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Experimental study of Ignition of Bulk Storage by Hot Points

JANES A.

Institut National de l'Environnement Industriel et des Risques (INERIS)

Parc ALATA BP 2 – 60550 VERNEUIL EN HALATTE - FRANCE

agnes.janes@ineris.fr

CHAIANEUX J., CARSON D., BENAÏSSA W.

Institut National de l'Environnement Industriel et des Risques (INERIS)

Parc ALATA BP 2 – 60550 VERNEUIL EN HALATTE - FRANCE

jacques.chaineaux@ineris.fr, douglas.carson@ineris.fr, wassila.benaïssa@ineris.fr

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Abstract

Fire and explosion risk is generated by chemical or biological oxidation of combustible materials. An experimental study of ignition risk due to hot points in the storage of bulk materials is required to ensure fire safety. Many parameters are involved in this phenomenon: nature of the material, storage volume and temperature, type and size of hot point, etc.

The aim of this study is to describe an adapted experimental procedure to determine critical ignition temperatures of powders for different conditions and with several types of hot points. Material selected for this study is a powder of « Lucy coal ». Ignition is carried out in 1000 and 2700 cm³ cubic baskets for two sizes of inert cylinders at a given temperature and for an inert sphere at a given initial temperature.

The critical ignition temperature is defined as the hot point temperature in the middle of a 5°C interval of both temperatures: 1) ignition and 2) no ignition. First results demonstrate that the set-up procedure is relevant. Critical temperatures measured for both cylinders and for the sphere are in the same range. Discrepancies between the results obtained under these three test conditions have been explained by different basket sizes and hot points geometry.

Data obtained need now to be compared to available theoretical modelling. These results will then allow predicting material behaviour under other storage conditions.

1. Introduction and overview

Fire and explosion risk is generated by chemical or biological oxidation of combustible materials. Self-ignition concerns exothermic oxidation reactions and occurs when the heat produced by oxidation is greater than that dissipated in the environment by storage surfaces. Then, the temperature increase may lead to a fire, sooner or later. The self-ignition phenomenon depends essentially on three parameters: 1) material temperature, 2) ambient temperature and 3) storage size.

Experimental characterization of self-ignition hazards in storage spaces is performed by thermal analysis of the material. Self-ignition tests in isothermal ovens lead to the critical storage size as a function of storage temperature, for a given shape. Test results are extrapolated to industrial scale by modelling using the Frank-Kamenetskii theory.

Studies on self-heating were performed in the 1920s by Semenov. They were completed in the 1950s-1960s by Frank-Kamenetskii [1].

Semenov considered a homogenous temperature in the whole volume (fig. 1). This model involves geometrical characteristics of storage spaces such as surface area and volume. However, it is not valid for large storage spaces, since it does not take into account the inner and outer thermal gradients of the material.

Frank-Kamenetskii theory is more precise. It includes the heat transfer resistance in the material. Frank-Kamenetskii considers that heat transfer is due to conduction inside the material, and is linked to an ideal convection at the outer surface. This model involves geometrical characteristics of the storage space and the thermal conductivity of the material.

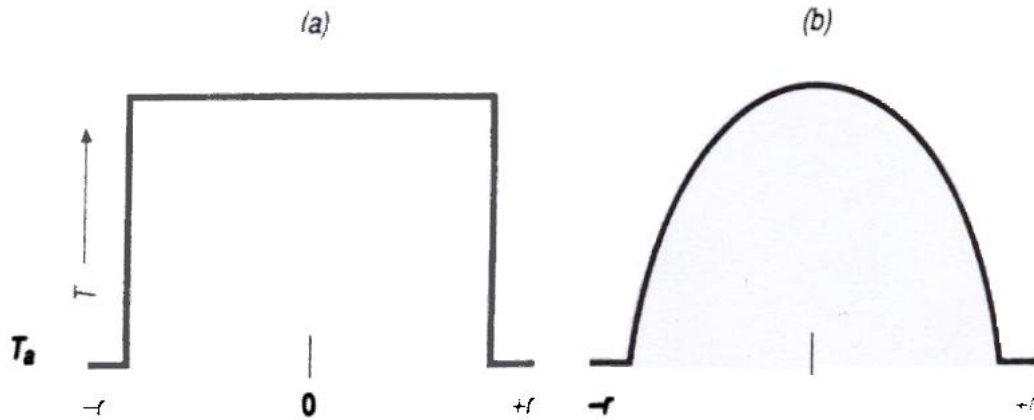


Figure 1: Shape of theoretical temperatures in Semenov (a) and Frank-Kamenetskii (b) models, from [1]

Frank-Kamenetskii's theory does not take into account the surface heat resistance, unlike Thomas and Bowes's theory [2]. Indeed, Thomas and Bowes consider simultaneously the heat transfer resistance into the material and the surface heat resistance. This model is the most complete and introduces the thermal conductivity of the material, the shape and finally convection and radiation parameters at the interface, using the Biot number (α). It corresponds to the ratio of conduction and convection coefficients.

In the case of heating by a hot spot, the initial heat contribution is not due to self-heating. Particularly four examples can be found in industrial situations [3]:

1. Hot spot of inert material at a given initial temperature introduced into powder storage. It can be metal particles introduced accidentally in a hot storage or mechanical sparks,
2. Hot spot of combustible material at a given initial temperature introduced into powder storage. This can be linked to a part of the storage locally overheated because of a failure of temperature regulation of a dryer, or even a cigarette butt,
3. Hot spot of inert material maintained at a given temperature. This corresponds to a limit case of the first two points: very high heat capacity of the inert material or reaction rate of the oxidation limited by oxygen diffusion. This could correspond to the case of surfaces heated by outside: welding or an electrical equipment,
4. Hot spot of inert material that generates a constant heat flow. This can be due to electrical devices.

The major difference between the self-heating and the heating by hot spot is the presence of the heat source term, which is different from the chemical oxidation term, in the heat balance.

The objective of the experimental device is to establish the relation between the bulk material storage space size and the temperature of the hot point placed on the centre.

2. Experimental

The critical ignition temperature by hot spots is determined in 1000 and 2700 cm³ cubic baskets. Tests are performed into a 125 L ventilated oven, regulated at ambient temperature.

The tested material is a coal, so called “Lucy coal” (median particle size: 28 µm; humidity: 0 %). The cubic baskets are made, except their upper face, of 10 µm wire mesh. This is sufficiently fine to avoid sieving, but do not restrain the oxygen diffusion.

Hot spots used are:

- Cylindrical heating cartridges of 6.5 mm or 10 mm diameter heated by Joule effect and connected to a power supply
- A steel sphere of 30 mm diameter, preheated in a oven

Each test is performed using a clean and dry cubic basket. The amount of coal introduced in the basket is weighted. Then, the coal is introduced into the basket, without compaction.

In the case of heating cylinders, they are introduced into the full basket. Then, six 1 mm K-thermocouples are placed inside the coal on the appropriate locations (fig. 2).

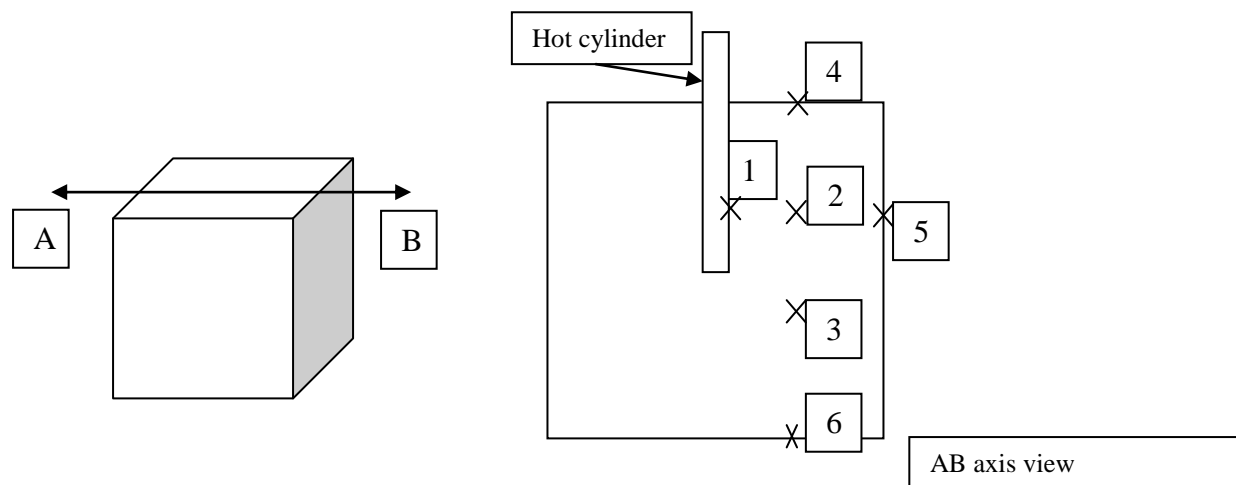


Figure 2: Location of temperature measurement points inside the coal - tests with heating cylinders

In the case of the heated sphere, four 1 mm K-thermocouples are placed into the basket before introduction of the coal sample and the sphere (fig. 3). This prevents the cooling of the heated sphere. The sphere is heated in a furnace regulated at 450°C. When the test temperature is reached, the sphere is then moved over in the full basket.

After the start of the test, the temperatures into the basket are measured as a function of time. When the temperatures increase dramatically and go over the hot point for at least 50°C, it can be considered that an ignition occurs.

When the temperatures grow up and go over hot point temperature, but stabilize in a plateau at the hot point temperature, ignition does not occur.

The critical ignition temperature is the hot point temperature in the centre of a 5°C interval of the 2 temperatures: 1) ignition and 2) no ignition.

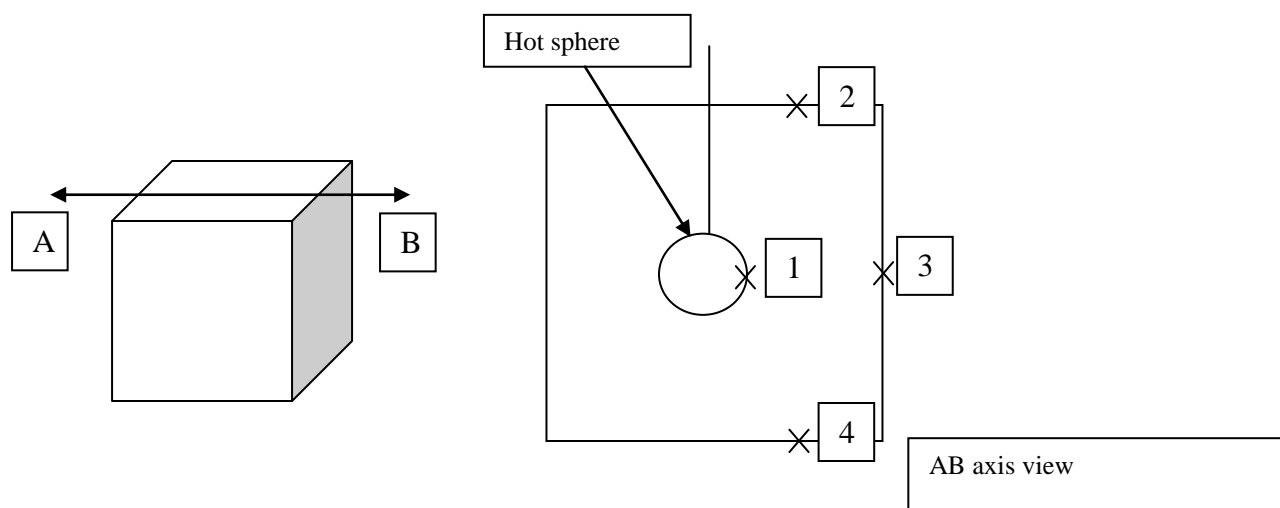


Figure 3: Location of temperature measurement points into the coal - tests with hot sphere

3. Results

Tests performed appears in tables 1 and 2.

Table 1. Tests performed with heating cylinders

N°	Cylinder diameter (mm)	Cylinder temperature (°C)	Basket volume (cm3)	Oven temperature (°C)	Initial weight (g)	Final weight (g)	Loss of weight (%)	Result: ignition ?
1	6.5	300	2700	27	2030	850	58	yes
2	6.5	200	2700	27	2030	2030	0	no
3	6.5	250	2700	27	2030	2030	0	no
4	6.5	270	2700	27	2030	2030	0	no
5	6.5	285	2700	27	2030	847	58	yes
6	10	280	2700	27	2030	865	57	yes
7	10	270	2700	27	2030	872	57	yes
8	10	260	2700	27	2030	2030	0	no
9	10	265	2700	27	2030	2030	0	no

Table 2. Tests performed with heated sphere

N°	Sphere diameter (mm)	Initial sphere temperature (°C)	Basket volume (cm3)	Oven temperature (°C)	Initial weight (g)	Final weight (g)	Loss of weight (%)	Result: ignition ?
10	30	Not measured	1000	27	536	192	64	yes
11	30	290	1000	27	536	133	75	yes
12	30	280	1000	27	536	134	75	yes
13	30	240	1000	27	536	536	0	no
14	30	270	1000	27	536	536	0	no

The evolution of measured temperatures is recorded on figures 4 to 7, given as examples.

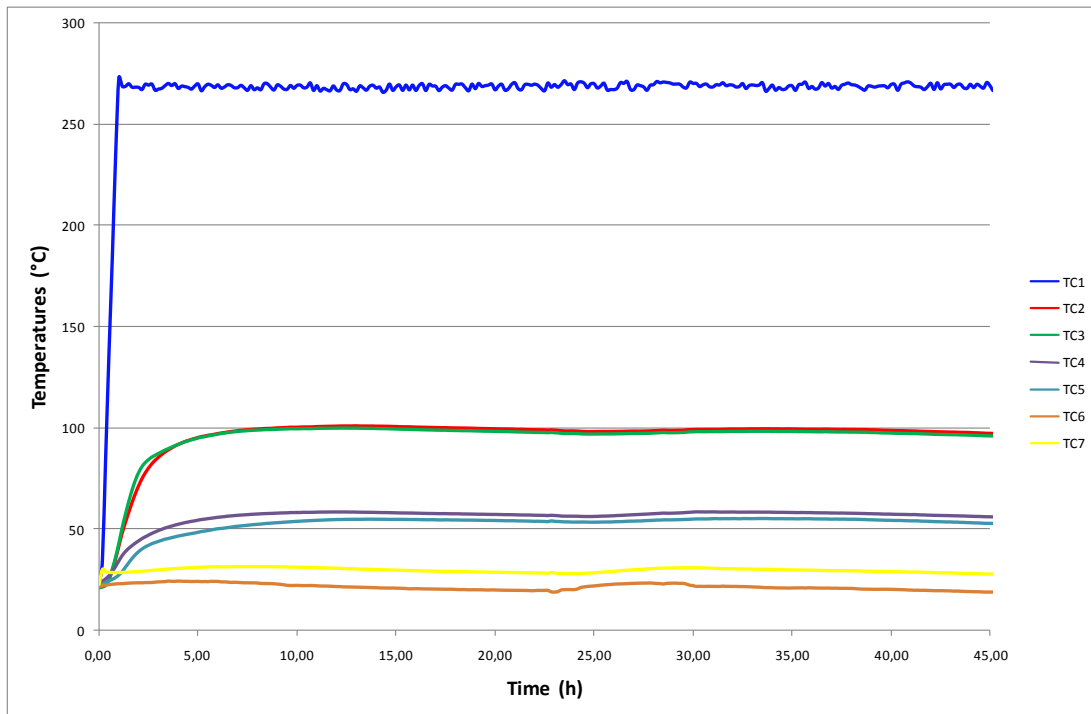


Figure 4: 2700 cm³ cubic basket, 6.5 mm cylinder heated at 270°C (TC1 to TC6: see fig. 2; TC7: inside oven temperature)

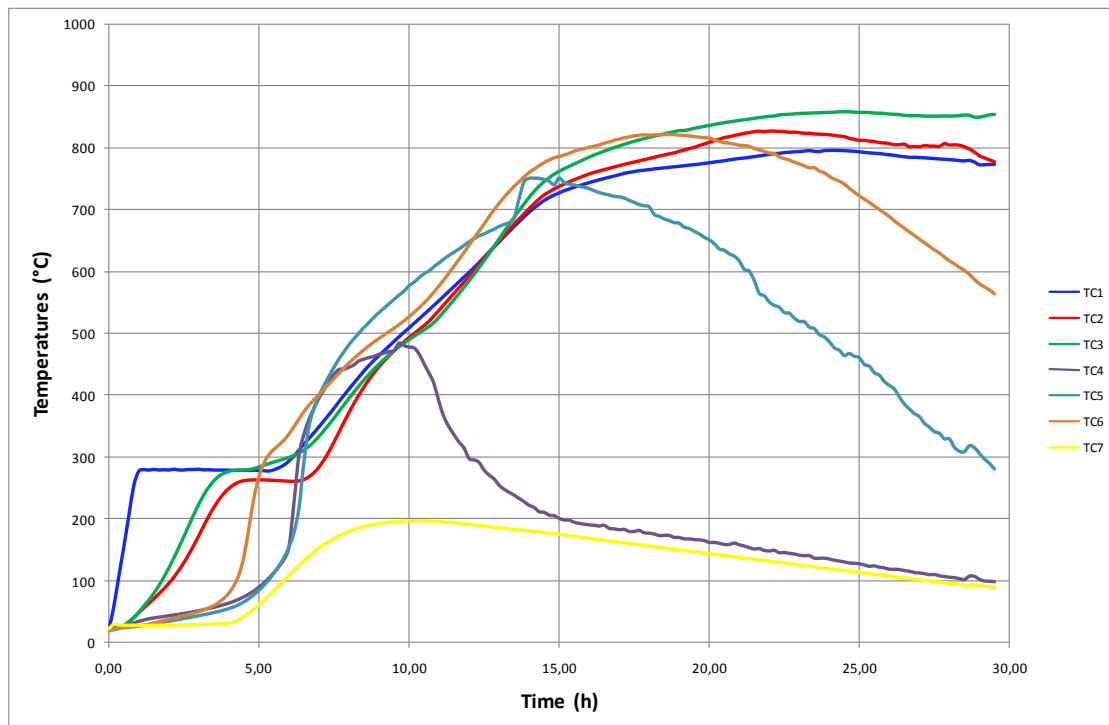


Figure 5: 2700 cm³ cubic basket, 6.5 mm cylinder heated at 285°C (TC1 to TC6: see fig. 2; TC7: inside oven temperature)

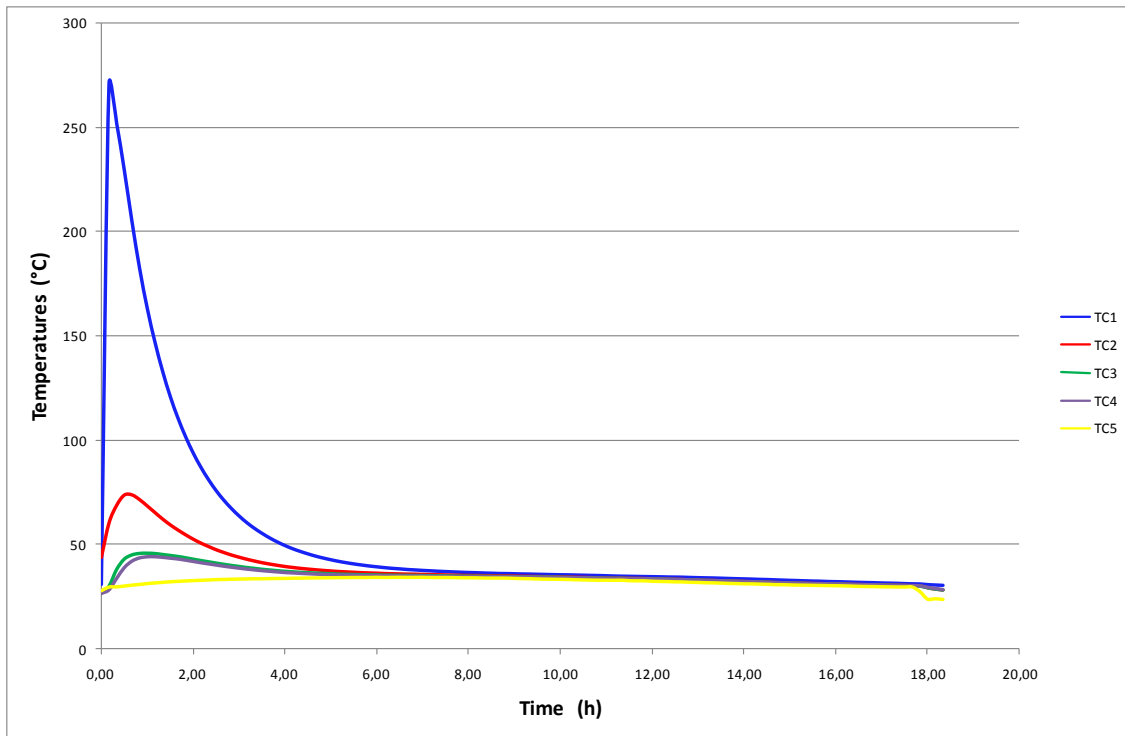


Figure 6: 1000 cm3 cubic basket, 30 mm sphere heated at 270°C (TC1 to TC4: see fig. 3; TC5: inside oven temperature)

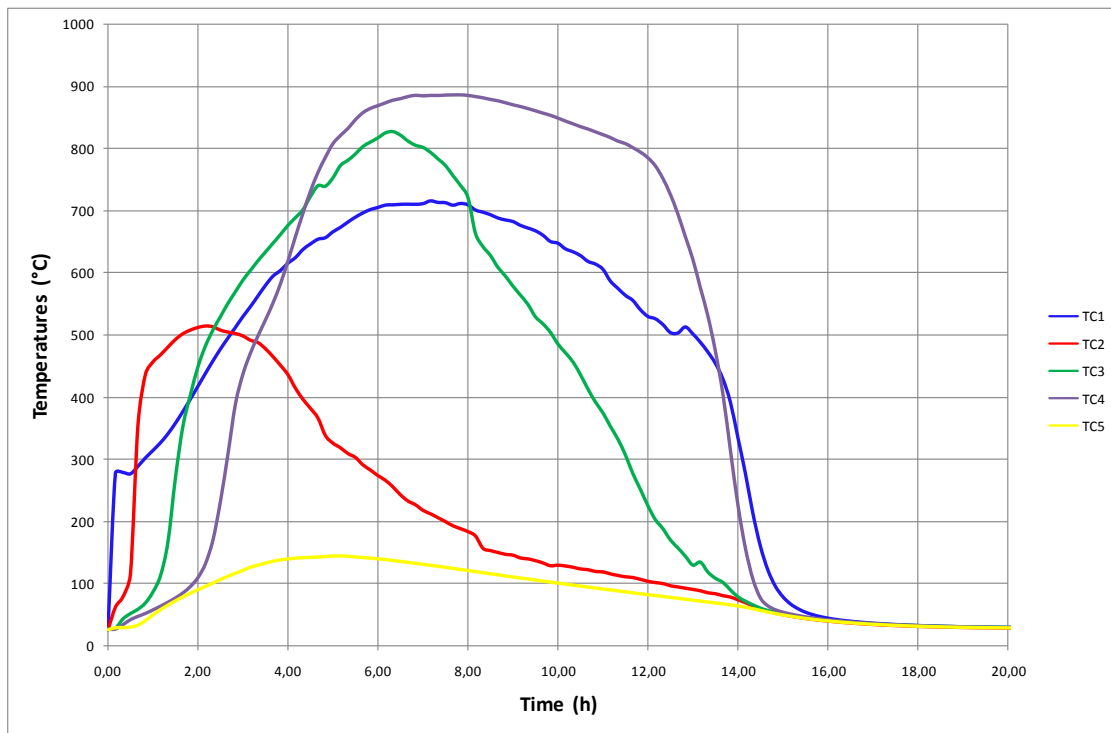


Figure 7: 1000 cm3 cubic basket, 30 mm sphere heated at 280°C (TC1 to TC4: see fig. 3; TC5: inside oven temperature)

4. Discussion

The aim of the experimental set-up is to determine critical ignition temperatures of powders under different conditions and with several types of hot points. The first results demonstrate that this protocol is relevant. Critical ignition temperatures obtained for both cylinders and sphere are in the same range.

When ignition occurs, the higher the temperature of the hot point, the shorter the induction time, likewise for the delay between the start of the test and the moment at which the nearest thermocouple reached the temperature of the hot point. Nevertheless, the induction time is shorter for the tests with the sphere than for the tests with the cylinders. This result corresponds to the fact that the basket used with the sphere is about three times smaller than the basket used with the cylinders.

The critical ignition temperature determined for the larger cylinder is lower than that obtained with the smaller one. This can be explained by the greater amount of energy transfer when the area of the hot point increases, at a given temperature.

When no ignition occurs, the temperatures measured evolved as a function of time and always have the same shape. However, the closer the measurement point to the hot point is, the higher the temperature. However, the temperature of the hot point is never reached in the coal, which is believed to always be less than 100 °C. The sample weight does not decrease during these no-ignition tests, which indicates that no runaway phenomenon occurs.

5. Conclusion

The aim of this paper was to describe an adapted experimental protocol to determine critical ignition temperatures of powders under different conditions and with several types of hot points.

The first results demonstrate that this protocol is relevant. The critical ignition temperatures for “Lucy coal” powder obtained are:

- Between 270 and 285 °C for inert 6.5 mm diameter cylinder at a given temperature in a 2700 cm³ cubic basket
- Between 265 and 270 °C for inert 10 mm diameter cylinder at a given temperature in a 2700 cm³ cubic basket:
- Between 270 and 280 °C for inert 30 mm diameter sphere at a given initial temperature in a 1000 cm³ cubic basket:

Discrepancies between the results obtained under these three test conditions have been explained considering basket sizes and hot points geometry. However, other test conditions should be experimented to acquire more data. For example, the ignition using an inert hot point at a given heating flow or using a combustible hot point at a given initial temperature was not tested.

These different test conditions will allow the simulation of industrial situations of incident such as the presence of an appliance power supplied or an incandescent particle in a storage space like a silo. It will then be possible to compare data obtained to available theoretical modelling.

6. References

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