

# Experimental investigation on the self-ignition behavior of dangerous dust accumulations

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**Abstract.** A process known as spontaneous combustion is brought on by the gradual oxidation of flammable organic particles and takes place when air passes over a mass of dust. Combustible powders react with air oxygen in a process known as oxidation, which produces carbon dioxide, carbon oxide, water, and other gases whose contents depend on the temperature at which the oxidation occurs. Combustible dusts can self-ignite depending on their chemical makeup, the characteristics of their constituent components, the particle size and mass geometry, and last but not least, the ambient temperature. Self-ignition is a complicated process that occurs in three subsequent or concurrent stages of development, namely self-heating, humidity evaporation, and self-ignition. Self-ignition is a complicated process that occurs in three separate or concurrent stages of development, namely self-heating, humidity evaporation and self-ignition, all of which interact with one another. Even at normal temperatures, the molecules on the surface of combustible dust particles are prone to exothermic interactions with oxygen in the air conveyed in the free volume between particles, which is the cause of self-heating (or possibly self-ignition). The temperature of the reactive-air dust system will then rise as a result of any heat emitted, hastening the reactivity of other dust molecules with oxygen. By using drying tests at constant temperatures, this work aims to demonstrate the self-ignition behavior of flammable dusts by volume.

## 1 Introduction

According to OSHA, combustible dust is "a solid material formed of separate particles or pieces, independent of size, shape, or chemical makeup, which may provide a fire or explosion danger when suspended in air or other oxidizing environments on a range of concentrations. Due to the potential for catastrophic fires and explosions, the presence of this dust, both in open and close spaces, can pose a major risk to workers, employers and installations [1,2].

Agriculture, chemicals, food (sugar, candy, spices, starch, flour and feed), cereals, fertilizers, tobacco, plastics, wood, forest, paper, pulp, rubber, furniture, textiles, pesticides, pharmaceuticals, tire and rubber manufacturers, dyes, coal, metalworking (aluminium, chromium, iron, magnesium and zinc), recycling, and coal operations are just a few of the

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industries that are susceptible to fire or dust explosion [1]. Given this extensive list of sectors that are at risk and the fact that many businesses struggle to recognize the harm posed by fuel dust, OSHA advises conducting a complete dust hazard assessment that takes into account the following factors:

- Materials that can be combustible;
- Processes that use any combustible dust;
- Open and especially hidden areas, where dust can collect;
- Opportunities that can cause air dust in the air;
- Any ignition source [3].

To accurately determine whether or not the dust is actually flammable is the key to risk assessment. Combustible dust is defined as "any fine solid material having a diameter of 420 microns or less that presents a fire or explosion hazard when dispersed and ignited in air" in both NFPA 654: Standard for the prevention of explosions against fire and dust in the manufacture, processing, and handling of combustible particulate solids and NFPA 454: Standard for combustible metals, metallic powders, and metallic dusts. Along with particle size, other factors to take into account include how the dust will be spread, the type of ventilation available, air currents, ignition sources, and the presence of physical barriers that guarantee dust containment or that separate work activities. The management and elimination of flammable dust is also crucial [3, 4].

The following ignition sources are among the many options used in industrial practice that are most crucial:

- Warm surfaces;
- Flames, shiny material (smoldering);
- Mechanically generated sparks;
- Electrical equipment (electrically generated sparks);
- Electrostatic discharge sparks [2,5].

OSHA also offers some suggestions for controlling ignition sources:

- Use only approved electrical and wiring equipment and methods;
- Tie the equipment to the ground and control the static electricity;
- Control open flames, sparks, smoking and rubbing;
- Separate materials to prevent combustible materials from working processes;
- Place the distance between heated surfaces / systems and dust exposure;
- Follow the appropriate operating instructions when using cartridge-enabled tools;
- Implement a preventive equipment maintenance program [1, 3].

The experimental determination of self-ignition temperatures as a function of volume is necessary for the evaluation of the self-ignition hazard of bulk materials. Two standardized techniques are available for this purpose: measuring the self-ignition temperature of a layer of dust put on a heated surface and determining the self-ignition temperature of dust samples in an oven. Sometimes, depending on how the sample behaves during these tests, the second method is difficult to use [6].

Combustible dusts can self-ignite depending on a variety of variables, including their chemical composition, the characteristics of the constituent parts, the particle size and geometry of the mass of the material, and last but not least, the surrounding temperature. Even at normal temperatures, molecules on the surface of combustible dust particles undergo exothermic interactions with oxygen in the air carried in the free volume between particles, which is the fundamental cause of self-heating (or maybe self-ignition). The temperature in the system of reactive dust and air will then increase as a result of any heat emitted, hastening the reactivity of further dust molecules with oxygen. The system's evolution will depend on the thermal balance between the heat produced inside the dust mass (quantity and surface area of surface reactive molecules, calorific value) and the heat lost to the environment

(thermal conductivity and dust mass size, heat transfer coefficient on the outer surface of the dust mass and size) [4, 7].

Self-ignition is a common source of ignition of porous storage of bulk materials such as powders and dusts. Evaluation of this ignition hazard, taking into account manufacturing or storage conditions, requires experimental determination of critical self-ignition temperatures as a function of volume [8].

Materials can be stored at room temperature, in bulk storage tanks, piles, silos and hoppers, or in dust collectors. The materials are then heated symmetrically to determine the self-ignition temperature and essential storage conditions using the European standard EN 15188 (ECS, 2007). This is the traditional case for grain silos or coal heaps. Risk analysis of self-heating phenomena of dust layers or bulk storages is required, as is the estimation of self-ignition and minimum ignition temperatures [9].

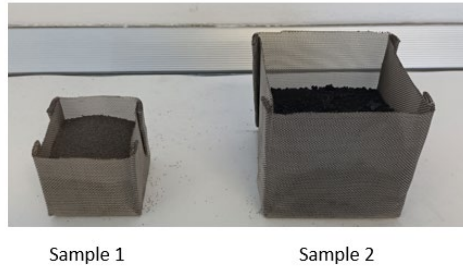
Dowbysz et al, investigated the self-ignition behavior of the accumulation of sludge dust and sludge pellets from the sewage sludge thermal drying station and found that sludge pellets have longer induction times and higher self-ignition temperatures than sludge dust, confirming that sludge after pelletization is safer for long-term storage. The smallest basket volume yielded the highest self-ignition temperatures. The temperature of the sludge pellets was 186 °C, whereas the temperature of the sludge dust was 26 °C lower. The obtained self ignition temperature values decrease with decreasing material content and are lowest for the largest basket volume (160 °C and 142 °C for sludge pellets and sludge dust, respectively) [10]. The self-ignition of dusts and solid bulk materials is important in process safety, and several variables on the self ignition temperature have not been thoroughly researched. The results of the influence of oxygen concentration in the surrounding environment, heat of wetting, evaporation and condensation of water in the bulk material on the self-ignition technique are presented in this paper. It has been discovered that the SIT for dusts and bulk materials increases when the oxygen level in the surrounding environment decreases. Furthermore, no oxygen concentrations were discovered in German lignite coal where self-ignition was present. Oxidation reactions were seen even with substantially reduced oxygen levels of 3 and 1.3% in the specimen's surroundings. At these oxygen concentrations, the reaction mechanism changed, resulting in substantially longer oxidation durations and lower oxidation temperatures. As a result of the heat storage tests, distinguishing between ignition and non-ignition became more difficult because not all of the material was transformed. Water, in addition to the oxygen concentration of the environment, regulates the self ignition temperature. Experiments revealed that wetness can transform a sub-critical dust deposit into a super-critical deposit, eventually resulting in an ignition. Pouring can thereby reduce the self ignition temperature of a given volume [11].

## **2 Materials and method**

### **2.1 Material**

Were performed tests to determine the self-ignition temperature for two samples, collected from economic agents, respectively:

- sample 1 – metal waste from the automotive industry, derived from aluminium and steel shot blasting;
- sample 2 – coke from the petrochemical industry, shown in Figure 1. The samples used were representative, obtained under normal operating conditions of the process.



**Fig. 1.** Sample tests

## 2.2. Experimental methods

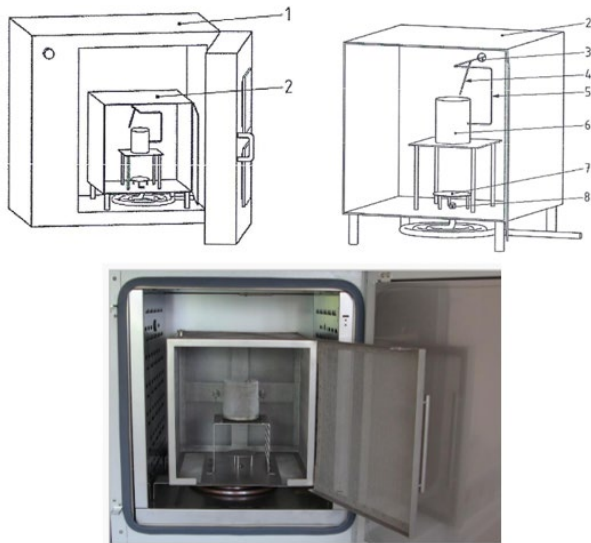
The basic experimental principle used to describe the self-ignition behaviour of a dust is to determine the self-ignition temperature of dust masses with different volumes, by steaming experiments in isoperibolic conditions (storage at constant oven temperatures) inside a heating oven. The dust sample is placed freely in baskets made of wire mesh of different sizes with a spatula, without compressing and levelling on top. The baskets are open at the top and closed at the bottom. The mesh size was chosen so that the dust could not fall through the net, but at the same time not prevents the diffusion of oxygen from the air supply system of the oven inside the dust sample [6, 8]. The volumes used for this study were: 100 cm<sup>3</sup>, 375 cm<sup>3</sup> and 785 cm<sup>3</sup>. These chimneys were placed in the center of the preheated oven at the test temperature.

Two temperature measurements are made during a test:

- oven temperature, with a thermocouple freely installed in the air space at half distance between the sample surface and the inner wall of the oven,
- sample temperature, with a thermocouple located with its hot junction directly at the centre of the sample. If sample temperature, after an induction delay, grows abruptly and rises at least 60 K above the oven temperature, it is considered that self-ignition is occurring [8, 12].

When a layer of dust is lit, a fire breaks out. A dust fire can turn into a dust explosion. On the other hand, the ignition of a cloud of dust can lead to an explosion which, unlike a fire, is associated with pressure changes (generally very rapid) and the sudden development of heat. This exceptionally violent reaction is responsible for the specific hazards associated with a dust explosion. In general, solid materials with high specific surfaces are the only ones that can spontaneously ignite or burn. As long as the air exchange is sufficiently high, which must be anticipated for the start of a self-ignition process, oxygen can react on the surfaces throughout the bulk [5, 7].

The experimental setup used to perform the tests is performed in accordance with the requirements of the standard SR EN 15188: 2008, and is shown in Figure 2.

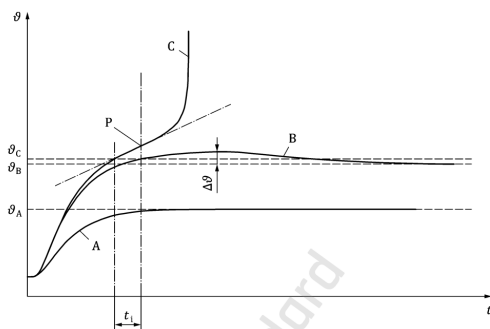


**Fig. 2.** Experimental assembly for hot steaming tests  
1 - heating oven; 2 - inner enclosure; 3 - air outlet, diameter = 10 mm air inlet (preheated air, flow); 4 - thermocouple for temperature measurement; 5 - thermocouple for measuring the sample temperature; 6 - wire mesh cylinder, with dust sample; 7 - deflector

Thermocouples with a protective coating with an outer diameter of approximately 1 mm and a data acquisition system corresponding to the recording of signals from thermocouples were used to measure and record the temperature of the sample and the oven.

To determine whether or not self-ignition occurs, there are two methods:

- a. When the temperature in the center of the sample rises by at least 60 K above the oven temperature;
- b. When the temperature in the center of the sample shows an inflection point, relative to time, if it appears above the oven temperature, figure 3 [12].



Legend:  $\theta$  temperature,  $t$  duration of the test, P inflection point

**Fig. 3.** Ideal time-varying temperature variation curves for dust samples of the same volume at different evaporation temperatures

If working at significantly lower temperatures, the sample temperature will approach asymptotically the oven temperature (curve A).

At higher oven temperatures, significant reactions with oxygen take place in the dust mass, the sample temperature will be temporarily higher than the oven temperature and the

self-heating process will start, without igniting the sample. Thereafter, the sample temperature decreases to the oven temperature (curve B).

The heat production in the sample has reached a point where it continuously exceeds the heat loss (through heat conduction, convection and radiation). After an induction time, the sample temperature rises rapidly until self-ignition occurs (curve C).

The self-ignition temperature is between the furnace temperatures of curves B and C.

For each test, the time interval between placing the sample in the oven and reaching the steaming temperature and the total steaming time was recorded. In addition, the time interval between reaching the steaming temperature and ignition was recorded, reaching the maximum temperature [12].

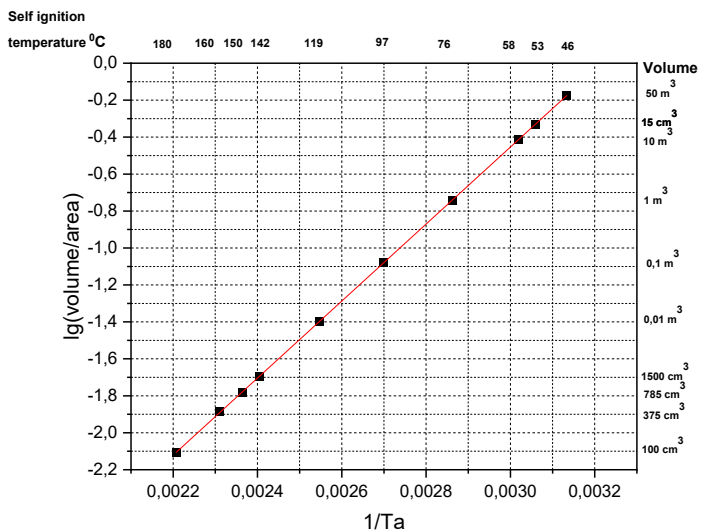
### 3 Results and discussions

The particle size distribution analysis showed that the minimum particle size is 63  $\mu\text{m}$  and the maximum is 800  $\mu\text{m}$ . The particles in a size over 800  $\mu\text{m}$  represent 1% of dust, which is the rarest frequency of particle sizes. The most frequent particle sizes are in the range of 200 – 400  $\mu\text{m}$  (60 %). Particle size influences the self-ignition temperature. The decrease of the self ignition temperature with the decrease in the particle size of the wheat biomass was observed by Restuccia et al. [13]. The results showed that the self-ignition temperature slightly decreases with the particle size. However, the higher bulk density of the sludge pellets may be a reason for the offsetting particle size effect due to the larger amount of fuel for a given basket volume.

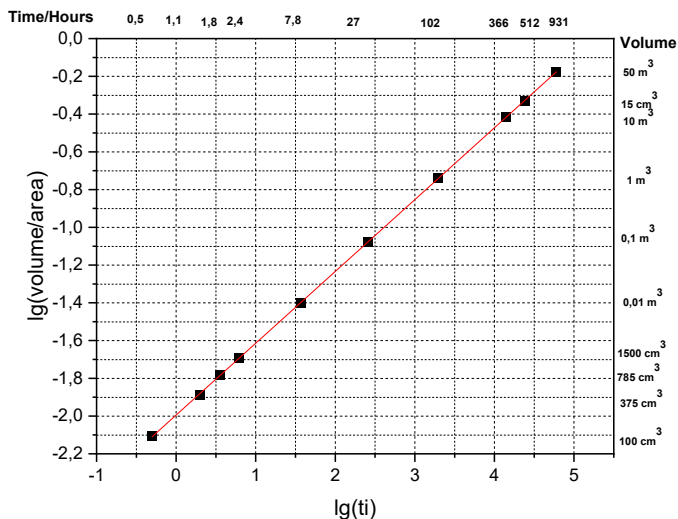
Following the analysis, the results presented in the tables 1 and 2 below were obtained experimentally. The obtained results were extrapolated following the indications in the method standard EN 15188:2008 and the results are given the graphs from the figures 4 – 7:

**Table 1.**

<i>Characterization of the sample</i>	<i>Dust volumes tested (cm<sup>3</sup>)</i>	<i>Self-ignition temperature (°C)</i>	<i>Induction time (hours)</i>
Sample 1 Metal waste	100	180	0,5
	375	160	1,1
	785	150	1,8



**Fig. 4.** Graphical representation of ignition temperatures after Arrhenius



**Fig. 5.** Dependence of the induction time of combustion (ti) on the volume/surface ratio

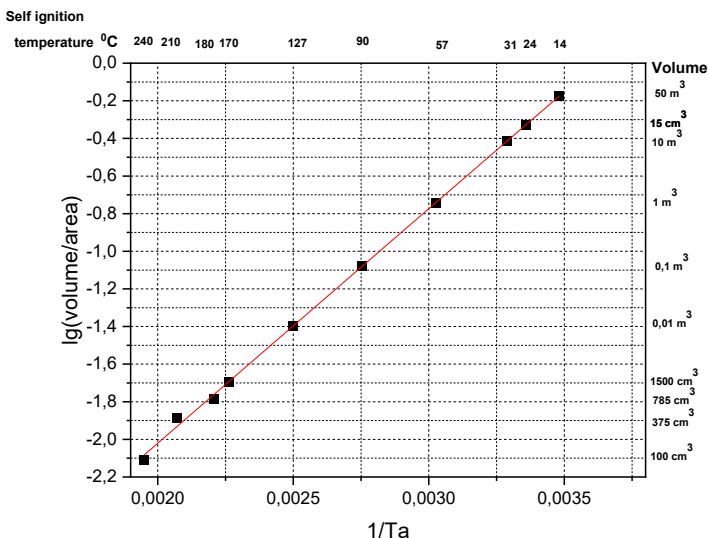
Interpretation of graphs:

A cylindrical volume of 1 m<sup>3</sup> of metal waste has a self-ignition temperature higher than 76°C. If this volume of dust is stored at this constant temperature, 4 days will elapse before an ignition could occur.

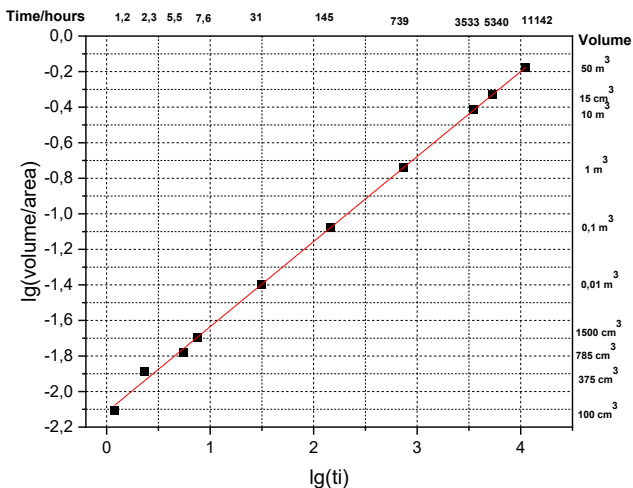
A cylindrical volume of 0.1 m<sup>3</sup> of metal waste has a self-ignition temperature higher than 97°C. If this volume of dust is stored at this constant temperature, 1 day will elapse before an ignition could occur.

**Table 2.**

<i>Characterization of the sample</i>	<i>Dust volumes tested (cm<sup>3</sup>)</i>	<i>Self-ignition temperature (°C)</i>	<i>Induction time (hours)</i>
Sample 2 Coke	100	240	1,2
	375	210	2,3
	785	180	5,5



**Fig. 6.** Graphical representation of ignition temperatures after Arrhenius



**Fig. 7.** Dependence of the induction time of temperatures after Arrhenius

Interpretation of graphs:

A cylindrical volume of 1 m<sup>3</sup> of coke has a self-ignition temperature higher than 57°C. If this volume of dust is stored at this constant temperature, about 31 days will elapse before an ignition could occur.



A cylindrical volume of 0.1 m<sup>3</sup> of coke has a self-ignition temperature higher than 90°C. If this volume of dust is stored at this constant temperature, 6 days will elapse before an ignition could occur.

Self-ignition of bulk dust is caused by the rate of heat production, oxidation and / or decomposition reactions of the dust, which is higher than the rate of heat loss.

In general, self-ignition or spontaneous combustion is limited to the contact of solids with high specific surfaces. Oxygen can react on surfaces in the entire amount, as long as the air exchange is large enough. The oxidation process can begin at room temperature depending on the substance.

## 4 Conclusions

Even if the dust industry takes every precaution, there are frequently circumstances that result in fatalities and major property damage. Self-ignition, or fires caused by dust accumulations, is therefore thought to be the primary cause of such events throughout the drying operations.

A frequent source of ignition in the storage of bulk materials, like dusts and powders, is self-ignition. The experimental determination of the critical self-ignition temperatures as a function of volume is necessary for the assessment of this ignition hazard, which takes into consideration the manufacturing or storage conditions.

For the metal waste sample was obtained for a 50 m<sup>3</sup> volume a temperature of 46 °C while for the coke sample was obtained for the same volume a much lower temperature of 14 °C, this finding suggesting that it is very important to investigate experimentally every combustible dust that can be accumulated in bulk, due to the composition of the dust mainly.

The experimental results demonstrated that the investigated dusts are flammable, and based on the graphs produced, safety precautions can be implemented to prevent unintentional fires and explosions.

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