CHEMICAL ENGINEERING TRANSACTIONS

VOL. 77, 2019

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano
Copyright © 2019, AIDIC Servizi S.r.l.
ISBN 978-88-95608-74-7; **ISSN** 2283-9216

DOI: 10.3303/CET1977110

Combustion Behaviour of Dusts in Quasi- Stationary State

Alexey Leksin*, Uli Barth

University of Wuppertal, School of Mechanical Engineering and Safety Engineering, Chair Methods of Safety Engineering/Incident Research, Wuppertal, Germany
leksin@uni-wuppertal.de

Within the scope of safety related assessment of combustible dusts, burning tests are of huge importance in the field of fire and explosion protection as they evaluate the burning ability of sedimented dust resulting in the so-called combustibility index. Looking at certain technical processes and process plants, dust exists not only in a dispersed or sedimented form but can also be detected in fluid beds and thus is situated in a transitional form between the sedimented and the dispersed form, meaning in a quasi-stationary state. Up to now, there is a knowledge deficiency whether and in how far a combustibility index, which was identified appropriately for sedimented dust, is applicable and acceptable for a safety-related assessment of fluid beds.
A description about the combustion behaviour for dust in fluid beds with the result of a possible increase of the so-called combustible index was published in the VDI-Report 2225 (VDI: Association of German Engineers) in 2014. The authors reported about a modified burning test instrument for fluid beds and the experiments for the examination of the combustibility in the quasi-stationary state. Since the gained research results in the context to the safety characteristic of dusts are of fundamental importance for the operational practice of the fire and explosion hazard assessment, the topic “quasi-stationary state“ in the updated VDI-Guideline 2263 deserves particularly mentioning. A detailed description of the modified burning test instrument and the test procedure is provided in the reworked VDI-Guideline 2263 Sheet 1. In other words a test method for the determination of a new safety characteristic of dust, the so-called “Brandverhaltenszahl” in quasi-stationary state (BVZqs) is developed, due the combustion behaviour in the modified burning test instrument for fluid beds cannot be described with the standardized combustion index definitions. The aim is to provide a basis of assessment for the user to recognize the quasi-stationary state in certain technical processes and plants which can be evaluate to take appropriate protective measures. In the following, the authors report about the future test-technical determinability of the combustion behaviour in the quasi-stationary state, as well as the determination of the test method and the modified burning test instrument.
The results of the research project are of huge importance for the fire and explosion hazard assessment in different sections, especially in industries of agriculture, food, chemical, pharmaceutical.

1. Introduction

The term fluidized bed originates from the field of fluidized bed technology for industrial applications in 1922 (Winkler, 1922), in which combustible dust is present in a quasi-stationary state. Nowadays fluidized bed technology is widely used in many areas of industry and process engineering. From the point of view of the engineering process, the heat and material transfer processes include the drying of moist bulk materials (granulates, agglomerates, crystals, powders) and their alternative cooling, as well as all multiphase processes such as roasting, calcination, agglomeration, build-up granulation or des-agglomeration, coating and moistening in the form of spray granulation and coating. The combustible dust occurs as a quasi-stationary fluidized bed. This quasi-stationary or fluid dynamic state can be seen as another form between a sediment static dust layer and a dynamic dust mixture which is dispersed. Observing this from a process engineering perspective, this state is achieved, e.g. by the dust particles flowing into a stationary bed (at a so-called loosening velocity), being brought into a suspended state and then kept in this state. This state is called fluidization. Two phases (solid-fluid) are involved in this process. The resulting fluidized bed behaves thermodynamically and fluidically analogous to a liquid. Due to the large contact surface between the two

Paper Received: 30 October 2018; Revised: 26 May 2019; Accepted: 27 June 2019

Please cite this article as: Leksin A., Barth U., 2019, Combustion behaviour of dusts in quasi- stationary state, Chemical Engineering Transactions, 77, 655-660 DOI:10.3303/CET1977110

phases, heat and mass transfer processes between the dust particles and fluid as well as between the particles themselves are favoured.
Some process examples in which combustible dust is present in a quasi-stationary state are:

- Pharmaceutical industry using fluidized bed dryers
- Agricultural industry using a combination of fluidized bed agglomeration and fluidized bed spray granulation drying in the production of agrochemicals
- Food industry in the production of dried milk powders, sugar industry, etc.
- Chemical industry, drying of polymers dissolved in water (with partially internal) and external fluidized beds

A description about the combustion behaviour for dust in fluid beds with the result of a possible increase of the so-called combustible index (burning ability of sediment dust) was published in VDI-Report 2014 (Leksin et al., 2014). The intention of investigation can be traced back to two triggering reasons:

- by the development of the (VDI-Guideline 2263 Part 7, 2010) and (VDI-Guideline 2263 Part 7.1, 2013), the committee members identified a knowledge deficit about the fire hazard and the problematic of the Ex-zone classification inside the fluidized beds (Figure 1)

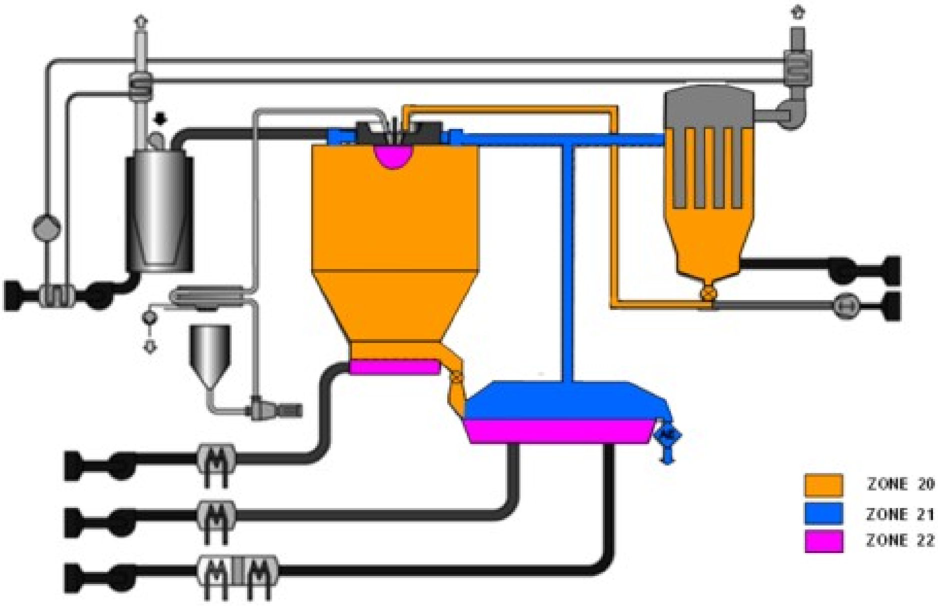


Figure 1: Spray dryer type G with integrated and external fluid bed technology.

- the occurrence of fires in industrial fluidised beds. An example is a dust explosion in an external fluidized bed during commissioning of the spray drying plant by “Fuda und Serrahn“ company in 2011 (Internetpublication, 2011)

Thus, in this context, one is not only talking about a theoretically conceivable or possible event but rather about the probability of such fire events.

2. Dust fires and dust explosions. Test methods for the determination of the safety characteristics of dusts

A systematic assessment process in operational explosion and fire protection begins always with the determination of certain the safety characteristics of dusts. Within the scope of safety related assessment of combustible dusts, burning tests are of huge importance in the field of fire and explosion protection as they evaluate the burning ability of sedimented dust resulting in the so-called class (Table 1) number (combustibility index) according the (VDI-Guideline 2263 Part 1, 1990).
This is the primary test method to detect and avoid explosion and fire hazards. In relation to a quasi-stationary state, the user is confronted with the question of assessing the combustion behaviour of his dust in most objective and comprehensible manner possible for third parties, in order to identify potential risks. Until now, there was a knowledge deficiency how far a combustibility index, which was identified appropriately for sedimented dust, is applicable and acceptable for a safety-related assessment of fluid beds.

Table 1: Examples of combustion behaviour at room temperature

Type of reaction		Class	Reference product
No spreading of fire	no ignition	1	table salt
	brief ignition and rapid extinction	2	tartaric acid
	localized combustion or glowing with practically no spreading	3	d + lactose
Fire spreads	glowing without sparks (smoldering) or slow decomposition without flame	4	H-acid, tobacco
	burning with flame or spark generation	5	sulfur
	very rapid combustion with flame propagation or rapid decomposition without flame	6	black powder

In 2014 and 2015 a description of combustion behaviour for dust in fluid beds with the result of a possible increase of the so- called combustible index was presented by the authors based on numerous laboratory-scale investigations and basic research projects, financially supported by the "German Employer's Liability Insurance Association for the Food and Catering Industry" and the "Intercontinental Association of Experts for Industrial Explosion Protection e.V." (Barth et al., 2015). Since the gained research results in the context to the safety characteristic of dusts are of fundamental importance for the operational practice of the fire and explosion hazard assessment, the topic "quasi-stationary state" in the updated (VDI-Guideline 2263, 2018) deserves particularly mentioning. In other words a test method for the determination of a new safety characteristic for dust, the so-called fire behaviour number in quasi-stationary state (BVZqs) was developed by the authors of this paper, due the combustion behaviour in the modified burning test instrument for fluid beds can not be described with the standardized combustion index definitions. A comparison between the defined fire behaviour number in quasi-stationary state (BVZqs) values and the standardized combustibility index values (BZ) can be seen in Figure 2.

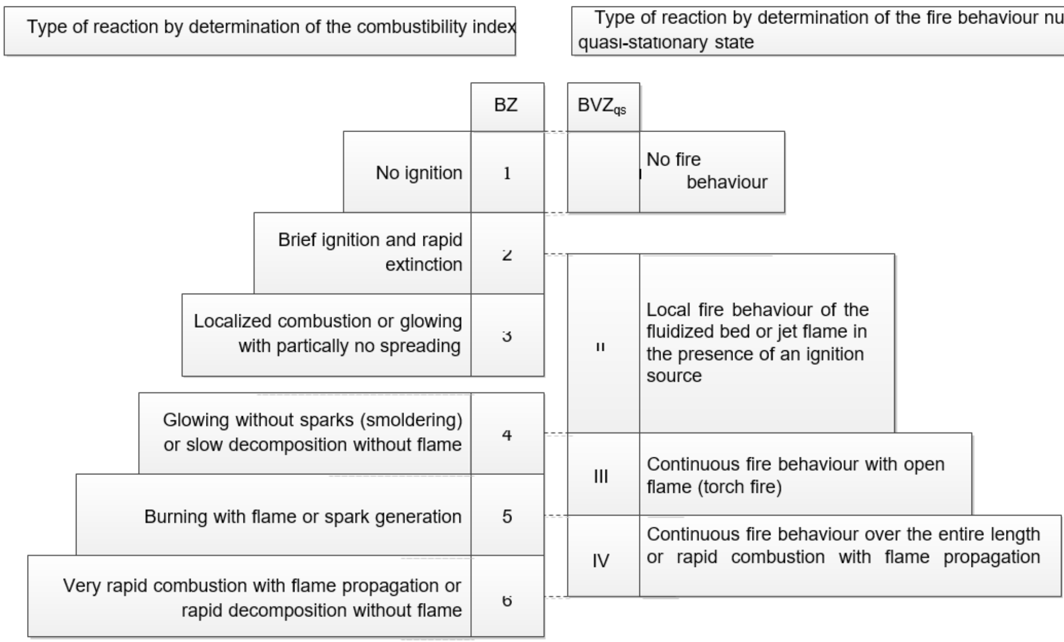


Figure 2: Comparison of the BZ and BVZqs (© Leksin, Barth)

An intolerable risk can be defined from a combustibility index value BZ 4. For the view of the safety related assessment process the determination of additional fire and explosion protection measures must be accrue. This is already fulfilled with a fire behaviour number in quasi-stationary state BVZqs II (Figure 3).

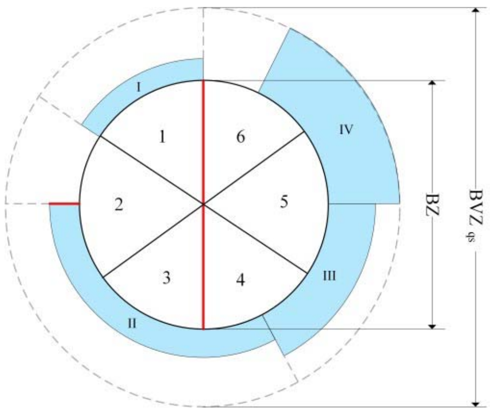


Figure 3: Comparison of the BZ and BVZqs (© Leksin, Barth).

3. Assessment

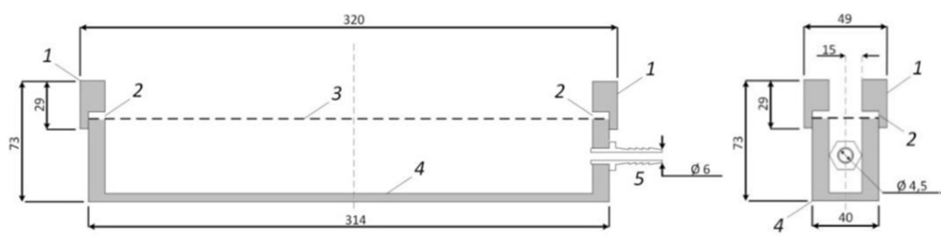
The aim of the test is how the combustion behaviour in a quasi-stationary state differs from the combustion behaviour of a sedimented dust. It is not the content of this test to examine ignition due to different types of ignition sources. A better assessment of fire hazard is to be achieved with the aid of the test for a change in the flammability/behaviour, so that the necessary protective measures can be determined.

The modified test apparatus as per *Barth & Leksin* consists of a metal box which is open at the top and covered with a special wire mesh. A metal frame is placed above the wire mesh and screwed to the metal box. This fixes the wire mesh and defines an area of 30 [mm] x 300 [mm]. This area forms an inflow area of 90 [cm^2] above where a formation of the quasi-stationary or fluid-dynamic state can develop. The room below the wire mesh is connected to a compressed air supply line (dry air). Since different overpressures are also required for different dusts, a control valve is installed which allows inlet pressures between 1 [bar] and 4 [bar] (Figure 4).

Ignition source: Annealing device with electrically heated platinum wire of approx. 1000 [°C] (diameter 1 [mm], length 86 [mm], I= 30 [A]) or gas flame (length approx. 20 [mm], diameter 2-3 [mm]).

Special experience with modified testing equipment:

- Design of the special wire mesh. The concrete design of the wire mesh determines the possibility of fluidizing the sedimented dust and creating a fluidized bed. If different dusts are used, this also requires different wire meshs (e.g. a wire mesh of 20 □□m□□is used for food dusts, such as dried milk or coffee whitener).
- Compressed air supply and control. In addition to the design of the wire mesh, compressed air supply and determine the fluidization. This affects, among other things, the "uniformity" of the generated fluidized bed along its longitudinal axis. The reproducibility of the fluidized beds also depends on this.



1 Metal frame, *2* Seal, *3* Wire mesh, *4* Metal box, *5* Supply of pressurized air

Figure 4: Modified test apparatus for the determination of the fire behaviour number in quasi-stationary state as per Barth & Leksin (© Leksin/Barth 2017).

The sedimented dust sample is deposited on the wire mesh (with a height of approx. 15-20 [mm]). In cases of doubt, the quasi-stationary state determined experimentally height of the the sedimented dust in the apparatus. The system pressure (supply of the pressuirized air) the fluidization must be determined in advance. After the formation of a constant quasi-stationary state, the sample is ignited by the hot platinum wire. The platinum wire is placed in the quasi-stationary layer at the side above the pressurized air connection for approx. 2 [s] (Figure 5). If no ignition occurs, the test must be repeated 5-10 times with the same sample.

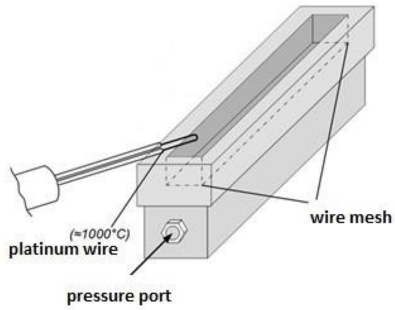


Figure 5: Testing of combustion behaviour of dust in a quasi-stationary state (© Leksin/Barth 2017).

The combustion behaviour of the product is characterized by the fire behaviour number in quasi-stationary state BVZqs (Table 2).

Table 2: Definition of the BVZqs

BVZqs	Type of reaction
I	No fire behaviour
II	Local fire behaviour of the fluidized bed or jet flame in the presence of an ignition source (No spreading of fire)
III	Continuous fire behaviour with open flame (torch fire)
IV	Continuous fire behaviour over the entire length or rapid combustion with flame propagation (Fire spreads)

Parallel to the experience with the modified test apparatus as per *Barth & Leksin* described above (the design of the inflow bottom and the compressed air supply), the product-specific conditions also have an influence on generating the quasi-stationary state and influence the result of the combustion behaviour test. Material properties such as particle size, density and tendency to hygroscopicity can influence the distribution of dust particles in fluidized bed and its height. The hygroscopicity of the dust can indirectly influences the combustion behaviour or the burning speed and depends strongly on the air humidity (Bartknecht et al., 1993). The results of the determination of the BVZqs for dusts with a strong tendency to hygroscopicity can be differ (e.g. a BVZqs II instead of a BVZqs III oder IV).

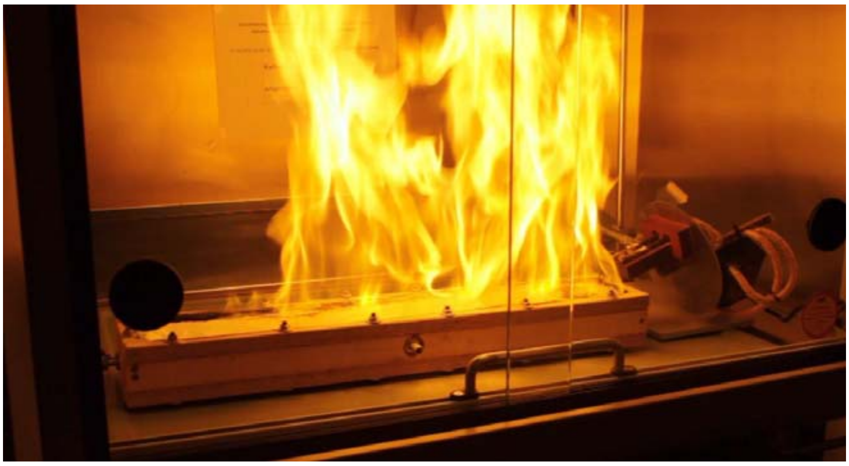


Figure 6: Testing of combustion behaviour of dust in a quasi-stationary state (© Leksin/Barth 2017).

Investigations in a large scale test apparatus (Figure 8) have also shown that the flame height rises enormously to 0,5 meters and higher. Compare to the modified test apparatus, where the flames are approx. 40 cm height, the determined BVZqs does not differ to the large scale apparatus. However, the large scale test show the severe consequences, which a fire could have in a real fluidized bed plant. Table 3 shows test results of the combustibility index (BZ) and fire behaviour number in quasi-stationary state (BVZqs) for different dust.

4. Conclusions

For an appropriate safety assessment of combustible dusts in a quasi-stationary state, the combustibility index known from the assessment of sedimented dust was first tested with the corresponding test apparatus. It is necessary to introduce a new safety factor for characterising dust with the fire behaviour number in quasi-stationary state (BVZqs).

In the updating the (VDI-Guideline 2263 Part 1, 1990), the BVZqs is already included. This give an operator an additional factor, the safety-related characteristic BVZqs, as a basis for assessment which one could objectively decide if protective measures should be required.

Acknowledgments

The authors would like to thank the following research partners for their informal and, in part, financial support for the investigations:

- Intercontinental Association of Experts for Industrial Explosion Protection e.V. (IND EX)
- Berufsgenossenschaft Nahrungsmittel und Gastgewerbe (BGN)
- Deutsches Milchkontor GmbH (DMK), Mr. Lars Dammann
- Dekra Exam GmbH

References

Bartknecht W., G. Zwahlen, 1993 Explosionsschutz: Grundlagen und Anwendung. Berlin: Springer Berlin.

Barth U., M. Bloching, A. Leksin, 2015, Neueste Erkenntnisse aus dem IND EX® -Forschungs-programm "Brand- und Explosionsverhalten von Stäuben in Fließbetttrocknern". 2. Deutscher Brand- und Explosionsschutz Kongress. Dortmund.

Leksin A., U. Barth, S. Laudenbacher, 2014, Ab-/Brandverhalten von Stäuben im Fließbett - Modifikation der Brennprüfung nach VDI 2263 Blatt 1. Sichere Handhabung brennbarer Stäube. VDI-Berichte 2225. Düsseldorf: VDI Verlag GmbH.

VDI 2263 Blatt 7: 2010-07 (Verein Deutscher Ingenieure: Richtlinie), 2010, Dust fires and dust explosions;

Hazards – assessment – protective measures: Dust fires and explosion protection in spraying and drying integrated equipment. Technical regulation, Beuth Verlag GmbH, Berlin.

VDI 2263 Blatt 7.1: 2013-03 (Verein Deutscher Ingenieure: Richtlinie), 2010, Dust fires and dust explosions; Hazards – assessment – protective measures: Dust fires and explosion protection in spraying and drying integrated equipment: Examples. Technical regulation, Beuth Verlag GmbH, Berlin.

Internetpublikation, 2011. Staubexplosion bei Fude und Serrahn in Gransee wird untersucht. www.moz.de/artikel-ansicht/dg/0/1/984973, accessed 01 August 2018.

VDI 2263 Blatt 1: 1990-05 (Verein Deutscher Ingenieure: Richtlinie), 1990, Dust Fires and Dust Explosions; Hazards – Assessment – Protective Measures: Test Methods for the Determination of the Safety Characteristic of Dusts. Technical regulation, Beuth Verlag GmbH, Berlin.

VDI 2263: 2018-07 (Verein Deutscher Ingenieure: Richtlinie), 2018, Dust fires and dust explosions; Hazards – assessment – safety measures. Technical regulation, Beuth Verlag GmbH, Berlin.

Winkler F., 1922, Verfahren zum Herstellen Wassergas, Patent DE437970C.