Studies on the Estimation of Lower Explosive Concentrations for Dust Clouds by Means of the Fluidizing Procedure

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Abstract

In this paper there has been given the experimental description on the estimation of lower explosive limits by means of the fluidizing procedure, using a convenient and useful apparatus made of glass. Since each test for determining ignition and flame propagation was conducted, while carefully checking the fluidized state of dusts by observation, samples to be tested for this apparatus should be taken to be coarser and to be more narrow size range than those for conventional apparatus.

The results can be summarized as follows:

1) This procedure, maintaining more uniform dispersion of each particle, has been probed to be convenient and useful in order to determine the lower explosive limit.

2) The lower explosive limit is decreased proportionally with decrease in the average diameter of dust clouds and the linear distance L between dispersing particles in the idealized model at this point is also reduced proportionally. The effect of average particle diameter on the lower explosive limit is greater for wood flour than for other samples.

3) The explosibility of wood charcoal dusts is closely related to their volatile constituents. At a given intensity of ignition source, however, increasing of volatile matter in the range of 12 to 30% has little effect on the lower explosive limit.

4) It can be seen that in so far as these tests are concerned, the lower explosive limit of dust mixtures may adequately be expressed by the equation of Le Chatellier.

1. Introduction

The economic importance of industrial dust explosions has long been recognized for the safe design and operation of plants in various dust-producing industries. However, it is not usually economically feasible to design systems to eliminate all possibility of dust explosions. In spite of all precaution taken to eliminate or protect the possibility of an ignition source, sufficiently intense to ignite the mixture, still exists.

Dust clouds like gas-air mixtures have well defined lower explosive limits. In recent years, an intensive investigation of explosion for industrial dusts has been undertaken[1)~5)]. According to Fishkin and Smith[1)] "the handling of dust explosion hazards is far from an exact science." They have suggested that there

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is still much work to be done on problems of these fields.

In the case of the previous work done on evaluation of the lower explosive limit, it was difficult to produce and maintain a perfectly dispersed dust cloud. The manner of dispersing dust into a cloud is important because it affects uniformity of dust clouds. There are some problems for dust-dispersing mechanism to assure dust cloud uniformity and consistent, reproducible results in comparison with gas mixtures. Accordingly, one of the reasons for the variation of experimental results is considered to be imperfect dust dispersion, incomplete combustion. Until now little progress has been made toward a practical solution of uniform dispersing.

The types of dispersing procedure that had been described in the literature might be classified as (1) pressure method[3),5)] and (2) reduced pressure method[1)]. Dust clouds were created by dispersion of weighed quantities of dusts (1) with jets of compressed air, or a blast of dry air (2) by evacuating the combustion chamber and releasing. When these conventional procedures are adopted, explosive clouds of relatively coarse particles cannot be kept in uniform suspension for longer than a fraction of a second. Especially with increased volume of combustion chamber, it becomes more difficult to produce uniform dust clouds. Therefore, to achieve ignition at the optimum concentration it is important that ignition and dust dispersion be carefully coordinated.

A satisfactory procedure, maintaining more uniform dispersion of dusts, for observing ignition and flame propagation of various flammable dusts at lower explosive concentration has been developed. In this paper there has been given an experimental description on the characteristics of this apparatus and the results obtained from it.

2. Experimental

2-1 Preparation of samples

The conditions necessary for this fluidized procedure should be prepared the sample ranging sufficiently narrow size distributions. Wood charcoal dusts of different degrees of carbonization (carbonized temperature was 300, 400, 500, 600 and 700°C respectively) were prepared in the stainless steel retort, passing through a current of nitrogen. A recrystalization of several times was effected in the purification of naphthalene and anthracene. The samples such organic dusts as naphthalene, anthracene, wood flour and wood charcoal were carefully screened with a close series of Tyler standard sieves in order to obtain narrow size fractions. As these materials were all somewhat hygroscopic they should be dried before the separation were initiated.

The properties of the samples to be tested are shown in Table 1.

Table 1. Properties of the Samples to be treated

Dusts	Carbonized temperature °C	Volatile matter[1)] %	True density[2)] ρ (g/cm^3)	Average particle diameter $\bar{d}$ (μ)
Naphthalene			1.17	0.109
				0.145
				0.207
Anthracene			1.25	0.062
				0.113
				0.197
Wood flour			1.54	0.059
				0.111
				0.161
Wood charcoal	300	38.6	1.45	0.111
				0.161
				0.211
	400	29.7	1.53	0.111
				0.161
				0.211
	500	22.4	1.54	0.111
				0.161
				0.211
	600	12.5	1.57	0.111
				0.161
				0.211
	700	9.7	1.64	0.111
				0.161
				0.211

1) Volatile matter is determined by the percentage loss in weight of given samples after ignition at 950°C for 7 minutes.

2) True density is determined with benzene, standing at 24°C after 3 days using a pycnometer.

2-2 Apparatus and Procedure

Numerous trials were made with various devices in order to obtain uniform dispersion of dusts. A satisfactory apparatus has been developd in order to estimate ignition and flame propagation at the lower explosive limit of various flammable dusts by means of the fluidizing procedure.

Such an apparatus is shown in Figure 1. Main parts of this apparatus consist of a cylindrical combustion chamber, 2.5 cm diameter by 26 cm long, of hard glass, a flow distribution filter, 3 mm thickness, of porous fused glass and two sets of ignition spark source spaced 4 and 7 cm apart from the filter. Each ignition system consists of two platinum electrodes 5 mm apart. Details of combustion

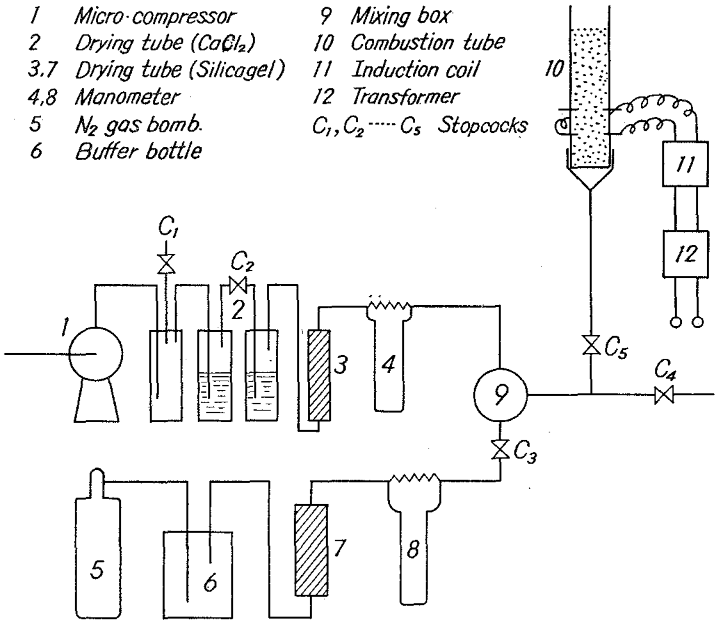

Fig. 1. Apparatus for determination of lower explosive limit of dust clouds by means of fluidizing procedure.

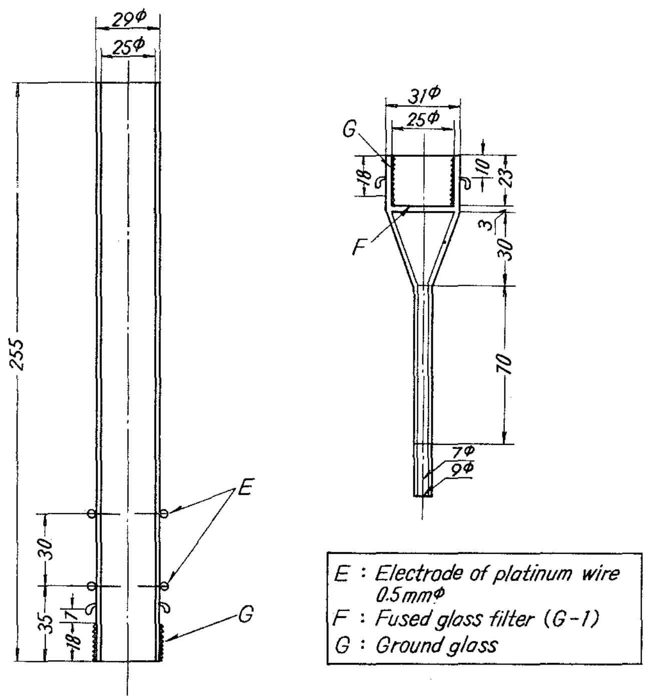

Fig. 2. Details of combustion chamber made of hardglass.

chamber are shown in Figure 2. Since moisture is frequently affected the explosibility of dusts, it is removed by passing through a series of drying tubes. An adequate flow rate for each dust must be determined in preliminary tests and the preliminary experiments for handling of the apparatus is also necessary. Otherwise, when particles are fluidized, part of them will fly out of the chamber with air flow.

To obtain test data, a measured quantity of dusts was placed on the glass filter and the coke was turned. A dry air was then allowed to pass into the combustion chamber through the filter. The dust mixtures were dispersed upward with a slight shock at the cylinder wall. Care should be taken to be fluidized particulately. The cloud thus generated was ignited by use of a high voltage electric spark between two pointed electrodes. In all tests the time interval was 6 sec and the flame propagation through dust clouds was observed.

In performing repetitive tests it is not difficult to produce two dust clouds of the same uniformity. By selecting flow rate corresponding to optimum fluidizing conditions to which each particle can be suspended uniformly, the lower explosive limit can be estimated with higher degree of certainty.

2–3 Calculation

The lower explosive concentration p (mg/l) is given by the following expression,

$$P = 1000 \text{ a } 4/\pi D^2 H$$

where a (mg) is the weight of sample used, D (cm) is the inner diameter of combustion chamber, H (cm) is the height of fluidizing zone.

For an idealized case where the particle is supposed to be composed of spheres all the same size, assuming the regular and uniform dispersion of particles as shown in Figure 3, the linear distance L (cm) of particle-particle at the lower explosive limit can be calculated approximately from the following expression

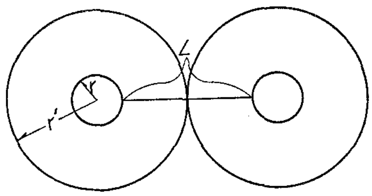

Fig. 3. Distance between dispersing particles in the idealized model of lower explosive concentration.

$$L = 2(r' - r) = 2r\left((\rho/p \times 10^{-6})^{1/3} - 1\right)$$

where r (cm) is the radius of each particle, ρ (g/cm^3) is the true density of particles.

3. Results and Discussion

The factors that affect the ease of ignition of dust particles in suspension are principally the chemical and physical properties of dust, properties of the atmosphere in the explosion space and ignition source in the test. Figure 4 illustrates the effect of intensity of ignition source on the lower explosive limit of various dust clouds. It is confirmed that the lower explosive concentration is increased with decreasing the electric spark energy required for ignition at a given average

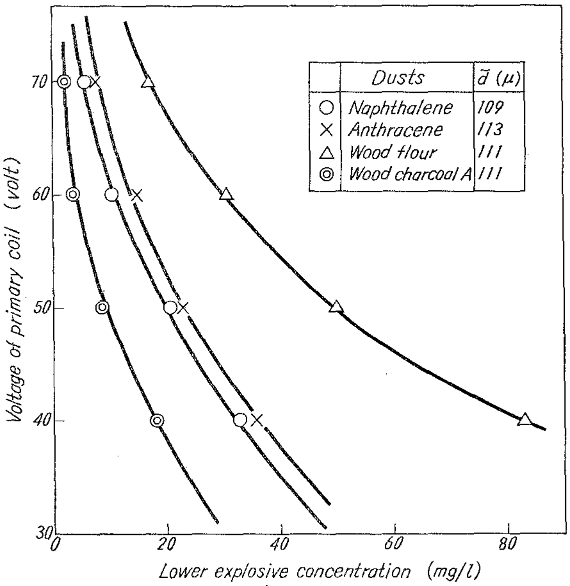

Fig. 4. Lower explosive limit curves of various dust clouds having the average particle diameter of 111 μ

diameter.

Smaller particles are dispersed more readily, remains in suspension longer, and burn more rapidly. These are chiefly due to the increase in the rate of the reaction with decreasing size of particles. The sample surface area is also important because combustion occurs at the surface and the total exposed area of particles affects the rate of reaction. This is apparent in Figure 5. At a given intensity of ignition source further decrease in the average diameter will cause a decrease in minimum explosive concentration. The effect of the average diameter is greater for wood flour than for naphthalene, anthracene, or wood charcoal dust. No measurable differences are observed between naphthalene and anthracene.

As can be seen from Figure 6, at a given spark energy increase in volatile combustion content in the range of 12 to 30% has little effect on the lower explosive limit, but further increase or increase up to about 12% in volatile matter results in considerable reduction in it. Thus the explosibility of wood charcoal dusts which there is some difference in carbonization temperature is closely related to their volatile constituents and it is probable that vapors evolved from the dust, or in some instances gases decomposed the outer part of particles by spark are ignited during the incipient stage of explosion.

Relation between the minimum explosive concentration and the limiting percentage of oxygen in atmos-

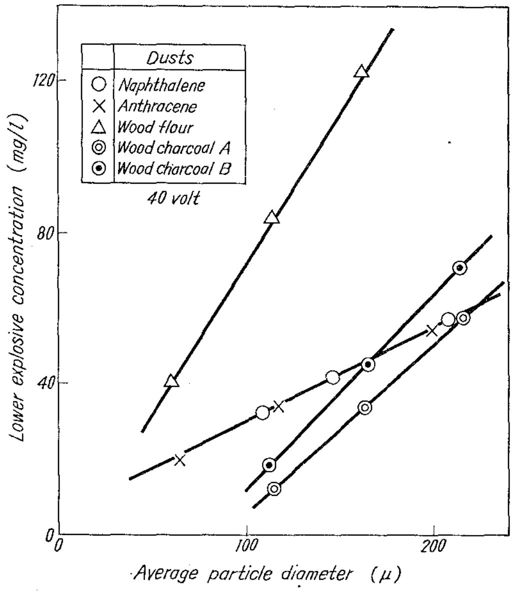

Fig. 5. Effect of average particle diameter of various dust clouds on the lower explosive limit

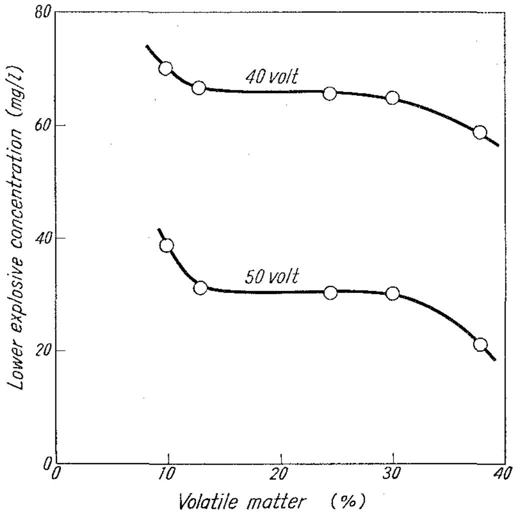

Fig. 6. Effect of volatile matter of wood charcoal dusts on the lower explosive limit, average particle diameter 211 μ

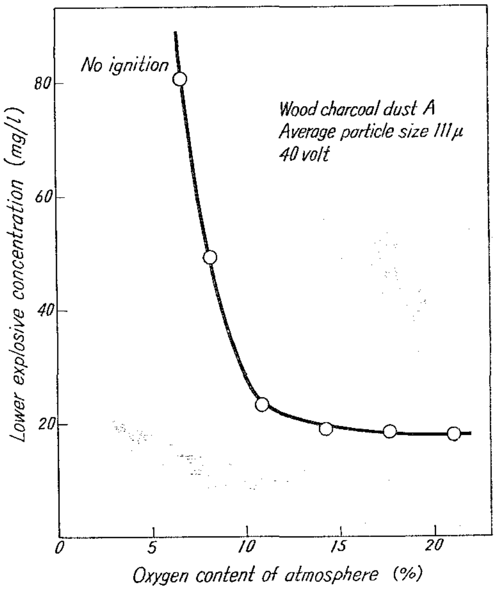

Fig. 7. Effect of oxygen content of atmosphere on minimum explosive concentration of wood charcoal dust clouds

phere containing dust clouds, below which dusts cannot be ignited by electric sparks is also confirmed. This is illustrated in Figure 7 for wood charcoal dust A of 111 μ in average diameter, other variables being fixed. Tests are shown that wood charcoal dust A will not maintain combustion if the oxygen content is reduced to about 6% by dilution of air with nitrogen.

As the proportion of the flammable dust to the supporting gas is decreased, a lower explosive concentration is reached at which point it can be imagined that the flammable particles are too widely separated to support the rapid flame propagation needed for an explosion. Experiments are shown that as the particle size decreases, generally the lower explosive limit is reduced and the linear distance (L) of particle-particle at this

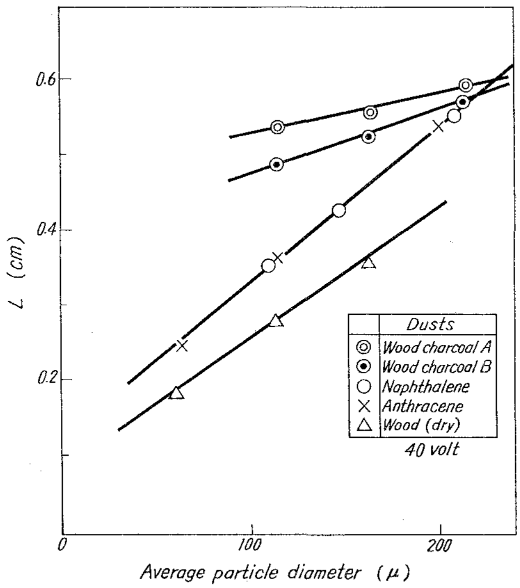

Fig. 8. Effect of fineness on the linear distance of particle-particle at the lower explosive concentration.

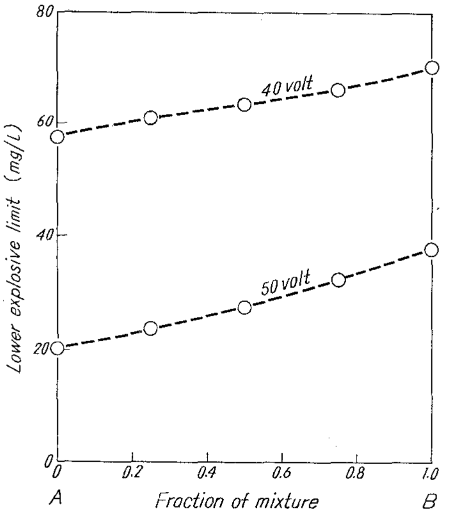

Fig. 9. Lower explosive limit of dust mixture of wood charcoal A and B
Average particle diameter 211 μ

point is also reduced as illustrated in Figure 8. As may be expected, higher distance between particles is obtained in explosions of coarse dust than in those of fine dust. However the expression of L can be regarded only as an approximation for an idealized condition by assuming the regular and uniform dispersion of dusts as shown in Figure 3.

The wood charcoal dusts (A and B) that were carbonized at the temperature of 300 and 700°C were used as blending samples. The average diameter of these dusts was 211 μ. Figure 9 shows the effect of increasing proportions of B on the lower explosive limit. It increases nearly linearly with increasing proportion of B. Broken lines are shown the values calculated from the equation of Le Chatellier that is adapted for the explosion of gas mixture.

Since each test for determining ignition and flame propagation was carried out, while carefully checking the fluidized state of particles by observation, particle size of samples for this apparatus should be taken to be coarser than those for conventional apparatus. In examining these data it should be remembered that the resulting values of lower explosive limit were to be larger than those of conventional apparatus because heat lost to the surroundings, which is a function of the flow rate, increases owing to the difference of dispersing mechanism, whereas the resulting values were to be smaller than those of previous investigations owing to the more regular and more uniform dispersion of dusts.

From the consideration of two points described above, the resulting values have been concluded to be relatively accurate in comparison with the previous investigations by the conventional apparatus. As very little is known at present of the basic mechanism of ignition of dust particles, the true significance of all the influencing factors is not fully understood. Based chiefly on the estimation of flame propagation of ignited dust particles, or lower explosive limit, it has been shown that the fluidized procedure was a convenient and useful method.

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