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Dust Explosions in the Food Industries

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Abstract-The ignition temperature of a dust cloud in the air atmosphere and of dust layers in hot environment, have been investigated for several particle sizes of a number of food materials. Mixtures of fine and coarse dusts of the same material have also been studied. Measurements for the dust cloud and the dust layer were made in a Godbert- Greenwald Furnace apparatus and in a tube furnace, respectively. The results obtained indicated that the ignition temperature is dependent on the type of the material and its particle size for the cloud and the layer. An admixture of fine lentil dust of 50% to coarse dust is sufficient to reduce the values of ignition temperature for the dust cloud by 63%. Value of the ignition temperature for layers of corn starch is lower than that of the other materials studied.

Keywords- *Dust Cloud, Dust Layer, Explosion*

I. INTRODUCTION

Dust explosions in the food industries have caused industrial accidents resulting in many fatalities, structural damage and devastating effects. Examples of explosible dusts in the food industries include powders of flour, sugar, rice, cornstarch, milk, coffee and many others. Common industrial operations producing dust in the food industries include milling, grinding, spray and tray drying, conveyance and storage etc.

The following rules must be available for a dust cloud explosion to occur

a. The dust must be explosible and of fine particle size.
b. The dust concentration in air must be within the flammable range.
c. An ignition source of suitable energy must be present.
d. An air atmosphere of sufficient oxygen to sustain combustion.

Whereas a dust fire may occur where:

a. Airborn dusts are settled to form a layer of suitable thickness.
b. Ignition of the layer is obtained due to spontaneous ignition, hot environment, hot surfaces, direct flame or any other source of ignition.
c. Access of air
d. Time.

The ignition source of sufficient energy is capable of igniting a dust cloud and a dust layer. Ignition sources are numerous, some of them are open flames, hot surfaces, electrical and mechanical sparks, electrostatic discharges and many others. The subject of dust explosion is published in such references [1-4].

Many dust explosions incidents have occurred in the world leading to destruction of industrial facilities and killing of many people. In the United States, there were 281 major dust explosions and fires from 1980 – 2005. These incidents resulted in 119 fatalities and 718 injuries, and destroyed many industrial facilities. Recently, in a food industry, a series of dust explosions occurred at a sugar manufacturing plant in Georgia, U.S.A. in 2008. The outcome of this accident was 14 people killed and 36 injured. The explosions and the accompanied fires destroyed every part of the operating plant. In terms of loss of money, the insured property damage ran into hundreds of millions of dollars. Also, two people were killed and dozens hurt from a fire occurred at a food plant in North Carolina, U.S.A. in 2009. Most recently, there was a fire at a food plant in Caldiero (Verona), Italy in 2011, injuring two people [5]. Every year many accidents go unreported worldwide, and there is hardly any reliable statistical report available. In Jordan, the only reliable information regarding the records and statistics of fires and explosions in industry can be obtained from the official publications of the Public Fire Brigades (PFB). Those records, however, generalize all the industries in one category, and do not classify the industries according to its type of production. Those records consist only of those fires which were attended by the PFB. Recently, parameters related to dust cloud explosion, dust layer fires, and spontaneous combustion are reported [6,7,8,9,10], whereas specific investigation on the effect of particle size, dust concentration and inert solids on the minimum ignition temperature are also published [11, 12, 13].

The experimental work presented in this paper was undertaken to investigate the explosibility of industrial (food) dusts, and to determine the effect of particle sizes on some of the parameters of dust explosion in air. Dust cloud and dust layer were considered in this work.

II. PROCESSING UNITS USED IN THE FOOD INDUSTRIES

There are a wide variety of processing units used in the food industries to process materials to form the required product [1]. Some of the used units may be summarized as follows:

A. Grinding and milling machines

Hammer mill and ball mill are often used to reduce the particle size of solid material to fine dusts. Ignition of dusts in mills and pulverizing equipment is most likely because of the presence of hot surfaces, friction, sparks arising from the energy used in the operation of these equipment.

B. Conveying

It usually requires for the fine dusts to be conveyed to another processing equipment. The main types of conveying systems can be specified as:

a. Manual: this type of conveying involves the transfer of the dust in bags.

b. Mechanical: this method involves transport the dust in bulk, such as screw, belt conveyers and bucket elevators.

c. Pneumatic: this system is different from the previous systems in that the dust is transported in suspension, usually air.

The above methods may allow the dust to escape to the atmosphere forming dust cloud, or settled on units and pipes in the plant to form dust layer. All sources of ignition mentioned previously are capable of igniting the dust cloud and dust layer.

C. Separation and collection

The common types of separator and collector include cyclones, filters, scrubbers, dryers and many others. The principle method of separation and collection of these units is different from each other. Ignition of dust may occur in any of these units. These units should always be regarded as a potentially hazardous operation.

D. Storage

After the dust has been milled and conveyed, it must be taken to further unit operations, e.g. storage, mixing and others. Silos are used as storage units. These units are liable to cause explosions and fires in dusts, and numerous accidents have occurred in the past, particularly with flour. The reason of ignition of many agricultural dusts in silos, because of its design, dust clouds are continuously present during operation, particularly at the top of the silo. Electrostatic charges are a major source of ignition in silos.

III. MATERIALS

The agricultural (food) dusts which are used in this work are semolina, lentils, cornstarch, milk powder and sugar. For each material, samples with a range of different particle sizes of d (53μm< d< 63μm, 63μm< d< 75μm, 75μm<d< 125μm, 125μm<d<150μm, 180μm <d<250μm) were prepared by sieving. The particle sizes of 57.8, 68.7, 97, 137, 212 μm were determined as the geometric mean of apertures of the bracketing meshes. The particle sizes chosen for each material were prepared from as received sample. All the dust samples were dried at 105^{o}C for 1 h.

IV. EQUIPMENT AND PROCEDURE

The experimental values of the ignition temperature were determined for the clouds and the layers of the tested materials using the Godbert- Greenwald Furnace apparatus and the horizontal tube furnace, respectively.

A Godbert-Greenwald Furnace apparatus was used to determine the ignition temperature for different particle sizes of the dust cloud in air. The general layout of the apparatus is shown in Fig. 1 and complete specifications of the furnace are given in many references [1,3].

The experimental procedure used was as follows:

1. The furnace tube was heated and fixed at the desired temperature.
2. A weighed quantity of the material was placed in the dust holder.
3. The air tank was filled up to the desired dispersion pressure (6-13 lb/in^2)
4. The dust sample was dispersed through the furnace combustion tube by a blast of pressurized air.

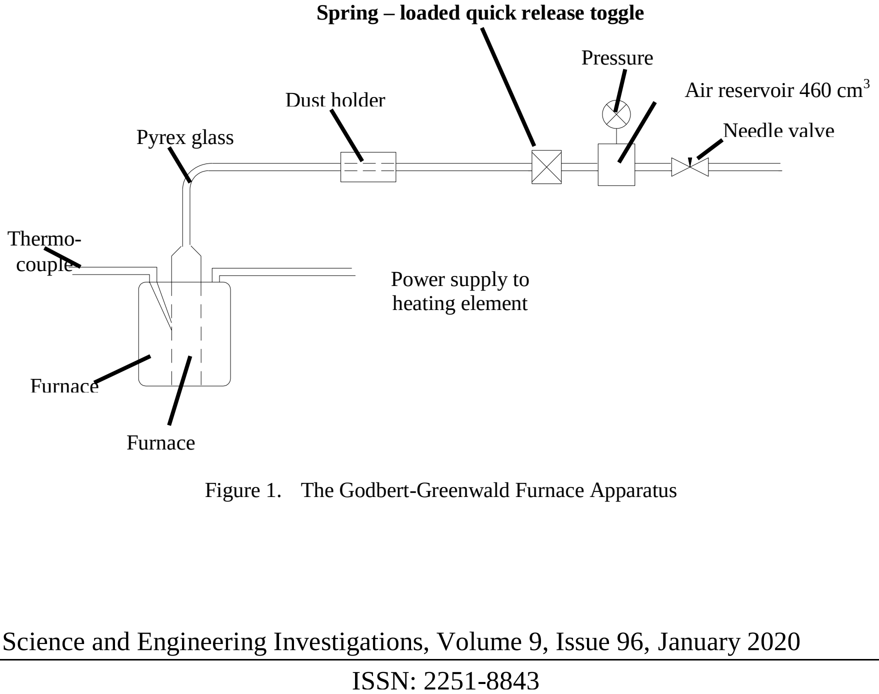

Figure 1. The Godbert-Greenwald Furnace Apparatus

The criterion for indicating an explosion was the observation of flame at the bottom open mouth of the furnace. If explosion occurred, the furnace temperature was lowered and testing continued with different dispersing pressures, until no flame was observed in at least 3 tests at the same amount of the dust. The difference in temperature between explosion and no explosion was 10^{o} C. The lowest temperature at which ignition with flame occurred was taken as the ignition temperature.

The horizontal tube furnace was used to determine the ignition temperature for the layers of the tested materials. The general layout of the furnace is shown in Fig. 2. It was similar in principle to the Godbert-Greenwald Furnace apparatus. It consisted of a refractory tube, 470 mm long and 40 mm inside diameter, heated externally by an electric winding. The furnace tube was fixed horizontally in a rolled stainless steel case fitted with aluminum end plates. Both ends of the furnace tube were open. The whole case was filled with wool of low thermal mass. Furnace temperatures up to 1200^{o}C were maintained by a temperature controller, governed by a thermocouple, whose junction was located on the furnace wall at its midpoint. This produced an even temperature distribution at the centre of the tube and extending to a distance of 5 cm on both sides.

The experimental procedure was as follows:

1. The furnace tube was heated and fixed at the desired temperature.
2. A mold of desired dimension was placed on the dust holder. The holder was a long sheet of steel, 30 mm wide and of 5 mm thickness.
3. A quantity of the dust was distributed in the mold to form a packed layer. The mold was then removed and a flat spatula was used to level the surfaces of the layer.
4. The dust holder together with the dust layer was placed in the centre of the furnace tube.
5. Time was measured from placing the sample in the furnace to the observation of flame.

The criterion for indicating an explosion in this test was the same as that adopted for the Godbert-Greenwald Furnace apparatus. The duration of the test in this apparatus was four minutes.

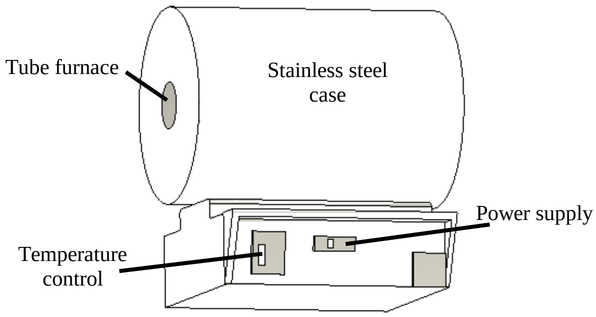

Figure 2. The Horizontal Tube Furnace Apparatus

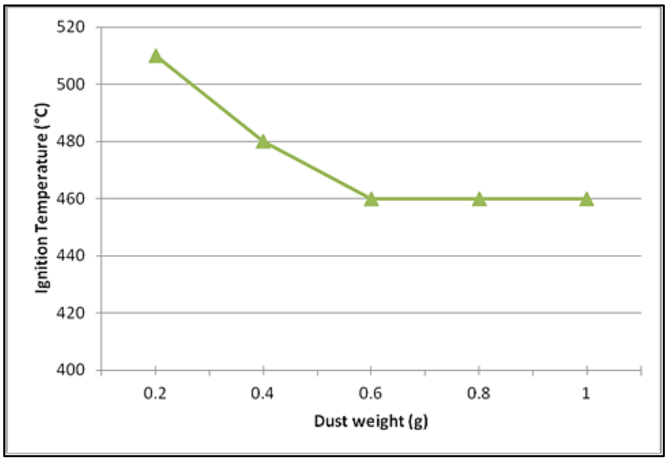

Figure 3. The variation of the ignition temperature (°C) with dust weight (g) of semolina (mean particle size 97 µm)

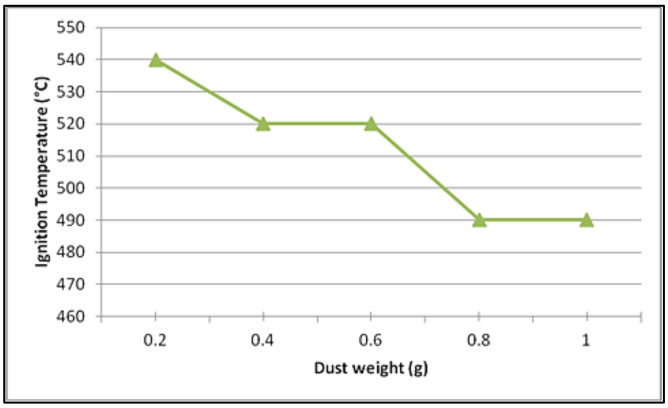

Figure 4. The variation of the ignition temperature (°C) with dust weight (g) of lentils (mean particle size 97 µm)

V. RESULTS AND DISCUSSION

A. Dust Cloud

Figures 3 and 4 show the variation of the ignition temperature (C^{o}) with weight of the dust (g) for semolina and lentils, respectively . The mean particle size for both materials was 97 µm.

They are representatives of the results obtained. Many experiments were carried out at each dust weight, and each point on the graphs represents the lowest temperature at which each material at the corresponding weight was ignited with flame.

It can be seen, that as the dust weight increased from 0.2 g to 0.6 g, the ignition temperature decreased sharply from 510^{o} C to 460^{o}C for semolina and slightly from 540^{o}C to 520^{o}C for lentils. Further increase in the weight, the ignition temperature was constant for semolina and decreased sharply for lentils. Values for the minimum ignition temperature, defined as the value of the ignition temperature at a weight of 1 g [14], of 460°C and 490°C were obtained for semolina and lentils, respectively.

In order to compare all the results obtained for all the particle sizes of each material together. Summary graphs were plotted for lentils, milk powder, semolina, corn starch and sugar in figures 5, 6, 7, 8, 9, respectively.

The general pattern of these results is the same as for the representative curves. In general, the curves divide the plot into two regions, in the region above the curve ignition with flame is possible, and in the region below the curve ignition with flame is not possible. Moreover values obtained in this study are comparable with published data [1].

It is important to study the effect of particle sizes of all the materials on the minimum ignition temperature obtained at a dust weight of 1 g. The results are plotted in Fig. 10. It can be seen that the points are scattered. A helpful linear relationship may exist if more data are available.

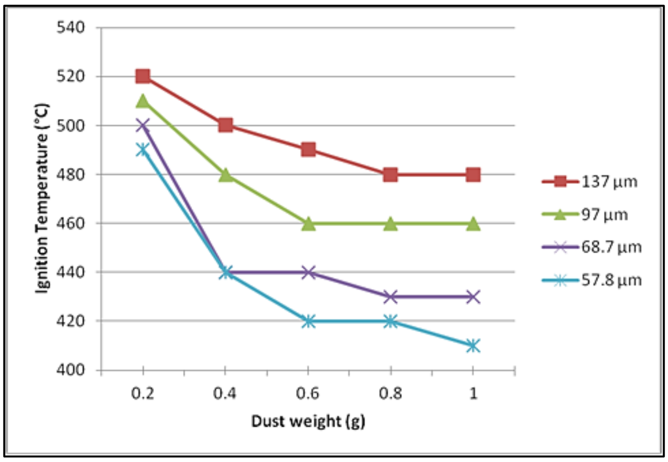

Figure 7. The variation of the ignition temperature (°C) with dust weight (g) for all the particle sizes of semolina

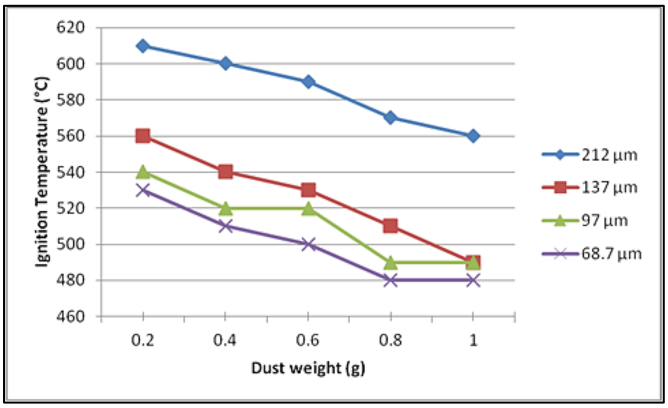

Figure 5. The variation of the ignition temperature (°C) with dust weight (g) for all the particle sizes of lentils

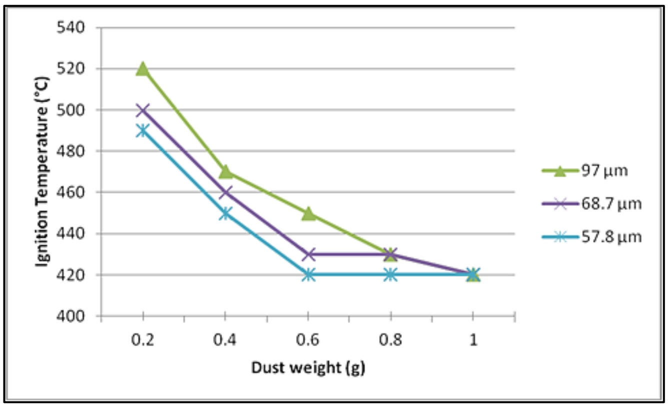

Figure 8. The variation of the ignition temperature (°C) with dust weight (g) for all the particle sizes of corn starch

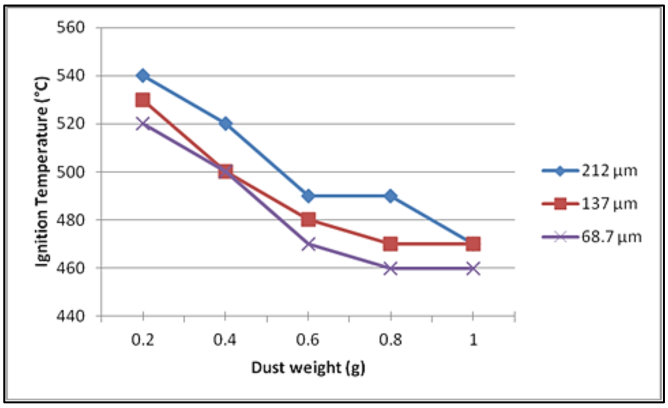

Figure 6. The variation of the ignition temperature (°C) with dust weight (g) for all the particle sizes of milk powder

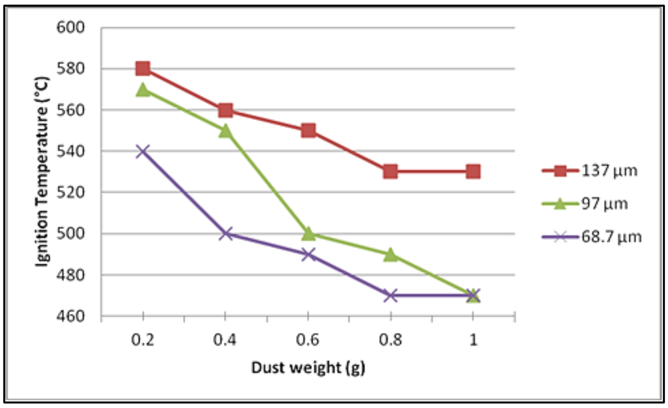

Figure 9. The variation of the ignition temperature (°C) with dust weight (g) for all the particle sizes of sugar

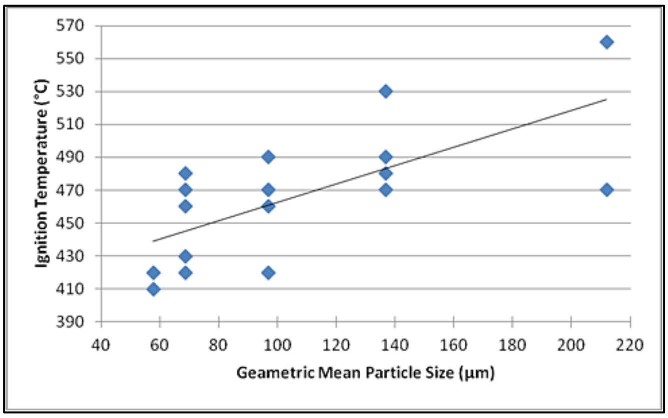

Figure 10. The variation of the minimum ignition temperature obtained at 1 g. with mean particle sizes for all the materials

VI. MIXTURES OF PARTICLE SIZES

In industrial situations, dusts are not usually of uniform particle size, and since the ignition temperature of fine particle size can be elevated by adding proportions of coarse particle size of the same material. It is important to study the effect of the particle size distribution of the same material on the values of the ignition temperature. Since the values of the ignition temperature obtained for lentils show a wide range with respect to its corresponding dust weight, it was then decided to mix several percentages of the fine (68.7 µm) and coarse (212 µm) dusts of lentils, and the values of the ignition temperature of the mixtures for the cloud were determined as those for different particle sizes. The behavior of this mixture may be considered to be representative for all the mixtures of other materials. The results are shown in Fig. 11. Curves obtained with 100% of coarse and fine dusts of lentils are also plotted. The general pattern for the mixtures is the same as for different particle sizes.

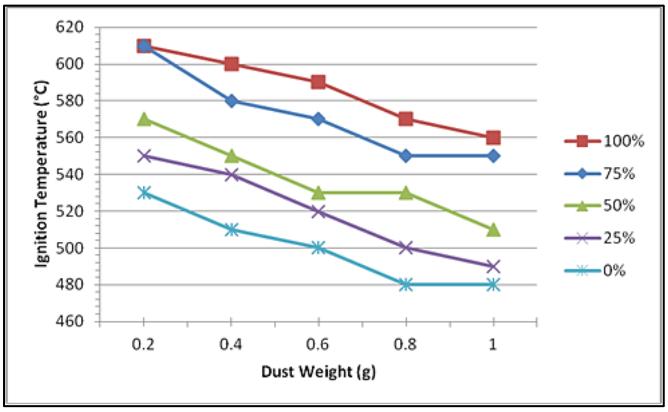

Figure 11. The variation of the ignition temperature (°C) with dust weight (g) for all the mixtures of lentils. Figures on the curves refer to the percentage of coarse dust in the mixture.

The most important result of these tests is the nonlinear relationship between the composition of the dust mixture (percent by weight of large particles) and the minimum ignition temperature obtained at 1 g for lentils. This is shown in Fig. 12. It illustrates that an admixture of 25, 50, and 75 percent by weight of fine particles with coarse reduces the minimum ignition temperature for lentils by 13, 63 and 88 percent, respectively, of the difference between the pure coarse and pure fine values. The ratio of particle diameters of coarse to fine was of the order of 3.1 to 1.

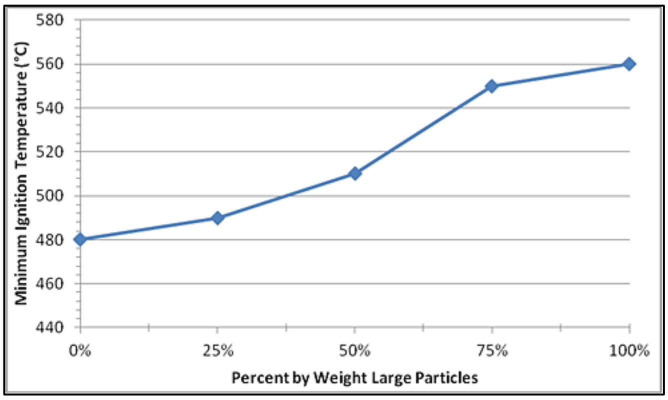

Figure 12. The variation of the minimum ignition temperature (°C) with percent weight of coarse dusts in the mixtures for lentils

VII. DUST LAYER

In this part of the work, the horizontal tube furnace was used to study the effect of particle size of the material on the ignition temperature. The results obtained from the furnace are applicable to situations where powders may be settled on warm parts of units, or may be processed in units, such as spray dryers.

In a previous study {9}, the effect of particle size on the ignition temperature for many dimensions of rectangular shapes was studied. In this work, a rectangular shape of the layer with a dimension of 50 mm long, 20 mm wide and 5 mm depth was chosen to be used. This dimension resembles the accumulation of dusts on the surfaces of process units, and also it can be maintained exactly throughout the test procedure.

Table 1 lists values of the ignition temperature together with the time required for ignition for all the particle sizes of the materials studied. The table illustrates that with increasing particle size of the layer, the ignition temperature increased and the time required for ignition decreased, respectively. In general, values of the ignition temperature of corn starch are lower than that of the other materials, whereas, the majority of values of the time required for ignition are almost around 150 seconds.

TABLE I. VALUES OF THE IGNITION TEMPERATURE AND THE TIME REQUIRED FOR IGNITION FOR ALL THE LAYERS

Material	Particle size (µm)	Ignition temperature (^{0}C)	Time (s)
Lentils	97	480	76
Milk powder	68.7	420	180
	137	440	162
	212	450	154
Semolina	57.8	460	142
	68.7	460	127
	97	490	112
	137	500	105
Corn starch	57.8	150	172
	68.7	150	124
	97	170	110
Sugar	68.7	melts	-----
	97	melts	------
	137	melts	-------

In general, values of the minimum ignition temperature obtained for the dust cloud and the dust layer of corn starch were lower than those obtained for the other materials of the same particle size. The lower the ignition temperatures needed to ignite a dust material, the more sensitive the dust to ignition and the more rigorous protective measures need to be. Surface temperatures of process equipment must be controlled and dust layers must be removed and not allowed to accumulate, ignition sources must be avoided through good engineering protective designs.

VIII. CONCLUSION

The experimental data presented for the minimum ignition temperature of a dust cloud and dust layer of food materials provide the necessary information for assessing the hazards of dust explosions and fires, and help in the design of protective measures in industrial plant where dust hazard is possible. By analyzing the data obtained, it has been possible to confirm that the type of the material and its particle size are important parameters affecting the minimum ignition temperature of the dust cloud and layer. It was also found that where fine particles of lentils were mixed with coarse particles of the same material, the value of the minimum ignition temperature for the fine particles of a dust cloud most influenced the value of the minimum ignition temperature for the mixture, and that an admixture of 50% by weight of fine particles would reduce the value of the minimum ignition temperature of the mixture by 63% of the total possible reduction. The results show that values of the minimum ignition temperature obtained for the dust cloud and the dust layer of corn starch were lower than those obtained for the other materials of the same particle size.

Values of the ignition temperature must include a safety factor of at least 75^{o}C below that required for ignition of the dust must be used.

A mathematical model to predict the minimum ignition temperature has not been developed in this study, because of lack of information and experimental data related to the rate of surface reaction of particles, but as more information becomes available, the situation will be improved.

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