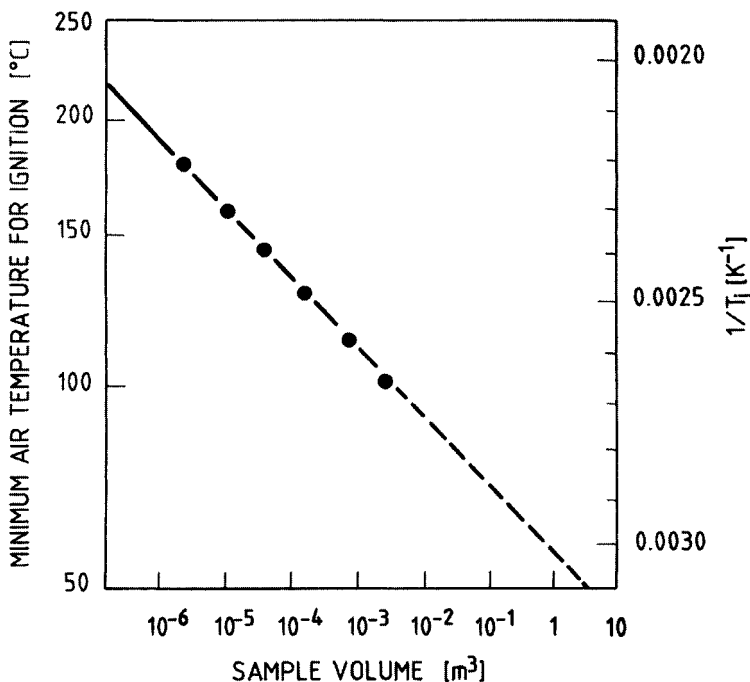


Figure 4-7 Example of results from the experiment illustrated in Figure 4-6 for a given powder/dust, using a range of sample volumes. From Eckhoff (2003).

4.3 Explosion Initiation Processes by Smoldering/Glowing Material

Smolder/glow processes in powder/dust deposits are in themselves a significant problem in some process industries. However, in some cases these processes are only the first step in an escalating chain of events that can lead to both gas and dust explosions. Figure 4-8 and Figure 4-9 illustrate how smoldering powder/dust layers/deposits can give rise to dust explosions.

Figure 4-10 illustrates a more complex scenario, whereby the smolder/glow process in a silo generates CO, which diffuses upwards through the powder/dust bed and mixes with the air in the empty space above the bed to form an explosive mixture. This mixture is then, in turn, ignited by the

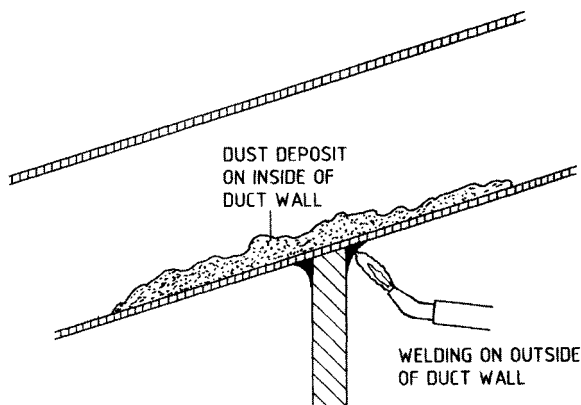


Figure 4–8 Initiation of combustion in a powder/dust layer inside a steel duct, by a welding operation on the outside of the duct. With an explosive dust cloud flowing through the duct, the glowing/flaming dust layer can initiate a dust explosion there. From Eckhoff (2003).

glow front as soon as it reaches the top of the powder/dust bed. Further escalation to a secondary dust explosion can occur if dust layers have accumulated in area above silo top. Case histories confirming this chain of events are given in Section 4.5.

4.4 Case Histories of Accidental Smoldering Combustion in Silos, Resulting in Gas Explosions, and Adopted Extinction Procedures

4.4.1 Fire and Subsequent Explosion in a Silo Plant in Stavanger, Norway (1985)

This accident, described by Braaten (1985), was primarily an explosion of combustible gases released from a solid organic material during self-heating in a silo cell.

The cause of events was in accordance with Figure 4–10. The explosion occurred in a fairly modern reinforced concrete silo complex used for storage of various feed stuffs. Pellets of Canadian rape seed flour had been stored in one of the silos for some time when it was discovered that

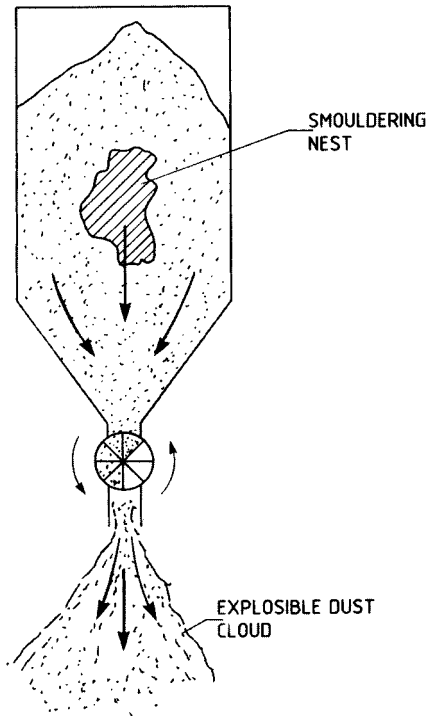


Figure 4-9 Initiation of dust explosion in cloud generated by discharge of powder/dust from silo/hopper, by smoldering nest in powder/dust. From Eckhoff (2003).

the material in the bottom part of the silo had become packed to a solid mass and could not be discharged through the silo exit. Some time later, one week before the explosion, flames were observed in the silo. The fire brigade was called and covered the pellets in the silo with foam from above. Various unsuccessful attempts were then made at discharging the pellets mass at the silo bottom. During this phase there was considerable development of smoke, which mixed with the air not only in the silo cell in question, but also in the silo loft above the cells. It is probable that the smoke contained combustible gases, e.g. CO, and that the strong explosion that occurred just after the top of the pellets had been covered with foam once more, was mainly a gas explosion. However, any dust deposits in the loft may also have become involved. The entire roof of the building was blown up, and debris was thrown into the surrounding area. Because the explosion occurred in the middle of the night (0300), and just after the fire brigade had left, nobody was killed or hurt.

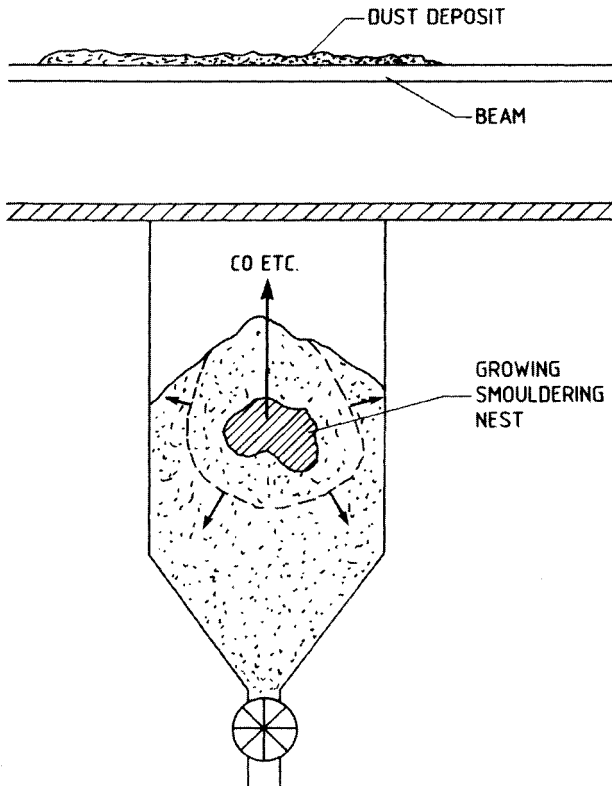


Figure 4-10 Initiation of explosion in a gas/air mixture developed by a smoldering nest inside powder/dust in a silo, and accumulated above the powder/dust in the silo, when the top surface of the smoldering nest reaches the top of the powder/dust.
From Eckhoff (2003).

4.4.2 Multiple Silo Fires and Resulting Gas Explosions in a Large Storage Facility in Tomylovo in the Knibyshev Region in Russia (1987-89)

This extensive series of explosions were of the same nature as the explosion discussed in Section 4.4.1. An oral report of the event was provided by Borisov and Gelfand (1989). The large storage facility for grain and feed stuffs, shown in Figure 4-11, consisted of four sections of sixty silo cells each, i.e. 240 silo cells altogether. Each cell was of 3 m × 3 m square cross-section and 30 m height.



Figure 4-11 The concrete silo complex in Tomylovo, Knibyshev region, Russia that was damaged by a series of smoldering gas explosions in the silo cells. (Courtesy of A. Borisov and B. Gelfand, Moscow, Russia).

The first explosion occurred in December 1987 in a silo cell containing moist sunflower seed, which was not supposed to be stored in such silos due to the risk of self-heating. However, this had nevertheless been

done, and the resulting self-heating developed into extensive smoldering decomposition during which methane and carbon monoxide were produced and mixed with the air in the empty top part of the silo, above the powder bed surface. It is reasonable to believe that the primary explosion was in this mixture of explosive gas and air, and that the ignition source was the smoldering combustion when it penetrated to the powder bed top surface, as illustrated in Figure 4–10. However, in addition dust deposits on the internal silo walls and roof may well have been entrained by the initial blast and become involved in the explosion.

This was only the first of a large series of 20–30 subsequent explosions that took place in the same facility, in one silo cell after the other, during 1988 and 1989. There are two main reasons for this continued explosion activity in the silo complex. The most important is the heat transfer from a silo cell in which smoldering combustion is taking place, to the neighboring cells. Such heat transfer was facilitated by the large contact surface area between the cells due to the square cross-section of the cells. The second main reason for the repeated explosions was that sunflower seed was not the only material in the facility that was not supposed to be stored there. Some of the silo cells contained buckwheat and wheat grain of higher moisture contents than the maximum permissible limits for storage in such facilities.

During the period of repeated explosions, a series of attempts were made at breaking the unfortunate chain of events. Cells were opened at the top for inspection. However, this admitted fresh air to the smoldering mass and enhanced the combustion process. Attempts were made at quenching and cooling the powder mass by liquid nitrogen, but this was only partly successful.

It was finally decided to demolish the entire facility using explosives.

4.4.3 Fire and Explosion in Pelletized Wheat Bran in a Silo Cell at Nord Mills in Malmö, Sweden, in 1989

A cross-section of the silo cell is shown in Figure 4–12.

The course of events, as recorded by Templin (1990), was as follows:

Saturday 28th January, 0700: The night shift stopped the production for the weekend according to schedule, and all activity in the grain silo plant terminated.

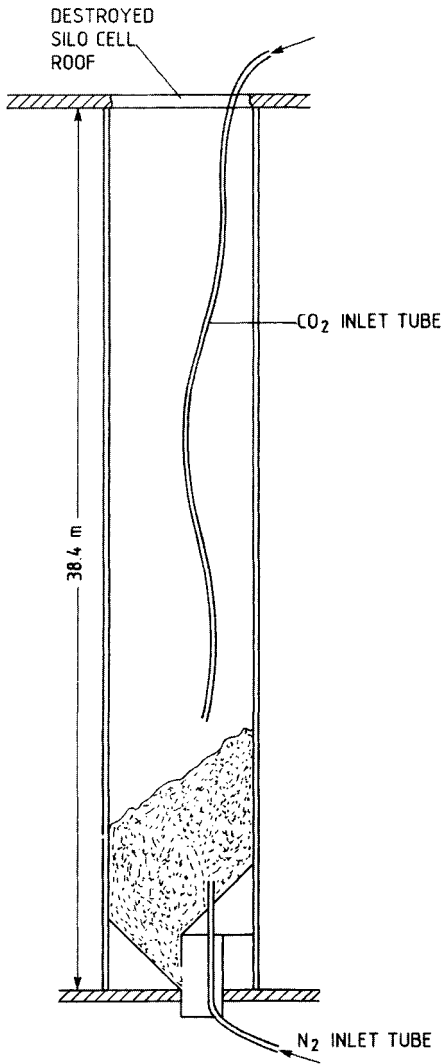


Figure 4-12 Cross-section of silo in Malmö, Sweden, in which a destructive explosion occurred in gas (CO) developed from smoldering combustion of wheat bran pellets in 1989. The inlets for subsequent supply/injection of carbon dioxide and nitrogen for extinction and cooling are also indicated. Courtesy of G. Templin, Nord Mills, Sweden.

Saturday 28th January, 1000: According to Nord Mills' safety procedures, the safety guard team made its inspection round through the entire plant. Nothing special was observed. No persons were encountered.

Saturday 28th January, 2300: A bang, muffled by the noise of strong winds, was heard in the neighborhood, but no action was taken.

Sunday 29th January, 0930: During its scheduled inspection round, the safety guard team discovered fragments of shattered window panes spread over the entire yard. Inspection of the loft of the silo building revealed that the roof of an intermediate star cell had blown up, and that dense smoke was emerging from the open cell top. The height of the cell involved was about 36 m and its cross-sectional area about 20 m². Most of the silo was empty, the pelletized wheat bran occupying only the seven first meters above the cell bottom.

Sunday 29th January, rest of day: Fire brigade and other personnel were called, and the entire plant area was cordoned off. About 2,000 kg of gaseous carbon dioxide was pumped into the burning silo from above through a long vertical pipe extending right down to the surface of the smoldering pellets.

Monday 30th January, early morning: The discharge valve at the cell bottom was removed, and discharge of the pellets mass, using a mobile suction unit, was started. This gave rise to increased smoke production, and at 0330 more carbon dioxide was loaded into the silo cell from above.

Tuesday 31st January: The discharge operation was interrupted. Carbon dioxide was emerging through the bottom silo exit, and more was loaded into the silo at the top.

Wednesday 1st February: More carbon dioxide was loaded into the silo at the top. From 0300 to 1250 the smoke development was enhanced by vibrations due to operation of another silo cell. The smoke temperature just above the pellets was 96°C, and just above the silo top 45°C.

Thursday 2nd February–Wednesday 8th February: Smoke development and temperature rise was suppressed temporarily by loading several tons of carbon dioxide into the silo from the top, but there was only slow permanent progress. Temperature rise was observed in the material stored in the four larger adjacent silo cells.

Thursday 9th February–Saturday 11th February: Holes were drilled through the silo bottom and at intervals a total of several tons of nitrogen

were pumped into the pellets from below, while carbon dioxide was charged from above.

Monday 13th February–Wednesday 15th February: Some 6,000 kg of carbon dioxide and 3,000 kg of N₂ was injected into the burning pellets. Temperatures in the burning and adjoining cells and contents of oxygen, CO and CO₂ in the gas above the pellets, were monitored regularly.

Monday 20th February: The smoldering combustion in the wheat bran pellets had finally been brought to an end.

This case history illustrates that fighting smoldering combustion in large silo complexes is not only a matter of quenching, or terminating the oxidation reaction. It is also indeed a matter of cooling massive bulks of poor heat conductors to a temperature level at which the combustion process will not start again once air is re-admitted to the system.

4.4.4 Extinction of Smoldering Fire in a Fish Meal Silo in Norway in 1992 Using Water

During the struggle with trying to fight the smoldering fires in the silo complex in Tomylovo, Russia (see Section 4.4.2) it was agreed that the use of water was not feasible. The arguments were that limited quantities of water would probably enhance the self-heating process rather than quench it, and use of extensive quantities would increase the load on the silo walls (hydrostatic pressure) and cause collapse of the entire structure.

In view of this it is interesting to consider the use of water for extinguishing a fire in a fish meal storage silo in Norway a few years later. In this case, described by Kroken (1997), the silo was cylindrical, of height 20 m and diameter 4.5 m. The bottom hopper was wedge-shaped and fitted with a horizontal screw conveyor for discharging of the meal. The sides of the hopper were at sixty degrees against the horizontal plane.

The entire sequence of events was as follows:

- The fresh fish meal from the production plant was filled into a mixing silo for being recycled and conditioned, before being transferred to a storage silo.

- In order to prevent self-heating in the meal during the conditioning period, recycling by discharging the meal from the silo bottom via the screw conveyor, and returning it to the silo at the top, was started.
- After some days it was discovered that the meal discharge operated by funnel flow rather than by mass flow, i.e. most of the material was not taking part in the recycling process.
- It was realized that digging out the material in the “dead” zones in the silo would be necessary, but due to lack of time, this work was not started until four weeks later. This made it possible for self-heating to develop in the stored fish meal.
- When trying to discharge the meal from the silo bottom after the four week break, bridging of the meal across the entire silo cross-section was discovered.
- Digging out was started from the silo top. When material had been removed down to the level of 2 m above the transition between the cylindrical silo wall and the hopper, the digging had to be stopped. The three main reasons were smoke development, that the meal was too hot to stand on and handle, and that the meal had become very hard very hard (a steel spear could only be forced 10 cm into the meal by hand).
- A nitrogen atmosphere was established in the silo above the meal surface.
- The fire brigade was called. However, they did not know how to deal with the matter, and left.
- The nitrogen atmosphere in the silo was kept for three weeks, but the smoldering fire inside the meal did not extinguish.
- It was then decided to try to fill water into the silo. But first information was collected about the strength of the bottom/hopper part of the silo. It was concluded that the bottom part could just about take the hydrostatic pressure that might result from soaking the meal with water.
- Water was filled into the silo. “Cracking” sounds were heard from the hopper section.
- After ten days the silo bottom was opened, and the water was drained out.

- Workers were admitted into the silo again to resume the digging-out work. The meal was then just like concrete and had to be removed by using pick-axes and hammers and chisels.
- After some digging-out regions with smoldering meal were once more encountered the digging had to be interrupted.
- The silo was once more sealed, and the remaining fish meal soaked with water.
- After ten more days the water was drained out, and the digging-out resumed. This time it was possible to empty the silo completely.
- Outwards buckling of the hopper walls was observed.

The total time, from the onset of the efforts to extinguish the fire to final completion, was about two months. This story illustrates that adequate procedures for extinction of fires in silos still remain to be developed.

4.5 Measures for Preventing Excessive Self-Heating in Silos

4.5.1 Temperature Measurement to Detect Self-Heating/ Self-Ignition

Temperature sensors positioned inside the bulk of material stored in silos by means of wires hanging from the silo roof have been used for detecting the onset of self-heating for many decades. However, in larger silos it is impossible in practice to cover the entire silo volume by temperature sensors, and self-heating and even smoldering fires may develop without being detected by the array of sensors available.

4.5.2 Early Detection of Tracer Gases from Self-Heating

More recently increasing focus has been on the use of very sensitive sensors for detecting the onset of generation of decomposition gases from self-ignition processes. Zockoll (1996) described the development of a new system for early detection of self-heating/self-ignition in deposits of organic powders, with special reference to milk powder in spray dryers, based on detection (infrared light) of low concentrations of CO in the 1–10 ppm range. Figure 4–13 gives some results from Zockoll's work,

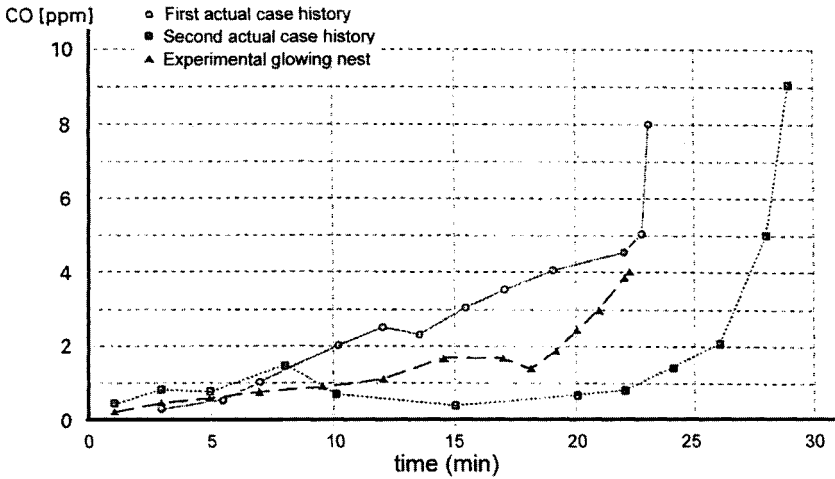


Figure 4-13 CO concentration development with time in two actual industrial cases of accidental self-ignition, and in one controlled self-ignition experiment. From Zockoll (1996).

showing how the measured CO concentrations increase with time. As soon as unacceptably high concentrations are detected, alarms are automatically activated, and measures to handle the problem are taken. In the case of early self-heating, re-circulation of the material in the silo can be an appropriate measure (see Section 4.5.3).

Kohl and Kelleter (1996) described a multi-sensor system for detection of combustible gases developed by slow smoldering fires in lignite. H_2 and CO were monitored continually, using electrochemical sensors. It was found that the ratio of the measured concentrations of the two gases could provide information about the development of the smoldering fire. When implementing systems for early detection of combustion gases, it is important that the supplier of the detection system and the user work closely together to ensure optimal system design for any given application.

4.5.3 Re-Circulation of Material in Silo by Discharging at Bottom and Re-Filling at Top

This method requires adequate silo design (mass flow as opposed to core flow) to ensure that the entire material becomes involved, not only a central

core. As illustrated by the case history described in Section 4.4.4, re-circulation can fail in smoothing out temperature differences in silos if only part of the stored material is participating in the re-circulation process.

4.5.4 Mathematical Modeling/Numerical Simulation of Self-Heating/Self-Ignition Processes

It is anticipated that in the future, the likelihood of onset of self-heating in any given industrial situation can be assessed by numerical simulation. Carson (1996) suggested such a method for assessing the tendency of combustible dusts to self-heat and start to burn spontaneously in a given practical situation. The method comprised various laboratory-scale tests combined with mathematical modeling. The test methods included Differential Thermal Analysis (DTA), Thermo Gravimetric Analysis (TGA), isothermal oven tests and adiabatic calorimetry. Krause and Hensel (1996) presented a numerical method by which non-steady temperature fields in dust deposits can be computed. This enables numerical analysis of a number of practical cases of self heating/self ignition that cannot be analyzed using the classical thermal explosion theory of Frank-Kamenetzki. Krause and Schmidt (2001) studied experimentally critical thermal conditions that may lead to initiation of smoldering processes, or to further development of such processes, once initiated. This type of evidence is important for further development of mathematical simulation models.