CHEMICAL ENGINEERING TRANSACTIONS

VOL. 48, 2016

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Eddy de Rademaeker, Peter Schmelzer

ISBN 978-88-95608-39-6; **ISSN** 2283-9216

DOI: 10.3303/CET1648068

Explosivity Properties of Dusts from Torrefied Biomass Pellets

Pedro Abelha*, Michiel Carbo, Mariusz Cieplik

Energy Research Centre of The Netherlands (ECN), Post Office Box 1, 1755 ZG Petten, The Netherlands
abelha@ecn.nl

A modified Hartmann tube apparatus was used to study the explosivity properties of dusts from torrefied biomass pellets. The sensitivity of the dusts to explode was assessed by determining the minimum ignition energies (MIE) and the minimum explosible concentrations (MEC). The severity of the explosion was evaluated by flame front velocity (FFV) measurements via a method developed by ECN. A comparison was made with reference materials like white wood and coal dusts.

Dust from torrefied biomass pellets presented MIE and MEC values in the same range as the white wood pellets dust, but depending on the material sometimes even higher values were obtained. The severity of an explosion of torrefied biomass dust tends to be lower when compared with white wood dust explosions, especially when comparing the impact effects of moisture, particle size and temperature, as in a real case scenario. However, torrefied biomass materials still present higher explosion reactivity than coals.

1. Introduction

Densification of biomass offers several advantages such as an increase in the energy density, relevant for transportation, and in the fuel homogeneity. This turns it in a more efficient and desirable material for co-firing or co-gasification, to partially replace fossil fuels, like coal. These benefits can even be higher with biomass upgrading by torrefaction, which also extends the range of usable biomass materials by including lower quality resources (forest residues, energy crops and agro/industrial wastes). Simultaneously, torrefaction potentially increases the share of biomass in the fuel mix, due to the upgraded characteristics particularly with respect to grinding, pneumatic transport and overall better control during thermal conversion (van der Stelt et al., 2011).

Significant amounts of combustible dust can be generated during pellets handling, transport and processing, depending on the durability of the original pellets. Dust explosions are one of the major concerns in the biomass fuel value chain, from biomass producers through logistics to the end users. Several incidents are registered every year due to limited experience and data related to biomass dust explosion characteristics (Huéscar Medina et al., 2015). This number will tend to rise with the foreseen increase of biomass utilization to accomplish the CO_2 emission reduction targets, unless safety precautions are considered and implemented to tackle this issue. The hazard level of a particular fuel dust depends, in the first place, on the amounts of the "ignitable" dust fraction that can be released during pellets handling. Secondly, it depends on the sensitivity of the dust to explode, and finally on the severity that the explosion can reach (Eckhoff, 2003).

In the last decade ECN has successfully developed and demonstrated a technological concept for the commercial production of torrefied pellets and achieved a patent for the process in partnership with Andritz Pulp and Paper (Kiel et al., 2012). In due course of this development a comprehensive study on the characteristics of different biomass fuels, including the dust explosivity properties, was carried out as part of ECN's research program dedicated to these issues (Carbo et al., 2015).

This paper focusses on the explosivity properties of biomass pellets dust. Several parameters like biomass type, torrefaction degree, pellets durability, particle size, moisture contents, etc. were studied and their impact on both the sensitivity and severity of a generated explosion was quantified. Explosivity properties, including minimum ignition energies (MIE), minimum explosible concentrations (MEC) and explosion flame front velocities (FFV) were determined. A comparison was made with references such as white wood dust and coal. The tests were conducted in a modified Hartmann tube developed at ECN, which is equipped with both discontinuous and continuous spark discharge systems as ignition sources.

Please cite this article as: Abelha P., Cieplik M., Carbo M., 2016, Explosivity properties of dusts from torrefied biomass pellets, Chemical Engineering Transactions, 48, 403-408 DOI:10.3303/CET1648068

The objective of this work is to disseminate the results and the main conclusions obtained regarding the explosivity properties of this new and improved renewable fuel, which might take a significant share among the next generation fuels for energy and heat production.

2. Experimental

The sensitivity of the dust explosion was assessed by the measurement of the MIE and the MEC. The MIE was measured in a modified Hartmann tube apparatus of 1.2 L
(presented in Figure1), following a standard method (EN 13821, 2002). The dust sample is dispersed in air at test conditions in a Hartmann tube apparatus, and the dust cloud is subjected to a discontinuous spark discharge from a capacitor with an energy in the range 0.001-0.003-0.01-0.03-0.1-0.3-1 J. The minimum ignition energy is a function of the dust/air mixture and of the dynamics/turbulence. The minimum ignition energy should be measured at the optimum dust concentration and at the lowest turbulence level experimentally possible by extending the ignition delay time. The MIE lies between the highest energy level at which ignition fails to occur in 10 successive attempts, and the lowest energy at which ignition occurs within up to 10 successive attempts. The MIE was determined using an inductance in the discharge circuit.

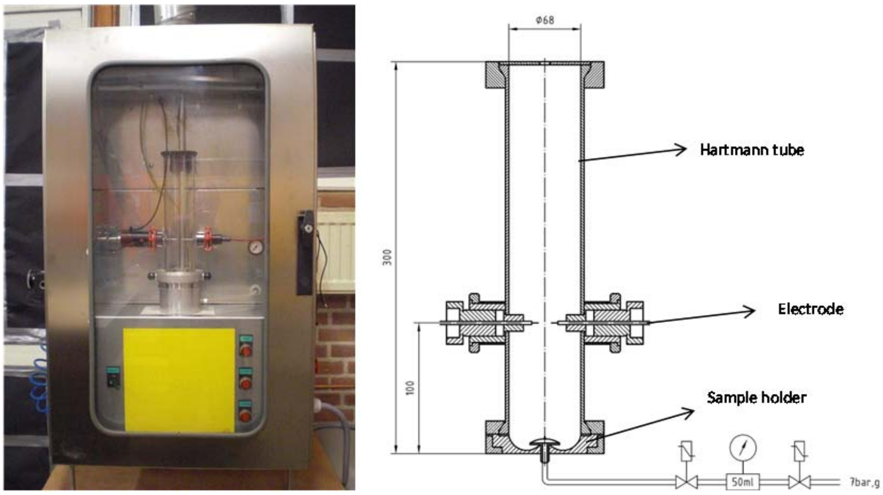

Figure 1: The ECN explosivity apparatus.

For the evaluation of the severity of a dust explosion, a dedicated method was developed by ECN consisting in the explosion FFV measurements with a Photron Fastcam SA3 high speed camera working at 1000 fps and connected to a PC for data acquisition. More reactive materials burns faster and develop higher flame velocities that can be correlated to the maximum rate of rise of the explosion pressure (Sattar et al., 2014), which is one other important parameter in explosivity hazard evaluation. Here a continuous spark system with a 15-20 W of power is used in the Hartmann tube apparatus coupled with a high speed camera that allows monitoring the explosion flame development. The average velocity between the ignition point and the end of the Hartmann tube is calculated using the camera software and video footage, and plotted as a function of the dust concentration. This method is also used to determine the MEC values. The MEC value lies in between the maximum concentration for which no ignition is obtained after 5 ignition attempts and the minimum for which it successfully ignites. During these experiments duplicates of each test were performed.
During this study it was found that for this type of sample dusts (biomass and torrefied biomass with dp < 63 μm) the dust could be ignited before the dust cloud once dispersed could reach the top of the Hartmann tube and, depending on the material, between 50-100ms are needed for complete dispersion. The consequence of this is that the real concentration cannot be calculated just on the basis of the weighted sample and the Hartmann tube volume. Instead, it has to be corrected based on the real volume occupied by the particles at the moment that ignition occurs, which most of the time is significant lower that the Hartmann tube volume, leading to actual higher concentrations. The high speed camera is essential to conduct this correction.
The torrefied materials were torrefied at the ECN torrefaction pilot installation (fixed moving bed) at temperatures between 270-280 °C. The materials were characterized in terms of proximate and ultimate analysis using standard methods at the accredited ECN laboratory.
The pellets used in this work were tumbled, after sieving with a 3.15 mm sieve to remove the native dust, according with the standard EN 15210-1(2009) to quantify the pellets durability and to produce dust to be used

for the tests. The dusts from tumbling (by definition the particle sizes below 3.15 mm remaining after sieving the tumbled pellets) were further sieved to collect the fractions below 500 μm (considered as upper boundary size limit for dust particles to be able to explode), as well as below 63 μm (considered the standard size for MIE determination). The results obtained with these two particle sizes distributions were compared.

Furthermore, also dust particles obtained by milling the samples with a Retsch SM2000 cutter mill, using a bottom sieve of 250 μm, were produced. These particles were further sieved and the fraction below 63 μm and the fraction between 63 and 125 μm were collected and used for the explosivity tests. All the dust samples were dried in an oven at 75 °C during 24 h prior to the tests and the moisture content was kept below 1 % during the tests. For the moisture influence evaluation during explosivity, the samples were put in contact with air saturated with water in a climate chamber, until the desired moisture content was achieved.

3. Results and Discussion

3.1 Dust explosion sensitivity

The native dust represents usually less than 1 % of the weight of the pellets when their durability is high (> 96 %). This dust can represent the kind of dust that is created by gentle handling of these pellets. Native dust samples of both torrefied and white wood pellets (with dp < 500 μm) demonstrated to be hardly ignitable presenting MIE values above 1 J, even for the torrefied pine pellets, which had a durability of only 92.4 % and therefore, presented also higher native dust contents (3.7 %). The durability of the other pellets presented values between 96-98 %. However, in Figure 2 it is possible to observe that the tumbling dusts, with the same particle size range, could explode and presented MIE values in the range of 40-200 mJ. The tumbling dust is regarded to be representative for the type of dust produced during severe pellets handling, where significant attrition forces are present. Thus, when comparing the particle size distribution between the native and the tumbling dusts a significant different in the fraction of the smaller particles (< 63 μm) was observed. While all the native dusts presented less than 7% of particles content with dp < 63 μm, the tumbling dusts presented about 11, 12, 24 and 32 % for the white wood, torrefied spruce, poplar and pine pellets respectively. The MIE of the tumbling dusts could be correlated quite well with the content of the fines (dp < 63 μm). However, when only the fraction below 63 μm is considered for the milling dusts in Figure 2, the MIE was lower for the torrefied spruce pellet and white wood pellet dusts, while these materials resulted in relatively higher MIE values for the tumbling dusts. Furthermore, tests with the dust particles fraction between 60-125 μm have shown that the MIE values were higher than 1 J for all the materials. The obtained differences in the MIE values for the milling dusts with dp < 63 μm most certainly depended on the material nature, related to how easy the materials devolatilize and to the nature of volatile species released. Most probably, low activation energies to devolatilize leads to lower MIE and lower MIE volatiles leads to lower MIE for the parent dusts.

The observed facts demonstrates clearly that besides the MIE obtained by the standard procedure (with dp < 63 μm), the dust content of smaller particles (dp < 63 μm) is a critical parameter for real dusts explosion evaluation.

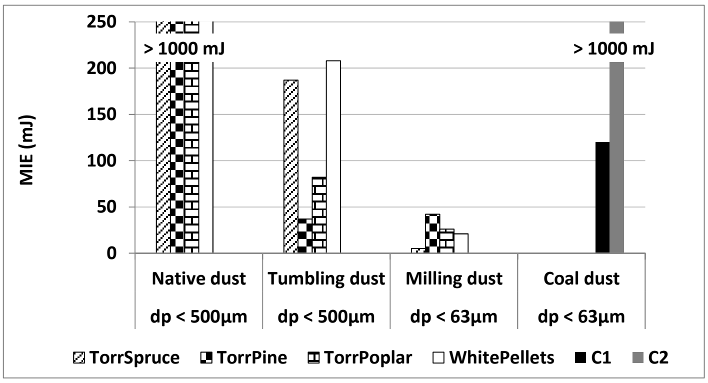

Figure 2: MIE values obtained for the native, tumbling and milling dusts of torrefied and white wood pellets. Also two samples of coal mill dusts are presented. All samples were dried at 75 °C during 24 h.

Different methods used for producing the dust lead to different MIE values, although similar sizes (< 63 μm) and distributions were obtained. As an example, the MIE for the torrefied pine and white pellets tumbling dust was 25 and 14 mJ respectively, while for the cutter mill dusts it amounted to 42 and 21 mJ. Here, it is possible that the different size reduction techniques resulted in different particle shapes enlarging the uncertainty of the

MIE method. These results emphasised the absolute need of having a standard milling procedure as a base when comparing different materials during the determination of MIE values.

In Table 1 a comparison between the MIE of the torrefied wood and the original white wood dusts is presented, using the same standard milling procedure under the same conditions (same size and distribution, same moisture contents). The results show that the MIE was equally dependent on the material nature independently of whether it was torrefied or not. One more observation was that the torrefaction process did not make the dust materials more sensitive to explode than the original raw wood dusts, with some of the torrefied dusts showing slightly higher MIE values than the corresponding raw feedstock materials.

Table 1: MIE of the torrefied and non torrefied dusts. Dusts were obtained with a cutter mill with a bottom sieve of 250 μm and the fraction below 63 μm was further sieved for the tests (dp < 63 μm, dried at 75 °C).

	Spruce		Pine		Poplar		White wood
	Raw	Torrefied	Raw	Torrefied	Raw	Torrefied	Raw
MIE (mJ)	6	5	37	42	26	22	21

Besides the particle size (and shape) as mentioned before, the moisture content significantly influences the MIE and at a moisture content of about 10% (a reference equilibrium moisture content of biomass pellets), the typical values for the MIE of both torrefied and raw biomass dusts were found to increase roughly linearly to 100-300 mJ. The more fibrous materials like raw biomass with needle shape particles are more difficult to disperse completely and uniformly in a dust cloud, leading also to problematic explosivity data experimental determination as reported by Huéscar Medina et al. (2013). More problems occurred when the moisture content was incremented in excess of 5-6% due to constant stickiness of the raw biomass particles on the Hartmann tube wall and to the electrodes surface preventing most sparks to occur. The extent of these issues was much smaller for the torrefied materials.

Comparing to coal dust samples, habitually burned in coal power stations, all the biomass dusts presented lower MIE values, at least by a factor of 3 when compared with the more reactive coal C1 (Figure 2).

The minimum explosible concentration (MEC) values are here represented as an equivalence ratio, i.e. the ratio between the real fuel concentration in air and the stoichiometric fuel to air concentration, to allow an easier and more effective comparison between different characteristic materials such as biomass and coals. In Table 2 it is possible to observe the limits of the MEC values for the different materials. The torrefied dusts seemed to present slightly higher MEC values than the parent raw materials with pine as exception. However, the difference between the biomass and coal dusts are much more significant.

Table 2: MEC (as an equivalence ratio) of the dust of the torrefied pellets, raw wood and coal materials used in this study (dp < 63 μm, dried at 75 °C).

MEC equivalence ratio	Spruce		Pine		Poplar		Coal1	Coal2
	Raw	Torrefied	Raw	Torrefied	Raw	Torrefied		
Explosible limit	0.52	0.57	0.40	0.37	0.46	0.61	1.05	2.69
Non explosible limit	0.30	0.38	0.33	0.25	0.36	0.44	0.97	2.35

The obtained MEC values further consolidates the observation previously given by the MIE analysis results that the torrefaction process does not increase the explosive sensitive nature of biomass dusts. It is often assumed that if a material presents lower MEC and MIE imply a higher hazard level, since lower concentrations and ignition energies are required to start an explosion. This study proves that torrefied material dusts are not more prone to ignite than the dusts of the raw parent biomass species.

3.2 Dust explosion severity

In Figure 3A it is possible to observe that pine wood dust produced a maximum FFV significantly higher than the torrefied material dust. The maximum FFV was obtained at an equivalent ratio between 1 and 2. Materials like pine, poplar, spruce and ash wood were tested and the conclusion is that the torrefied materials explodes with maximum FFV equal or lower than raw materials. The higher FFV values were obtained for spruce and pine. Comparing to coal1 (Figure 3B), the maximum FFV of the torrefied material was twice as high. However, a mixture of the torrefied material (25 %wt) with the coal seemed to just slightly increase the FFV when compared to the coal material (Figure 7). With coal dusts the more reactive mixtures seems to be obtained at higher equivalence ratios (2-4). For instance with a less reactive coal (coal 2 in Figure 2) the maximum FFV (1.7 m/s) was obtained at an equivalence ratio of 4. The upper explosible limit for both biomass and coal materials dusts seemed to be significantly higher than the maximum equivalence ratios tested here (fuel rich stoichiometry up to 15).

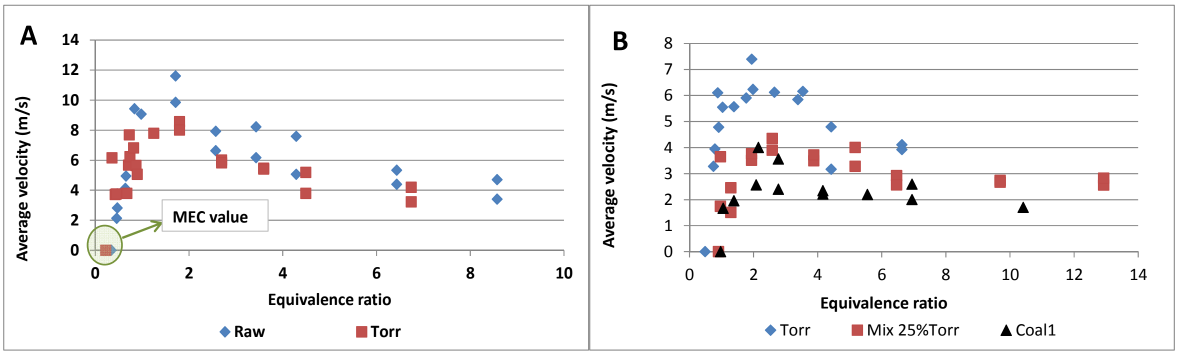

Figure 3: Average FFV measured during the explosions of dusts of torrefied and white wood and coal. All samples below 63 μm and dried at 75 °C during 24 h. A – white wood dust versus torrefied dust (pine), B – torrefied material dust versus coal dust.

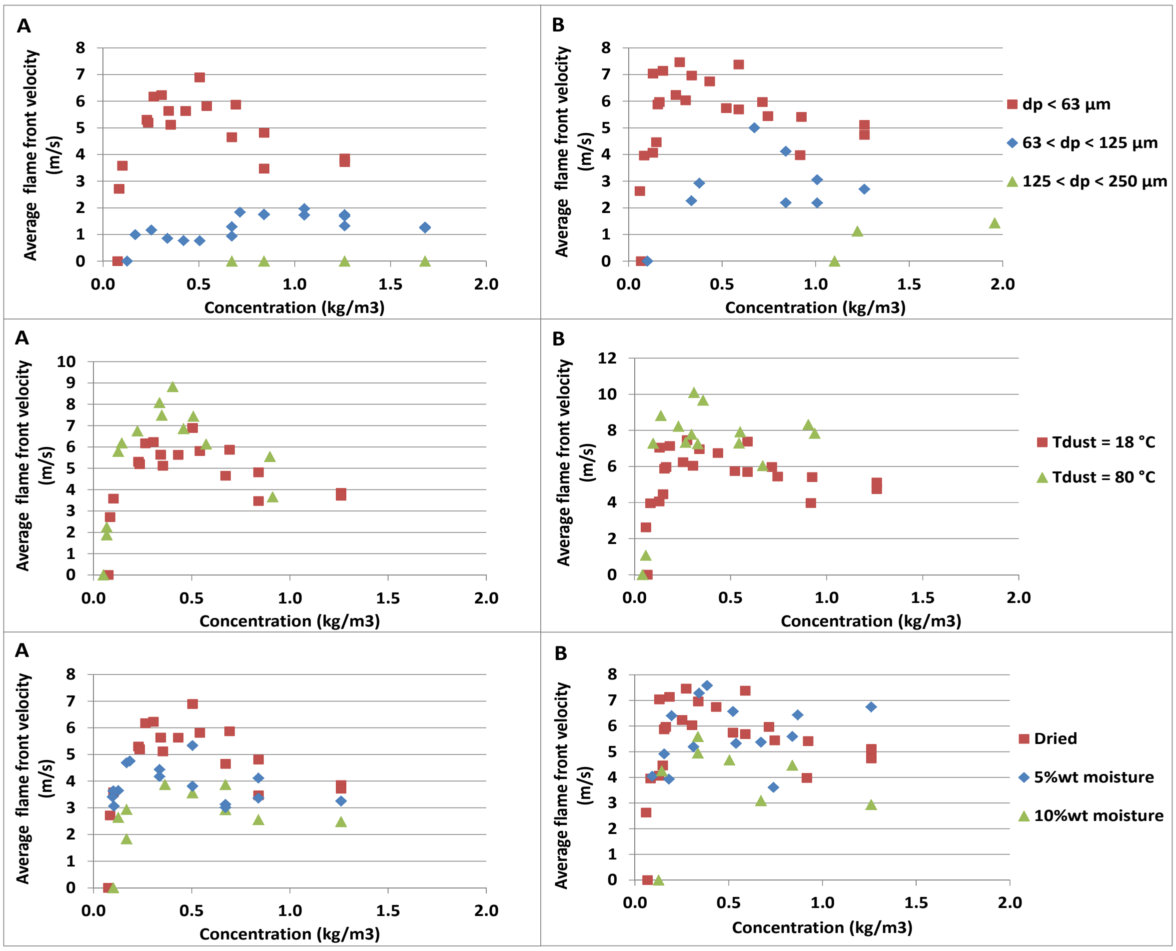

Figure 4: Effect of the particle size, temperature and moisture of the dust in the FFV during the explosions of: A – dust of torrefied wood, B – dust of white wood.

In Figure 4 it is possible to observe the influence of several parameters like the particle diameter, the sample temperature and the moisture content on the MEC and FFV.

Three different particle size ranges with a factor of 2 difference between each range were used. Incrementing the dp by a factor of 2 the maximum FFV of the white wood dust decreased and the MEC increased, about 30

and 40 % respectively. A further increase caused the maximum FFV to decrease about 80 % and the MEC increased by a factor of 15. The maximum FFV is clearly shifted to higher concentrations when the dp increases. The same effects were observed with the dust of the torrefied wood material, where the increase of the dp by a factor of 2 have decreased the maximum FFV about 70 % and the MEC increased roughly 60 %, while the torrefied dust sample did not ignite for a dp between 125-250 μm.
The increment in the temperature from ambient conditions to 80 °C affected the maximum FFV in similar extends for both dusts from white and torrefied wood pellets showed increased maximum FFV by 33 and 28 % respectively. Also, a 40 % decreased in the MEC value was recorded.
For the white wood pellet dust, the maximum FFV seemed unaffected with the increase in the moisture content of the dust from dry to 5 %, contrary to the observations with the torrefied dust for which a decrease in the maximum FFV of 23 % was recorded. With the increase of the moisture content from dry to 10 %, the white wood pellets maximum FFV was reduced by 35 %, while for the torrefied pellets the reduction in the maximum FFV was more evident reaching about 45 %.

4. Conclusions

A relatively high pellet mechanical durability is required (≥ 96 %) to reduce explosivity hazard during transport and handling by limiting the quantities of released airborne dust, while the explosion sensitivity of the biomass feedstock appears more important to reduce explosivity during milling and pneumatic conveying operations.
At exactly the same standard conditions the dust from torrefied biomass pellets presented MIE and MEC values in the same range as the white wood pellets dust, but depending on the material sometimes even higher. However, under the exact basis conditions, the severity of an explosion of torrefied biomass dust tends to be lower when compared with white wood dust explosions. Especially when comparing realistic conditions, since the negative impacts of increasing temperature and decreasing moisture contents and dp seemed to increase the severity explosion of white wood dusts further beyond compared to the torrefied dusts. However, torrefied biomass materials still present significantly higher explosion reactivity than coal dusts. The FFV method develop by ECN seems to be simple, quick, flexible and reliable to compare different materials with respect to explosion severity, like torrefied and raw biomass and coal dusts, under more realistic conditions than prescribed by the standard.

Acknowledgments

The TKI Biobased Economy (TKI BBE) and the Netherlands Enterprise Agency (RVO) are gratefully acknowledged for their financial support of the Pre-treatment/INVENT project under agreement no. TKIBE01011.

References

Carbo M.C., Abelha P., Cieplik M.K. and Mourão C., 2015, Ch5: Fuel (pre-)processing, pre-treatment and storage for co-firing of biomass and coal, in: Fuel Flexible Energy Generation: Solid, Liquid and Gaseous Fuels, Eds. John Oakey, Cranfield University, UK, Woodhead Publishing, ISBN 1782423990, 9781782423997.
Eckhoff R.K. Dust explosions in the process industries, 2003, 3rd ed. Gulf Professional Publishing, USA.
EN15210-1, 2009, Solid biofuels - Determination of mechanical durability of pellets and briquettes - Part 1: Pellets.
EN13821, (2002), Potentially explosive atmospheres - Explosion prevention and protection - Determination of minimum ignition energy of dust/air mixtures.
Huéscar Medina C., Phylaktou H.N., Andrews G.E. and Gibbs B.M., 2015, Explosion characteristics of pulverised torrefied and raw Norway spruce (Picea abies) and Southern pine (Pinus palustris) in comparison to bituminous coal, Biomass and Bioenergy, 79, 1156-127.
Huéscar Medina C., Phylaktou H.N., Sattar H., Andrews G.E. and Gibbs B.M., 2013, The development of an experimental method for the determination of the minimum explosible concentration of biomass powders, Biomass Bioenergy, 53, 95-104.
Kiel J.H.A., Zwart R.W.R and Verhoeff F., 2012, Status of ECN torrefaction technology, International Workshop on Biomass Torrefaction for Energy, May 10-11, Albi , France.
Sattar H., Andrews G.E., Phylaktou H.N. and Gibbs B.M., 2014,Turbulent Flames Speeds and Laminar Burning Velocities of dusts using the ISO 1 m3 Dust Explosion Method, Chemical Engineering Transactions, 36, 157-162.
van der Stelt M.J.C., Gerhauser H., Kiel J.H.A. and Ptasinski K.J., 2011, Biomass upgrading by torrefaction for the production of biofuels: A review, Biomass and Bioenergy, 35, 3748-3762.