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Effect of Inerts on Ignition Sensitivity of Dusts

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This work studies the influence of added inert dust on the ignition sensitivity of the combustible/inert dust mixture.
Different types of combustible dust of various sizes, such as coal, powdered sugar, lycopodium, anthraquinone, rice and coffee husks, beech wood flour or ground coffee were mixed with alumina and kieselguhr before being tested. Parameters measured were 1) minimum ignition temperature (MIT) in 5 mm layer, 2) minimum ignition temperature in cloud (Godbert-Greenwald oven) and 3) minimum ignition energy (MIE) (in a Kühner-Mike 3 apparatus).
It appears from this study that the MIT in 5 mm layer is strongly influenced by an inert fraction ≥ 60 % (weight). There is also a significant increase in MIT in cloud form when the fraction of inert dust exceeds 60 % (weight). This threshold is a function of the bulk density of the inert substance selected for these tests.
However, in cases where the density of the inert dust is different from that of the combustible dust, there appears to be a separation of the two constituents of the mixture after its pneumatic dispersion during the test. As a consequence, the influence of inert dust is less pronounced in the case of MIT for dust clouds than for the MIT of a dust layer. A similar phenomenon is observed for the MIE of dust clouds.

1. Introduction

The effect of the admixed inert material on the ignition temperature of a dust layer was studied in the past, for example in the specific cases of coal (Reddy, 1998) or zirconium powder (Bideau et al., 2011). These works on combustion of dust accumulations are partially based on the self-heating theory, introduced in the 1920s by Semenov and complemented by Frank-Kamenetskii (1969) and Bowes (1984). Some models have been developed (El Sayed and Abdel-Latif, 2000; Krause and Schmitt, 2001) in order to predict the initiation and the propagation of smouldering combustion of a dust layer on a hot surface.
Assessing the risk of fire or explosion of an explosive atmosphere (ATEX) in a process where combustible dust is present is based in part on identifying potential ignition sources.
The ignition sensitivity of combustible dust can be characterized by measuring the minimum ignition temperatures (MIT) of a dust cloud or for dust layers and the minimum ignition energy (MIE) for dust clouds. The MIT is used to evaluate the probability of ignition by hot surfaces, like a furnace, or moving parts being heated by friction, whereas MIE provides information on which types of sparks can be considered as ignition sources. If the MIE is sufficiently low, electrostatic sparks are likely to ignite a dust cloud. These elements are very important to consider insofar as electric and electrostatic sparks are identified as the most frequent ignition sources for dust explosions occurring in the workplace.
Moreover, solid inert materials are commonly used in dust explosion prevention and mitigation, in inerting systems or in explosion suppression devices (Amyotte, 2005).

2. Experimental

Material tested and methods used are described below.

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2.1 Materials tested

The combustible bulk materials selected for these tests are listed in Table 1, and inert materials used are listed in Table 2. Their characteristics have been measured at INERIS.

Table 1: List of combustible materials selected for the tests

Material	Particle size	Humidity	Bulk density
Lucy coal	Median: 29 μm (LASER diffraction)	1.4 rel. %	0.51 g/cm^3
Rice and coffee husks	Median: 50 μm (LASER diffraction)	10.1 rel. %	0.33 g/cm^3
Bran	Median: 208 μm (LASER diffraction)	7.7 rel. %	0.26 g/cm^3
Ground coffee	83% > 315 μm (sieving)	2.6 rel. %	0.31 g/cm^3
Lycopodium	Median: 30 μm (LASER diffraction)	3.5 rel. %	0.30 g/cm^3
Anthraquinone	Median: 33 μm (LASER diffraction)	0.2 rel. %	0.40 g/cm^3
Powdered sugar	Median: 23 μm (LASER diffraction)	3.6 rel. %	0.55 g/cm^3
Beech wood flour	Median: 20 μm (LASER diffraction)	2.4 rel. %	0.38 g/cm^3

Table 2: List of inert materials used for combustible/inert mixtures

Material	Particle size	Humidity	Specific heat (mean value between 40 and 250 °C)	Bulk density
Alumina	Median: 87 μm (LASER diffraction)	0.2 rel. %	0.921 $J.g^{-1}.K^{-1}$	0.90 g/cm^3
Kieselguhr	Median: 21 μm (LASER diffraction)	0.7 rel. %	2.189 $J.g^{-1}.K^{-1}$	0.18 g/cm^3

2.2 Minimum ignition temperatures measurement

The minimum ignition temperatures (MIT) in 5 mm layer and in cloud were performed using the EN 50281-2-1 (ECS, 2000) methods A and B. INERIS test apparatuses are presented on Figure 1.

The MIT of a dust layer is defined as the lowest temperature of a hot plate at which the ignition of a dust layer of a specified thickness occurs. An ignition is considered to have occurred if during the test glowing or flames are observed, or if a temperature higher than or equal to 450 °C or a temperature increase higher than or equal to 250 K is measured in the tested material.

The MIT of a dust cloud is defined as the lowest temperature of the inner wall of a heated oven at which the ignition of a cloud of the tested material dispersed into the oven occurs. This test is performed in a “Godbert-Greenwald” oven, and consists in blowing different mass of dust in the heated oven with different air pressure values, and observing an ignition or not. MIT of a 5 mm layer and of a dust cloud were measured with an accuracy of 10 °C.

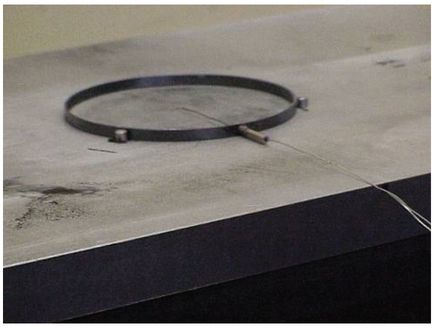

Figure 1: View of INERIS MIT of a layer (left) and of a cloud (right) testing apparatuses

2.3 Minimum ignition energy measurement

The minimum ignition energy (MIE) is defined as the lowest electrical energy stored in a capacitor which upon discharge is just sufficient to effect ignition of the most ignitable mixture of a given dust under specific test conditions.

The MIE were measured using an electric spark igniter (MIKE 3 apparatus, from KÜHNER), according to a protocol similar to that defined in EN 13821 standard (ECS, 2003). The dust is pneumatically dispersed within a vertical tube open at the top. The ignition is provided by an electric spark initiated within the cloud between two electrodes separated by a 6 mm gap. The electrical energy is stored in electrical capacitors associated to the tube. The diagnosis of inflammation is visual: propagation of a flame or not. The parameters that are varied during a test are the delay between the dust dispersion and the ignition spark (60, 120 and 180 ms are used), the weight of dust deposited on the bottom of the tube (a range from 150 to 3600 g were explored) and the energy stored in the capacitors (values available are 1, 3, 10, 30, 100, 300 and 1000 mJ) and delivered between the two electrodes. The minimum ignition energy MIE lies between the highest energy at which ignition fails to occur in 5 successive attempts to ignite the dust/air mixture, and the lowest energy at which ignition occurs within up to 5 successive attempts. For the purpose of comparison between different combustible/inert mixtures, instead of the energy range defined above, only one single value, estimated by use of the probability of ignition as specified in EN 13821 standard (ECS, 2003) was used.

3. Results

Tables 3 to 5 summarize the tests conducted in this work and the results obtained, while Figures 2 to 7 present the results obtained, expressing the inert concentration in the mixture in vol. %, calculated according bulk density values.

Table 3: List of MIT in 5 mm layer tests performed and results obtained

Sample	Inert material	Inert composition of the combustible/inert mixture (Weight %) (* Not measured)					
		0	20	40	50	60	80
Lucy coal	Alumina	280	320	360	380	400	*
Lucy coal	Kieselguhr	280	340	350	400	>400	>400
Rice and coffee husks	Alumina	280	290	290	*	310	400
Rice and coffee husks	Kieselguhr	280	290	300	*	310	400
Beech wood flour	Alumina	270	290	300	*	320	350
Beech wood flour	Kieselguhr	270	310	320	*	330	390
Bran	Alumina	340	370	390	400	>400	>400
Ground coffee	Kieselguhr	290	300	320	320	400	*

Table 4: List of MIT in cloud tests performed and results obtained

Sample	Inert material	Inert composition of the combustible/inert mixture (Weight %) (* Not measured)					
		0	20	40	50	60	80
Lucy coal	Alumina	640	630	640	*	640	>800
Lucy coal	Kieselguhr	640	630	640	*	670	>800
Rice and coffee husks	Alumina	460	490	510	*	530	>800
Rice and coffee husks	Kieselguhr	460	480	490	*	540	630
Bran	Alumina	460	460	460	*	490	550
Bran	Kieselguhr	460	460	480	*	490	530
Ground coffee	Alumina	470	510	520	*	530	710

Table 5: List of MIE tests performed and results obtained

Sample	Inert material	Inert composition of the combustible/inert mixture (Weight %) (* Not measured)					
		0	20	40	50	60	80
Beech wood flour	Alumina	22	17	16	*	60	>1000
Beech wood flour	Kieselguhr	22	21	82	*	800	>1000
Lycopodium	Alumina	21	24	22	*	23	17
Lycopodium	Kieselguhr	21	13	19	*	41	570
Anthraquinone	Alumina	1.7	1.7	24	*	22	71
Anthraquinone	Kieselguhr	1.7	8	8	*	17	190
Powdered sugar	Alumina	4	13	7	*	26	>1000

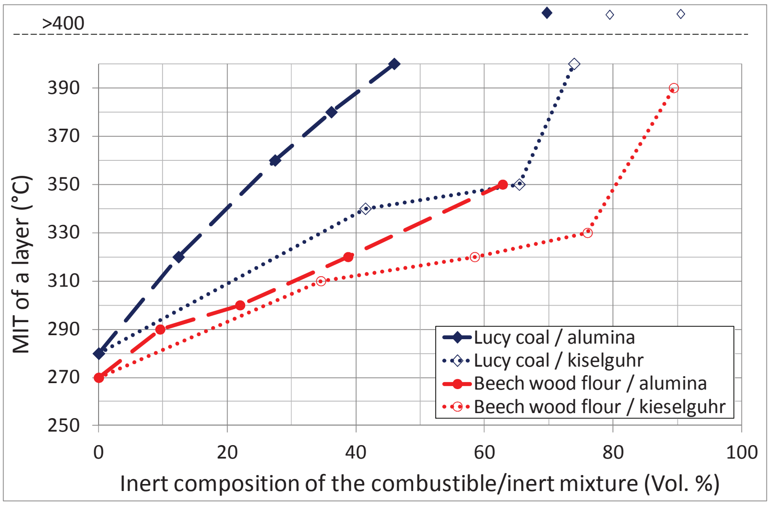

Figure 2: Lucy coal and beech wood flour MIT in 5 mm layer, as a function of inert concentration in vol. %

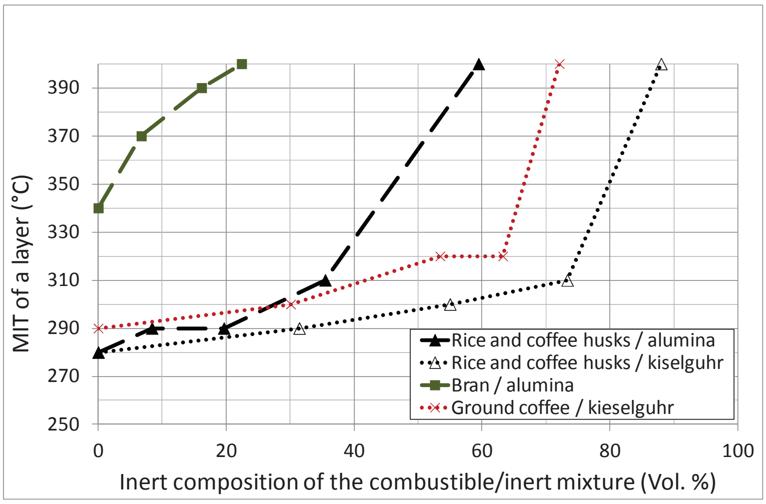

Figure 3: Rice and coffee husks, bran and ground coffee MIT in 5 mm layer, as a function of inert concentration in vol. %

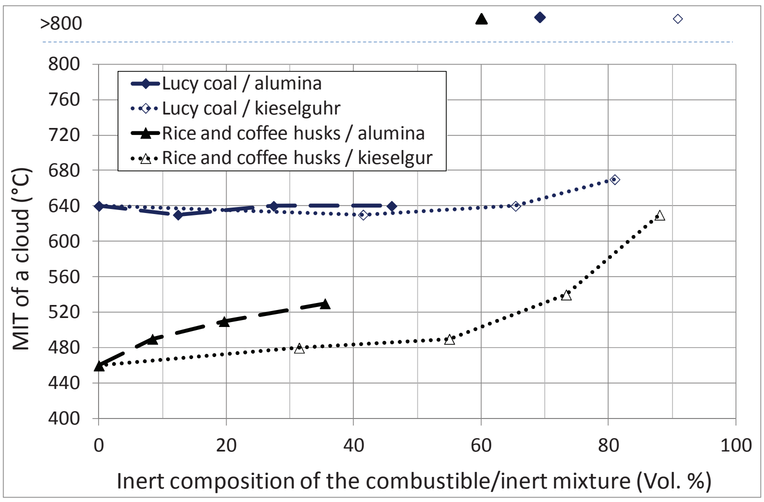

Figure 4: Lucy coal and rice and coffee husks MIT in cloud, as a function of inert concentration in vol. %

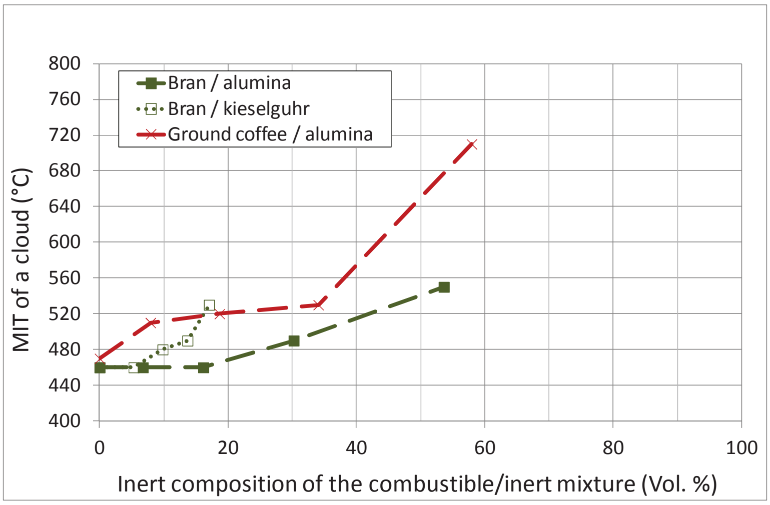

Figure 5: Bran and ground coffee MIT in cloud, as a function of inert concentration in vol. %

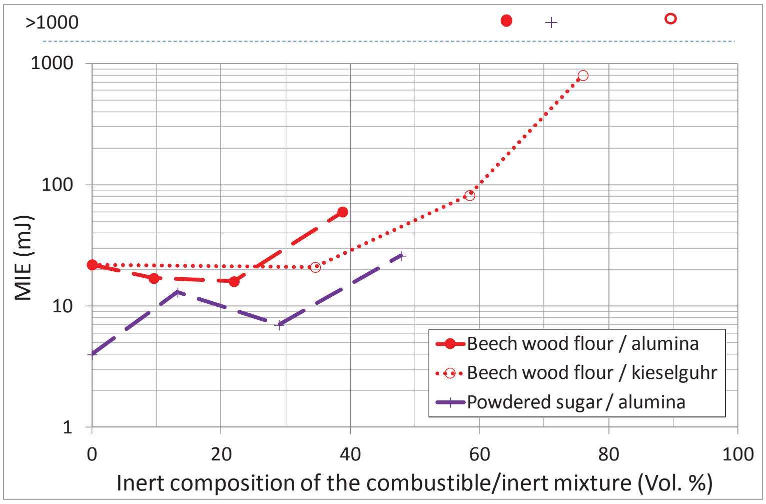

Figure 6: Beech wood flour and powdered sugar MIE in cloud, as a function of inert concentration in vol. %

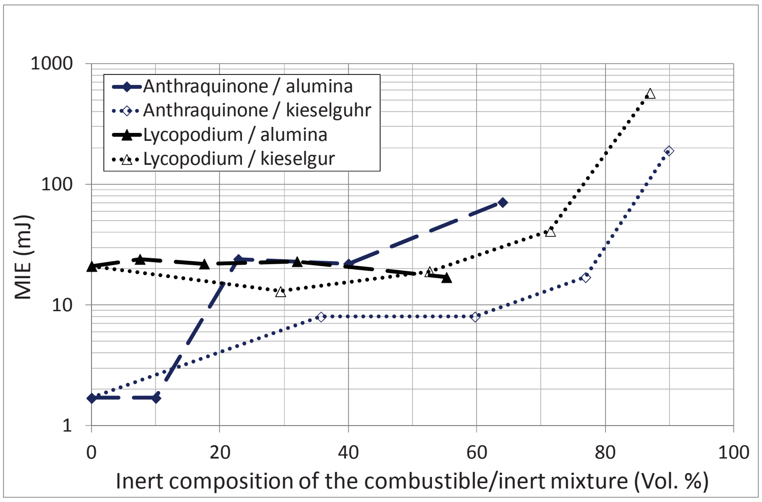

Figure 7: Anthraquinone and lycopodium MIE, as a function of inert concentration in vol. %

4. Discussion

Tables 3 to 5 and Figures 2 to 4 show that the presence of an inert material tends to increase the MIT temperatures and the EMI of the different materials tested.

The MIT in layer obtained seems to increase sharply from an inert threshold concentration. Indeed, the MIT in layer is strongly influenced from 60 % (weight) of inert. This corresponds to a volume concentration of inert from 60 to 80 % in kieselguhr. The observation of MIT in layer depending on the volume concentration shows that the inerting with alumina seems more efficient, since the MIT increases more rapidly with the concentration of inert in the case of coal, rice and coffee husks and beech wood flour. This is related to the much higher density of alumina as the kieselguhr.

In the case of MIT in layers, the MIT in cloud and the MIE does not vary linearly with the inert concentration but there seems to be a threshold beyond which it increases sharply. This threshold is, according to the products tested, about 60 % (weight) but this is less obvious than MIT in layer tests. This threshold corresponds to a volume concentration between 50 and 90 %. Inerting with alumina is more efficient in the case of MIT in cloud for coal and rice and coffee husks and in the case of MIE of beech wood flour and anthraquinone. On the contrary, it is the kieselguhr which is the most efficient on the MIT in cloud for bran.

In the case of tests performed on clouds (MIT in cloud and MIE), it seems that the bulk density difference between the two constituents of the mixture results sometimes in a sedimentation of the heavier dusts. This has a significant influence on results obtained.

5. Conclusion

This work provides some results about the influence of the inert concentration on the sensibility to ignition (MIT in 5 mm layer, MIT in cloud, MIE) of combustible dust/inert powder mixtures.

It appears that the MIT in 5 mm layer is strongly influenced by an inert weight concentration ≥ 60 %, which corresponds to a volume concentration between 50 and 90 %, depending on the bulk density of products tested. There is also a significant increase of the MIT in cloud when the weight concentration of inert exceeds 60 %. However, in cases where the bulk density of the inert is different from that of the combustible dust, there appears to be segregation between the two constituents of the mixture after its dispersion. Therefore the influence of inert is less marked in the case of MIT in cloud than in the MIT in layer. This is observed also for MIE.

These trends should nevertheless be confirmed by further testing, to be completed to enrich the data with other products. Then, models could be implemented to predict ignition characteristics of combustible dust/inert powder mixtures.

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