Inert Hot Particle – Unconventional Ignition Source

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The fact that the entry of sparks, for example in dust separators, can cause fires and explosions has been known for many years, as well as operationally proven and partly normatively prescribed protective measures like spark extinguishing systems.

Nevertheless, there is a leak of knowledge about this apparently well-known protective technology. In practice there the conventional ignition source "mechanical sparks" exist beside other phenomena of ignition e.g. inert hot particles. Neither the EN 1127 nor the combustible dust test methods (cf. EN ISO/IEC 80079-20-2) describe the characteristics of e.g. inert hot particles precisely. An example for inert hot particles can be a small piece of heated metal, which is able to transfer the heat to a combustible material. Thus a smouldering fire or dust explosion will be initiated.

The contribution will show the hazard of inert hot particles and the typical characteristics of this unconventional ignition source. Practical test setups for the ignition efficiency of inert hot particles in relation to different parameters will be presented. Finally the possibility of hazard assessment method in relation to an example plant will be pointed out.

Keywords: hot particle, ignition source, dust layer, mechanical sparks, wood dust

Introduction

In dust transporting plants, like the production of particle board, inert hot particles can occur. They can be formed when a metallic foreign body drops into a crusher or mill. If an inert hot particle ends up in a dust collector, it can cause a dust fire. Round about 600 dust explosions were investigated in the years 1970 – 1995 by Jeske and Beck. They determined that 32,7 % dust explosions were ignited by mechanical generated sparks (cf. Jeske, Beck 1997). So this problem has been well-known for many years. Furthermore, this statistical study by Jeske and Beck shows that 28% of all explosions occurred in the wood processing industry.

Still, inert hot particles are not really included as an ignition source in (DIN EN 1127-1). These particles are numbered among the ignition source "flames and hot gases (incl. hot particles)". According to the standard, these hot particles can be welding beads. However, there is no further and detailed definition of these hot particles on the part of the standard.

For safe operation of these plants, it is necessary to perform a risk assessment. In the context of this risk assessment 13 ignition sources out of the DIN EN 1127-1 are usually used to identify possible ignition sources in the process. Furthermore, it is important to evaluate the fire risk and flammability of the dust in the process. To obtain these information combustible dust test methods can be used (cf. DIN EN ISO IEC 80079-20-2). However, any test method names inert hot particles as ignition source.

Therefore inert hot particles can cause a dust fire, but still, these particles are not completely nominally described. So the inert hot particles can be seen as an unconventional ignition source.

In the following the inert hot particle will be characterised in detail and by means of experimental ignition test the hazard of these particles will be pointed out. For these ignition tests wood dust was use as combustible dust sample.

Characteristics of inert hot particles

As already mentioned, inert hot particles could be termed an unconventional ignition source. These inert hot particles are an ignition source between the conventional ignition sources "mechanical generated sparks" and "hot surface", which are both described in DIN EN 1127-1.

The ignition source of mechanically generated sparks is characterized by small particle size (diameter and surface), high temperature up to 2,900 °C (burning or vaporise metal) (cf. Pedersen, Eckhoff 1987) and a short lifetime of only a few seconds. These sparks can be transported by pneumatic transport pipes or conveyor. However, a single mechanical spark cannot ignite deposited dust layers (cf. Wingerden et al. 2011). These sparks can be formed by defect vents or if two hard materials hit each other. On the other hand, hot surfaces are characterized by a constant surface temperature and an immovable position. These ignition sources often occur at electrical components.

If inert hot particles are compared with mechanical generated sparks the inert hot particle shows similar transport properties but significantly lower temperature (glowing solid metal), and a longer lifetime (about a few minutes), whereas inert hot particles are usually smaller and not constant heated then hot surfaces. Figure 1 shows a scheme of a model approach of the inert hot particle. Inert describes in this context that it has no chemical reaction to particles in the sense of combustion. Likewise, a possible ignition occurs only by the physical heat transfer from the particle to the fuel.

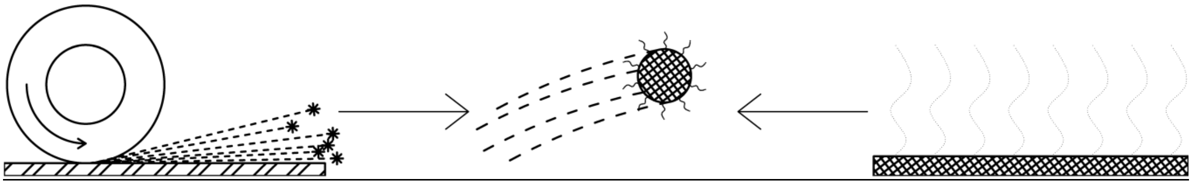

Figure 1: Scheme of the inert hot particle Model

This model approach is also deducible from past or other research projects. In experimental ignition tests of mechanical sparks Bartknecht determined, that perhaps the mechanical sparks did not ignite a dust air mixture but a small part of the experiment apparatus (Bartknecht 1989b, 1989a). This phenomenon was also observed by ignition tests at the Physikalisch-technische Bundesanstalt Braunschweig (cf. in VDI 2017).

Experimental Ignition Test of inert hot particles

Literature review of experimental test

In the last year, some ignition tests with hot metal spheres were performed in the USA in the context of forest fire research (cf. Urban et al. 2014; Hadden et al. 2011). In both studies, metal spheres were heated in a tube furnace and then dropped into a cellulose dust bed. The aim of these investigations was to establish a correlation between sphere diameter and sphere temperature, which causes the ignition of the dust sample. Hadden et al. used steel spheres, whereas Urban et al. carried out experiments with different metals (stainless steel, aluminium, brass and copper). These investigations differ in the representation of the correlation between sphere diameter and sphere temperature which leads to an ignition. Urban et al. basically assumes a flaming ignition. He represents three areas in a diagram. Firstly, an area where flaming ignition always occurs. Secondly, an area in which no ignition was observed and thirdly, an area in which ignition probabilities are indicated. Hadden et al. differentiates between the formation of a smouldering and a flaming fire, but no ignition probabilities are given. Similar experiments with aluminium balls were carried out by Rowntree and Stokes (cf. Rowntree, Stokes 1994; in Babrauskas 2014). They investigated the ignition of various natural samples (barley grass, cotton lint, pine needles and hardwood samples of blackbutt and bluegum [eucalyptus species]). These tests evaluated the formation of a smouldering fire as an ignition. They also represented three areas in the results, just like Urban et al. (no Ignition, possible Ignition and definite ignition). Krause and Schmidt also investigate the ignition behaviour of hot particles (cf. Krause, Schmidt 2000). They investigated the formation of smouldering fires in dust. For this purpose, ceramic spheres were placed directly into the core of a cork dust bulk material. All descriptive tests show that as the particle diameter increases, the particle temperature decreases, which is necessary to ignite the dust sample.

Experimental test setup

As already stated, inert hot particles can cause a dust fire in a dust collector. In a dust collector, dust occurs in two states. On the one hand, it can be a deposited dust layer of the floor near the rotary valve; on the other hand, it can be a deposited dust layer with forced convection on the filter fleece. Because of this, two various test setups were developed to evaluate the ignition efficiency of inert hot particles. In the first step, the minimal temperature of an inert hot particle that can initiate a smouldering fire in a deposited dust layer was determined. With the second test setup the ignition efficiency of inert hot particles on deposited dust layer with forced convection was investigated. In Figure 2 and Figure 3 the experimental setups for deposited dust layer with and without forced convection are shown.

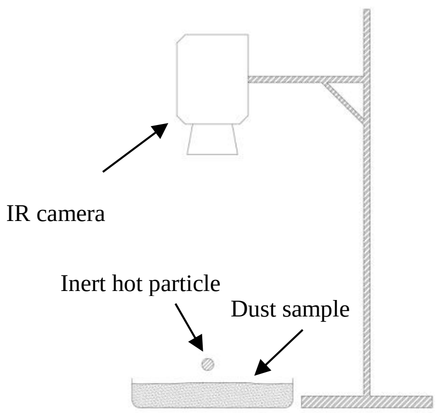

Figure 2: Scheme of the experimental setup for deposited dust layers (cf. Bechem et al. 2016)

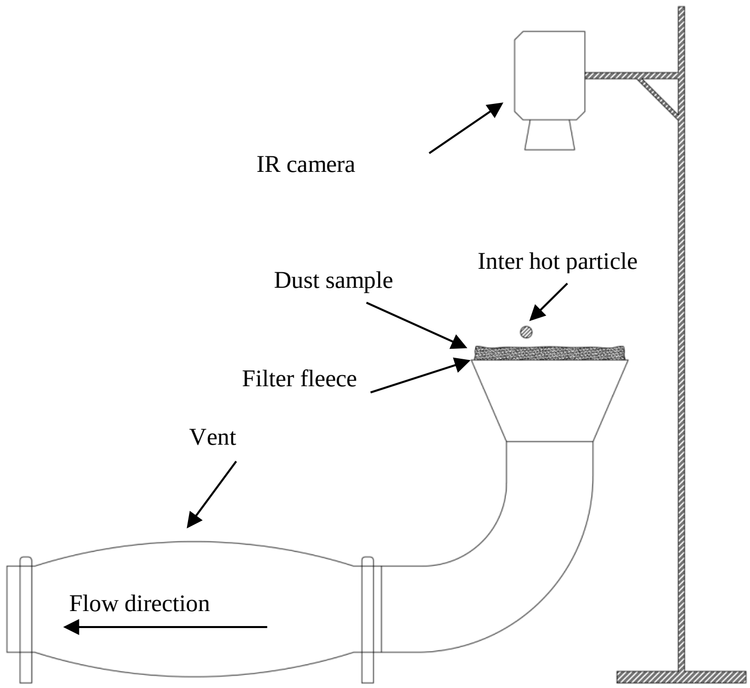

Figure 3: Scheme of the experimental setup for deposited dust layers with forced convection (cf. Bechem et al. 2016)

For these studies, ball bearing sphere (chrome steel: 1.3505) with different diameters were used as inert hot particles. The used chrome steel is common steel in many dust transporting plants. As a result, this steel is also likely to produce inert hot particles. These ball bearing spheres were heated in an oven and then dropped on the dust sample. All tests were filmed top down with an infrared (IR) camera (Optris PI 400) to evaluate the exact temperature of these spheres. In these tests, the formation of a self-contained smouldering fire was defined as the ignition criteria. A smouldering fire is understood as a self-expanding combustion of fuel at surface temperatures between about 400 °C and 650 °C without any visible light appearances like flaming or glowing. Table 1 shows the parameters of these ignition tests.

Table 1: Parameters of Experimental Ignition Test of inert hot particles

Particle diameter	3 mm, 4 mm, 5 mm, 7 mm, 10 mm, 15 mm
Temperature of the oven:	300 – 1.100 °C
Dust sample	Beech, yellow pine
Layer thickness	15 mm (deposited layer)
	5 mm (deposited layer with forced convection)
Ambient temperature:	21±2 °C
Humidity:	50 – 75%

This experimental ignition test was performed in a number of test series. In each test series, nine single tests were run simultaneously. Apart from that, in two test series with yellow pine only five single tests were run. In each test series the oven temperature and sphere diameter were the same. For each combination (sphere diameter and oven temperature), at least two test series were performed. For beech dust, 127 test series with 1,143 single tests were performed; for yellow pine, 83 test series with 739 single tests were performed.

Results of Experimental Ignition Test

The results show the minimum temperature of the respective sphere diameter that caused an ignition of the dust sample. The results of the test with deposited dust layer are shown in Figure 4. The minimal ignition temperature of inert hot particles in beech dust decreases by increasing the diameter of these particles. No ignition of beech dust by inert hot particles with a diameter of 3 mm was observed. The behaviour of yellow pine is diverging significantly. In the range of particle diameters from 3 mm to 7 mm, the minimal ignition temperature of inter hot particles increases by increasing the particle diameter. In the range up to 15 mm, the temperature is decreasing.

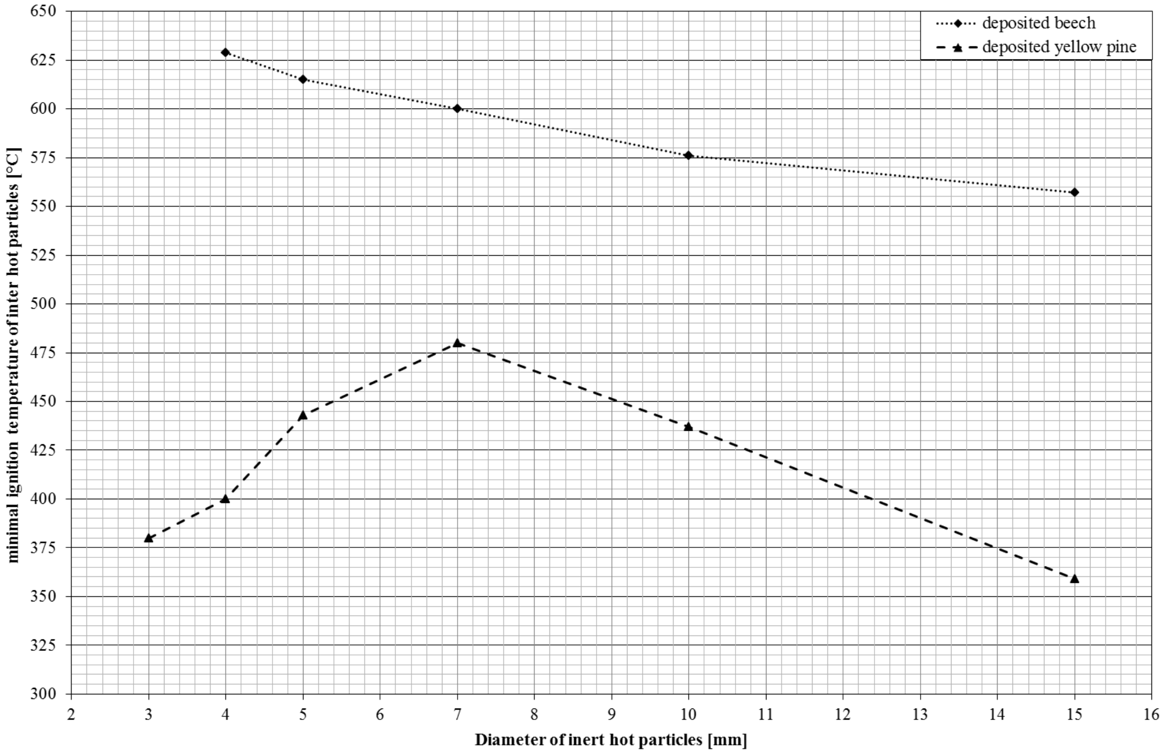

Figure 4: results of the Experimental Ignition Test of inert hot particles for deposited dust layers

Figure 5 shows the results of the test for deposited dust layers with forced convection. The behaviour of the minimal ignition temperature of inert hot particles in beech dust is similar to the result in deposited dust layer without force convection. By increasing the particle diameter, the temperature decreases. For yellow pine, this behaviour is roughly recognisable, but the particles with a diameter of 4 mm and 7 mm are drifting a bit. If an inert hot particle initiates an ignition, a smouldering fire with visibly glowing and temperatures more than 1,000 °C were always observed.

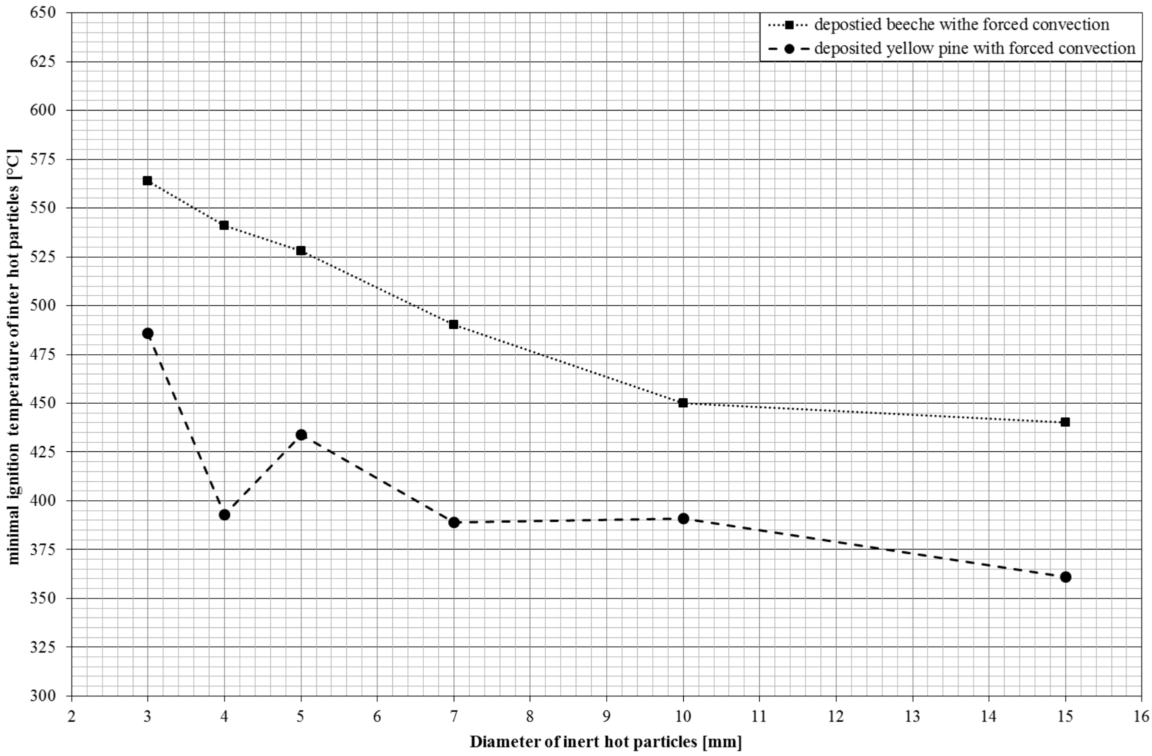

Figure 5: results of the Experimental Ignition Test of inert hot particles for deposited dust layers with forced convection (cf. Tessendorf 2017)

Table 2 collected all minimal ignition temperatures of inert hot particles from the experimental ignition tests.

Table 2: minimal particle temperature with ignition

		Diameter of inert hot particle [mm]					
		3	4	5	7	10	15
minimal ignition temperature of inert hot particles [°C]	Beech	No ignition	629	615	600	576	557
	Beech forced convection	564	541	528	490	450	440
	Yellow Pine	380	400	443	480	437	359
	Yellow Pine forced convection	486	393	434	389	391	361

In comparison, the results of the minimal ignition temperature of inert hot particles with and without forced convection show that the temperatures are lower with forced convection. For beech dust, a difference from 80 K till 100 K is revealed. The results of yellow pine are quite different. For inert hot particles with a diameter of 3 mm the temperature is much higher for deposited dust layer with forced convection. The same behaviour as for beech dust is only observed at particles with a diameter of 7 mm and 10 mm. For a diameter of 15 mm, the temperature is quite the same. Figure 6 shows these comparisons.

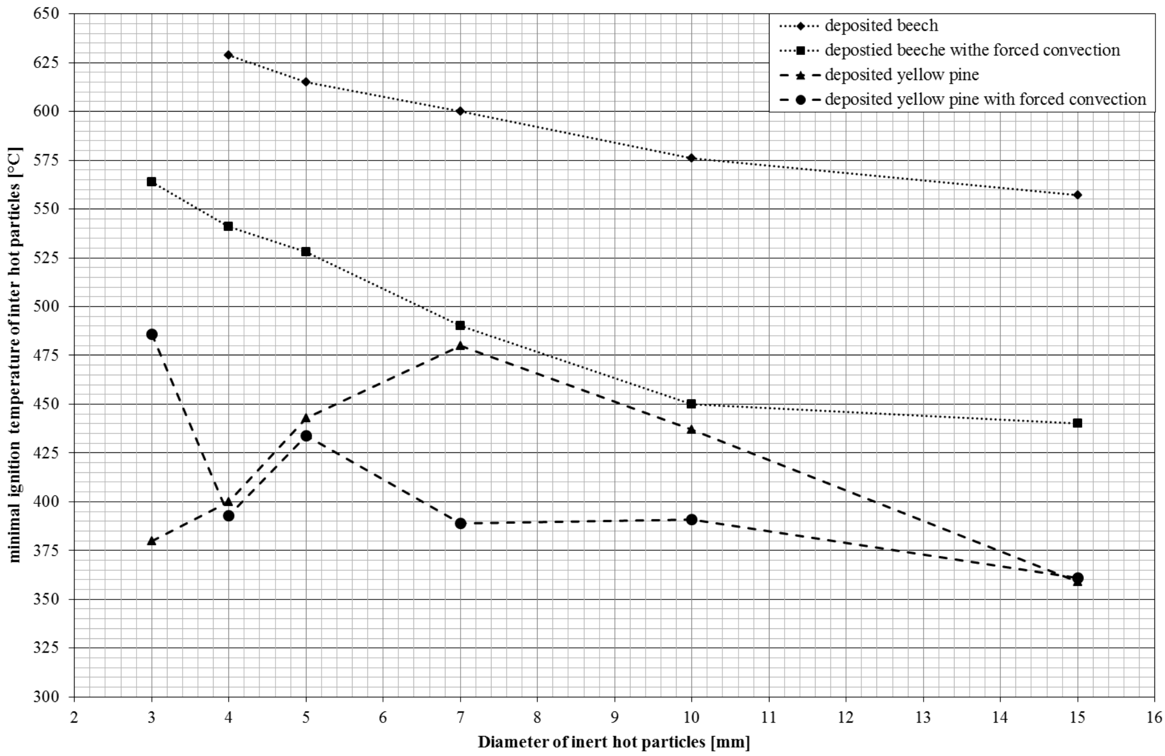

Figure 6: results of the Experimental Ignition Test of inert hot particles

The two dust samples show various surface structures. Beech dust always has a homogeneous surface of a dust layer. In contrast to that, yellow pine dust shows a heterogeneous surface of the dust layer. The fibrous yellow pine dust created agglutination with small hollows. In these hollows, small particles can drop down and completely sink in cf. Figure 7. Therefore, smaller inert hot particles immersed into the dust and the IR camera could not detect the exact temperature of these particles anymore. In addition to that, heat transfer from the inert hot particles to the dust sample was higher than for particles that only lay on top of the surface. That could be an explanation for the lower minimal ignition temperature of smaller inert hot particles. The test with forced convection did not show this behaviour so strongly, due to compaction. Another reason is, that the layer thickness is lower and the particles cannot immerse deeply. Additional problem with this heterogeneous surface structure of yellow pine dust could be that in the tests with forced convection, the bigger inert hot particles (diameter of 10 mm und 15 mm) ignited the filter fleece but not the dust.

Beech Yellow pine

Figure 7: Surface structure of the deposited dust layer (cf. Tessendorf 2017)

In the following diagram, the results in the deposited dust are compared to the tests from literature. For better comparability, the results of the tests carried out with steel spheres (Urban et al. and Hadden et al.) are listed. Therefore, the investigations of Krause and Schmidt as well as Rowntree and Stokes were not taken into account. The respective minimum ignition temperature of inert hot particles is shown. In Hadden et al. this usually corresponds to the formation of a smouldering fire. From the results of Urban et al. the relationship between sphere diameter and temperature was chosen which showed a certain ignition probability.

Since the publications of Hadden et al. and Urban et al. do not provide precise information on the determination of the sphere temperature, it is assumed that the corresponding furnace temperature was specified as the minimum ignition temperature of inert hot particles. It is therefore difficult to compare these temperatures directly with the tests carried out (measurement of the sphere surface temperature). However, it can be seen that the basic course of the ignition tests carried out corresponds to the literature values. The minimal ignition temperature of inert hot particles in beech dust decreases when the diameter of these particles increases. Furthermore, the comparison shows that the investigated dust has an influence on the minimum ignition temperature of inert hot particles.

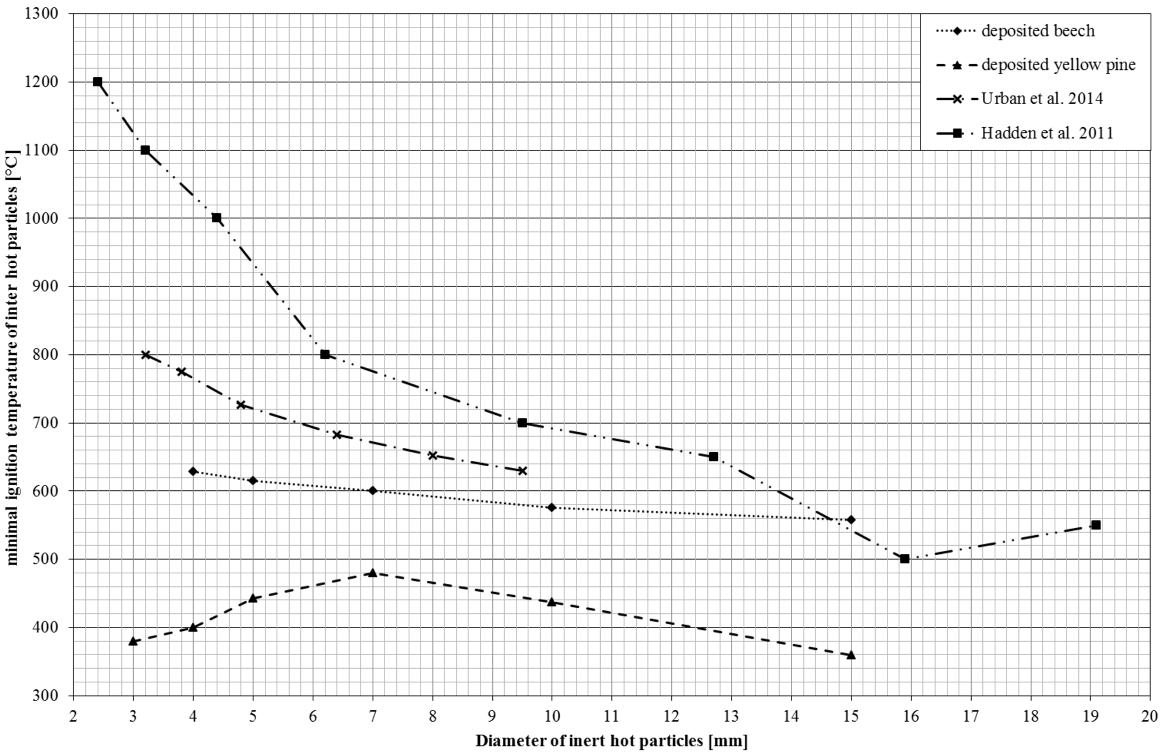

Figure 8: Comparison of results of deposited dust layers and the investigations of (Urban et al. 2014) and (Hadden et al. 2011)

Conclusion

The results of the present study show that inert hot particles can ignite deposited dust layer with and without forced convection. The minimal temperatures of inert hot particles were lower in the tests with forced convection. This behaviour was expected, because with forced convection, more oxygen gets to the fire reaction zone. Increasing the oxygen inflow will improve the combustion conditions. Furthermore the results show that dust itself (material, surface structure etc.) has an influence on ignition characteristics of inert hot particles.

As a result of the direct measurement of the surface temperature of the spheres, it was determined that the spheres suffer a temperature loss of 50 K to 120 K on their way from the furnace to the dust sample. This cooling behaviour is also shown by Urban et al. In order to correctly determine the hazard of inert hot particles, it is therefore essential to determine the exact temperature of an inert hot particle that causes ignition. If only the furnace temperature is considered to be the minimum ignition temperature, this temperature is shifted to the unsafe side. In this case, a higher ignition temperature is assumed.

The investigations carried out and published so far to determine the ignition efficiency of inert hot particles are located in the field of forest fire research. Up to now, the ignition efficiency of these particles was only investigated in isolated cases in industrial processes, in particular dust-transporting systems. Thus, these results provide first but essential knowledge about the hazard of inert hot particles in dust transporting plants.

In the following, ignition tests with other dust samples such as rubber or cocoa and other geometric shapes of the inert hot particles will be performed in order to further characterize the inert hot particle and determine its hazard to real processes.

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