Chapter II

Literature Review

Throughout the chemical process industries (CPI), substances such as plastics, fertilizers, fuels and pharmaceuticals, are routinely dried to powder or dust. When suspended in the air or other oxidants, these dusts are capable of producing a dangerous and costly explosion.

While it is difficult to precisely define the explosion risk created during the handling of potentially explosive materials, the risk is ever present. Explosions should be anticipated, and preventive measures must be taken in the design and selection of bulk-solids-handling equipment, such as dust collectors, conveyors, bins, grain elevators, and size-reduction equipment, such as grinders, crushers and pulverizers.

The Vertical Tube apparatus (Hartmann apparatus developed at the US Bureau of Mines) was used for testing of Lower Explosion Limit (LEL), maximum explosion pressure and rate of pressure rise of dust samples. Improvements in dust explosibility tester would be desirable. Many study of dust explosion testing have been made. These and development of test apparatus, are summarized below.

Vital (1875) was one of the first to conduct comparative tests to determine the hazards of various dust types. He blew a dust cloud through a gas flame into a long pipe which had a ball made of elder wood at the end. From the shape and length of the explosion flame as well as the throw of the wooden ball, Vital estimated the "relative hazard" of the tested dust.

Approximately at the same time, R. Weber (1875) ran flour tests using the sieve shaking equipment. The dust was deposited on top of a sieve. Through shaking action, the product fell into a vessel containing an ignition source.

The apparatus which was developed by Steinbrecher (1968) for the determination of the lower explosible limit of industrial dusts differs from the previously described units in its singly activated dust dispersion system through a blast of air. The combustion chamber consisted of a vertical glass pipe with a hemispherical end and a volume of 0.135 L. The pipe also housed an ignition source and a thermocouple.

The dust sample was stored just ahead of the explosion chamber and then dispersed in the cylinder by a jet of air. These ignition tests often destroyed the glass tube.

The Chemisch-Technische Reichsanstalt (1933-1935) (German Chemical Technical Institute) used the apparatus for the determination of the explosibility of dust/air mixtures.

The dust was first deposited at the bottom of the apparatus and then swirled up by a jet of compressed air discharged through a nozzle. A glowing wire was used as an ignition source. The test results indicated that Zirconium was especially explosible over a markedly wide range of concentrations.

Until recently Eckhoff (1979) used an oxyacetylene torch for ignition in testing the explosibility of dust in order to eliminate the risk of a misjudgement.

The hazard of a combustible dust is not only defined by its explosibility and explosible range but also by the pressure and violence of its combustion. In such a context, the maximum explosion pressure and the pertinent pressure are of special interest. Closed equipment is needed to test for these parameters. Obviously, the test equipment as mentioned above is unsuited for this purpose.

In 1957, the US Bureau of Mines developed the so - called "Hartmann apparatus" . The closed explosion chamber was cylindrical and had a volume of 1.2 L . The dust to be tested was dispersed into the chamber onto a continuous electrical spark (arc) or a glowing wire coil. The values of the pressure and rate of pressure rise were recorded with either a mechanical indicator or a piezoelectrical pressure transducer (Anonym, 1982) .

Subsequently, J. Lutolf (1971) simplified the Hartmann apparatus, a modification which became known as the "modified Hartmann apparatus" . It was made out of pyrex glass and the violence of the explosion was expressed at two levels, depending upon the opening angle of the hinged cover. The test apparatus resembled closely that which was used by the "Chemisch Technische Reichsanstalt".

W. Bartknecht (1989) studied the influence of temperature upon the LEL and found that an increase in temperature will reduce the value of the LEL. Furthermore, he studied the effect of initial pressure and initial temperature on the maximum explosion pressure. He observed that a doubling of the initial pressure caused a doubling of the maximum explosion pressure. The elevated explosion data could only be obtained at relatively high dust concentrations. Explosions were not possible below about 1 millibar (absolute). Regarding the effect of initial temperature, he found that explosion pressure decreased linearly with the value of increasing absolute initial temperature.

Bodurtha (1980) reported that the maximum and rate of pressure rise for dusts occurred within a concentration of 200 to 1000 g/m^3. Where combustible dusts are being handled it is necessary to rely on test data to determine if the dust is explosible and estimate the degree of hazard. If the dusts are accompanied by flammable vapors, called hybrid mixtures, they can be much easier to ignite than if free of flammable vapors. The lowest minimum ignition energy (LMIE) of a dust cloud is the least spark energy required to produce flame propagation 10 cm or longer in a 30 - cm long test apparatus, volume 1.2 liters. Particle size has a profound effect on LMIE; fine dust is much easier to ignite than coarse dust.

A literature survey by Hertzberg et. al. (1977) shows that the reported values of LEL of coal dusts similar to Pittsburgh coal (volatile matter approximately 35%) range from 5 to 310 g/m^3. This does not really mean that the actual lower limit concentration of a certain coal dust varies in such a wide range, but it is believed to be a matter of accuracy of measurement and also of the criteria of the explosion limit applied.

Tapping sieve method is a technique which was developed by Ishihama (1961) more than 20 years ago and has been used to obtain reliable data on the LEL of dust clouds. With this system Ishihama carried out the research work on the measurement of LEL of coal dust clouds as a function of particle size, coal rank, methane concentration, and rock dust percentage mixed. However, unfortunately, the system is open, so that the pressure generated by the explosion cannot be measured. Furthermore, the concentration of dust cloud that the apparatus can produce is at most 350 g/m^3, which is not high enough to carry on the investigation in the whole explosion region of dust clouds. Then other equipment is required.

Ishihama, Okada and Yoshida (1964) investigated experimentally the effect of solid incombustibles on the LEL. Generally coal contains the inherent solid incombustibles known as ash, therefore, fineness of brick powder is the same as that of the coal fraction to which it is added. The difference of the effect is evident, brick dust is less effective than the natural ash contained in coal particles.

Ishihama, Enomoto, and Sekitomo (1982) reported that the upper explosion limit (UEL) of coal dust cloud was obtained as a function of volatile content and particle size. The upper limit (UEL) varied very widely with fineness and coal rank compared to the lower limit, but the upper limits of most bituminous coal dust would be at most 3,000 g/m^3. This concentration 3,000 g/m^3 is not very high as an UEL, compared to those of plastics, agricultural products, and metal powders. For example the upper limits of potato starch (Ishihama, 1979), aluminum powder (Ishihama,1975), and magnesium powder (Ishihama,1975) are higher than 8,000 g/m^3, and they could not be obtained even with the rotating chamber equipment.

The UEL and LEL have been related to a percentage of rock dust in coal by Ishihama and Enomoto (1980). He reported that an increase of percentage of rock dust would raise the value of LEL, but reduce the value of UEL . Ishihama and Enomoto (1983), analysed experimental data between the explosion limit and percentage of rock dust in coal by suggesting was approximate equations.

NFPA 68 (1988) evaluated the test results by dividing them into three Explosion Class, i.e., Class St 1, Class St 2, and Class St 3, and showed the relationship between Explosion Class and K_{st}. Dusts are sometimes described by the Class to which they belong. Class St 3 includes dusts that can have very serious dust explosion characteristics.

Variation of the volume of enclosure will cause the variation of the rate of pressure rise while P_{max} remains unchanged. In general experiments are done with small scale laboratory eqipment. For the application of results obtained in such small-scale tests to large-scale industrial systems, the so-called cubic law is used. This was first experimentally obtained by Barknecht (1971) and later theoretically by Tanaka (1981).

Most of the experimental data on the flame propagation in the dust-air mixtures in large dusts are concerned with that in large-scale coal mine galleries such as those 2-m in diameter, and although the information is not strictly relevant to dust explosions in pneumatic transport some of the conclusions are likely to be applicable. In those studies (Rae,1973 , Grumer,1975 and Richmond,1975), it is general practice for a length of coal dust deposits to be laid on the floor or shelves of the mine gallery. A strong ignition source, such as a quantity of gun powder or an explosion of a volume of natural gas-air mixture, is then activated near a closed end to raise and disperse the dust into the air and ignite the resulting cloud. The turbulent airflow induced by the explosion disperses the dust further and the expanding turbulent flame front can travel into the just-formed mixtures, then continuing the process towards the open end of the gallery until dust is exhausted. Since the explosion feeds itself by dispersing the dust from mine surfaces, the local dust concentration ahead of the combustion front fluctuates continuously in time and space. In this respect it can be seen that phenomena are basically unsteady and three dimensional in nature (Richmond,1979) .

Nettleton, M.A. (1977) investigated dust explosions in small ducts and pipes. In smaller ducts or pipes it seems to be more difficult to initiate such coal dust explosion, as shown by the observation that only low flame speeds have been obtained with laboratory flames in ducts. Use of an atmosphere of oxygen in place of air is required to generate a much higher velocity wave front in a small duct.

Matsuda, T., et al. (1982) observed dust explosions in a pneumatic transport system. A pneumatic transport line is an enclosed piping system in which, depending on the utilization of air at greater or less than atmospheric pressure, pressure - and suction-type systems or a combination of both are principally used for transporting dusts in suspension and a very wide range of phenomena is involved in the two-phase flow.

Experimental data on flame propagations in pre-existing dust-air flows may be limited to those in small pipes 5-10 cm diameter. They show that it is unlikely that the flame can be accelerated into higher speeds similar to detonation. Furthermore, Matsuda indicates that explosibility limits, especially upper limits are narrowed as air speeds of transportation in a pipe are increased up to a critical level, above which no flame is propagated at any dust concentrations, with a small source of ignition such as a spark or a gas torch (Matsuda,1982 and Essenhigh,1958) .

Lunn, G.A. (1985) reported actual data of aspirin dust explosion characteristics. They show the variation of explosion violence (dP/dt), maximum pressure, and K_{st} with dust concentration. Data were from a 20 - liter sphere, and the sample had a moisture content of 1.2 %. The highest value of K_{st}, 190 (bar)(m)/s, shows that this material is in Explosion Class St 2.

O'Shaughnessey (1992) has found that for many dusts the dust cloud is barely visible at the LEL concentration. At the LEL concentration the ignition energy may be several orders of magnitude higher than at stiochiometric concentration and pressure rise and rate pressure rise, if there is an explosion, are small. O'Shaughnessey has also found that at the stoichiometric concentration the dust cloud is so thick that one can barely see one's outstretched hand if one is in the dust cloud. At the stoichiometric concentration the ignition energy is above the minimum value and the pressure rise and rate of pressure rise upon ignition are below their maximum values. The maximum explosion pressure and rate of pressure rise are at a concentration two to three times higher than the stoichiometric concentration. The ignition energy also decreases above the stoichiometric concentration. The LEL concentration of many industrial dusts is between 15 to 60 g/m^3 . The stoichiometric concentration for many industrial dusts is in the range of 100 to 300 g/m^3 . From a practical point of view, it may be concluded that if a cloud of an explosible dust is very transparent, it is not much of a hazard bacause it will be hard to ignite. If it does ignite the pressure rise and rate of pressure rise will be small, although the potential for serious burns exists. If a cloud of an explosible dust is quite opaque, it may be a serious hazard.