RESEARCH PAPERS
FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY IN TRNAVA
SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

2012 Number 32

INFLUENCE OF THE FLOW RATE OF OXIDISING ATMOSPHERE ON THE FLAME SPREAD RATE ON THE SURFACE OF ORGANIC SETLLED DUST

Jozef MARTINKA, Karol BALOG, Ivan HRUŠOVSKÝ,
Veronika VALENTOVÁ

Abstract

The presented paper deals with determining the influence of the flow rate of oxidising atmosphere on the flame spread along the surface of the organic settled dust layer. We determined the rate of the flame spread on the surface of the organic settled dust layer (whole grain rye and spelt flour) with absolute moisture of 10 % wt., for the flow rates of oxidising atmosphere 1, 3, 5 and 10 cm/s. Pure oxygen was used as an oxidising atmosphere. The obtained results suggest that there exists a power relationship of the flame spread rate along the surface of organic settled dust layer to the flow rate of the oxidising mixture. The method described is suitable for the relative comparison of the organic settled dust layer from the point of its ability to spread the flame and the influence of the air flow rate on this process.

Key words

Dust · Dust layer · Flame spread rate · Oxidising mixture flow rate · Dust fire risk assessment.

Introduction

Dust is defined as all particles less than 0.5 mm in two dimensions (1). In the working area, dust can occur in the form of dispersed dust (aerosol) or settled dust (aerogel).

---

[1] Ing. Jozef Martinka, PhD., Prof. Ing. Karol Balog, PhD., Ing. Ivan Hrušovský, Bc. Veronika Valentová – Institute of Safety and Environmental Engineering, Faculty of Materials Science and Technology, Slovak University of Technology, Paulínska 16, 917 24 Trnava, Slovak Republic, e-mail: jozef.martinka@stuba.sk, karol.balog@stuba.sk, ivan.hrusovsky@stuba.sk, vera.valentova@gmail.com

Fire hazard of dispersed dust is primarily determined by its ability of explosive combustion in the cases when its concentration in the air is between the lower and the upper explosive limits. The influence of the external conditions as well as of the chemical and physical characteristics of the dispersed dust on its initiation ability is more thoroughly described in (2-4). The most important influence on the sensitivity of a dust cloud to ignition and the resulting explosion has, besides its chemical composition, dust distribution of particle size. The sensitivity of a dust cloud to ignition and the resulting explosion violence (severity) increases with a decrease in particle size (4).

Fire hazard of settled dust depends on its chemical composition, particle size distribution and external conditions (flow rate of oxidising atmosphere, temperature, oxygen concentration in oxidising atmosphere, direction of oxidising atmosphere flow and a number of other factors). Fire hazard of settled dust depends on its ability of flameless combustion. During flameless combustion, a great amount of toxic combustion gases is released. In addition, flameless combustion can take place with no visible signs which would enable its identification without detectors. After a relatively long period, flameless combustion can shift to flame combustion at the most unexpected time. In a manufacturing site with the minimum number of persons present, such a shift can cause great damages owing to the late observation of fire.

Figure 1 illustrates the ratio of chosen dust species involved in dust incidents in the USA.

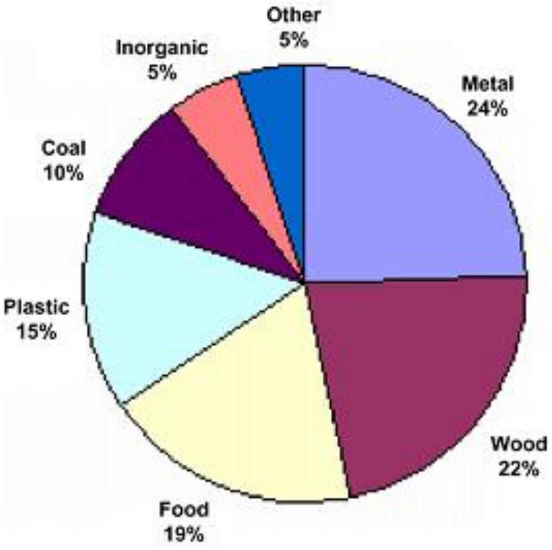


Fig. 1 *Type of material involved in dust incidents (5)*

Figure 2 shows dust incident breakdowns per industry in the USA.

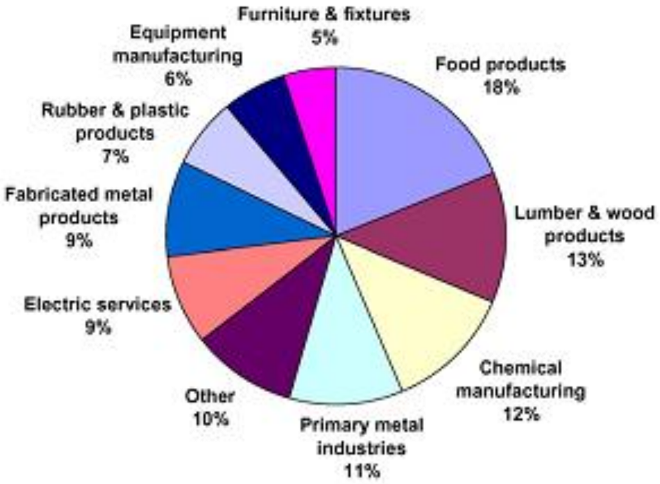


Fig. 2 *Dust incident breakdown per industry (5)*

Similar breakdown of a material type involved in dust incident and dust incident per industry is valid for the European Union or Slovak Republic. The most dangerous are organic dusts processed in the wood and food industry.

Fire risk assessment of dust is practicable by the determination of dusts fire characteristics. Fire characteristics of wood and food dusts have been determined by several authors (6, 7 and 8). For example Slabá and Kasalová-Balog (6, 7) measured the minimum self-ignition temperatures of settled dust of oak (320 °C), beech (320 °C) and spruce wood (320 °C) and also wheat (> 400 °C) and corn flour (> 400 °C). According to (6, 7) the minimum ignition temperature of wheat flour dust cloud is 458 ± 2.7 °C and the minimum ignition temperature of corn flour dust cloud is 460 ± 3.5 °C.

The flame spread rate along the surface of chosen wood and food dusts was measured by Slosiarik (9). The flame spread rate was determined at the oxygen flow rate 0.85 cm/s. Figure 3 illustrates the influence of water content and thickness of dust layer of smooth flour on the flame spread rate along its surface.

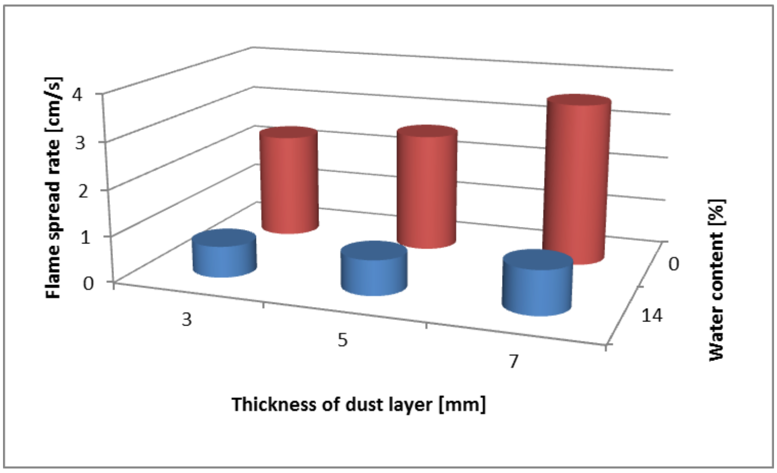


Fig. 3 *Influence of smooth flour layer thickness and its water content on flame spread rate on its surface (9)*

Despite the relatively deep research into dust clouds and settled dust behaviour under fire conditions, there are still missing data about the influence of oxidising atmosphere flow rate on flame spread rate along the surface of settled organic dust. Therefore, the goal of this paper is to measure the influence of the flow rate of oxidising atmosphere (pure oxygen) on the flame spread rate along the surface of the whole grain rye and spelt flour. Another goal is to compare the inflammibility of the investigated materials.

Methods

In the experiment, whole grain rye and spelt flour with absolute moisture of 10 % were used. The particle size distribution of the tested flour is shown in Figure 4.

The influence of the flow rate of oxidising atmosphere was determined using the FTA Flammability apparatus schematically presented in Figure 5. The photo of the used testing apparatus is shown in Figure 6.

Pure oxygen was used as an oxidant. The flame spread rate was determined for four different oxygen flow rates (1, 3, 5 and 10) cm/s. The thickness of dust layer was 5 mm.

The oxidising atmosphere was flowing against the direction of the flame spread. The counter current flame spread was chosen in order to retain the opportunity to compare the measured data with the data in the scientific literature valid for the oxygen flow rate close to 1 cm/s.

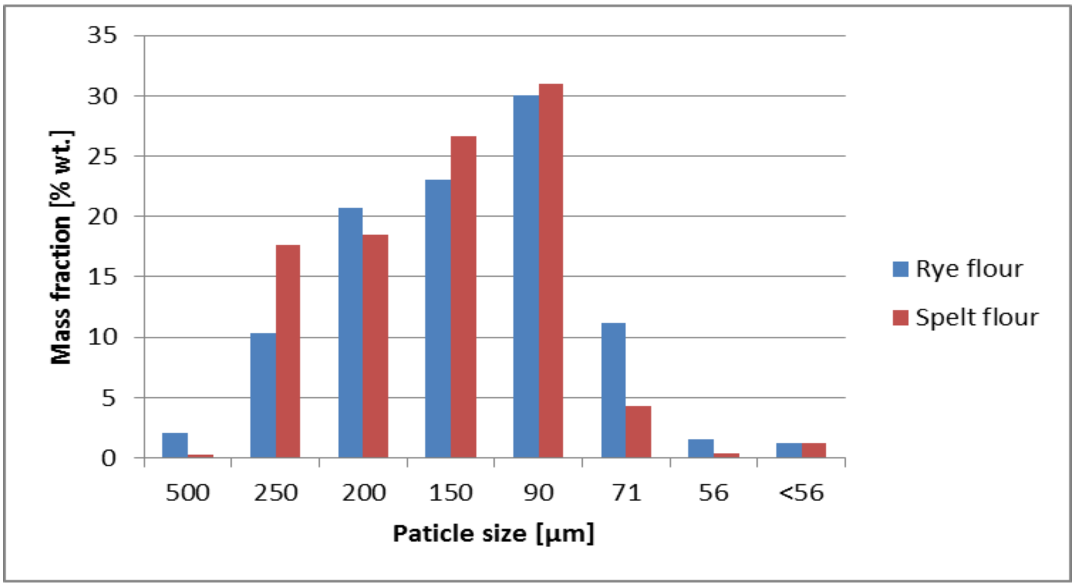
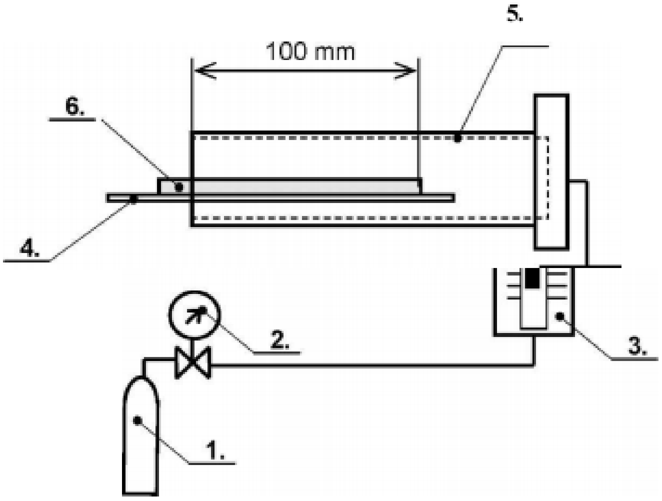


Fig. 4 *Particle size of the tested flours*



1 – oxygen pressure vessel, 2 – reducing valve, 3 – flow meter with a needle valve, 4 – sample holder,
5 – fused-silica tube, 6 – sample

***Fig. 5** Schematic diagram of the FTA Flammability apparatus*

***Fig. 6** Photo of the used FTA Flammability apparatus*

Prior to the measurement, oxygen flow was set to the measured oxygen flow rate using the flow meter with a needle valve (3). The vessel for the sample (4) was filled with the analysed sample in the form of dust. The sample was aligned with the upper edge of the vessel and put into the fused-silica tube (5). The prepared apparatus was left for five minutes to ensure thorough mixture homogenisation. After this period, the sample was lit at the edge of the vessel. When the flame spread up to the first mark (i.e. 20 mm from the sample edge), the stopwatch was started. The stopwatch was stopped when the flame spreading along the surface of the dust layer reached the second mark (at the distance of 100 mm from the first mark). The flame spread rate along the surface of the settled dust was calculated using the known distance between the two marks and the spread time.

Results

The performance of the flame spread rate on the surface of the whole grain rye and the spelt flour is presented in Figures 7 and 8, respectively.

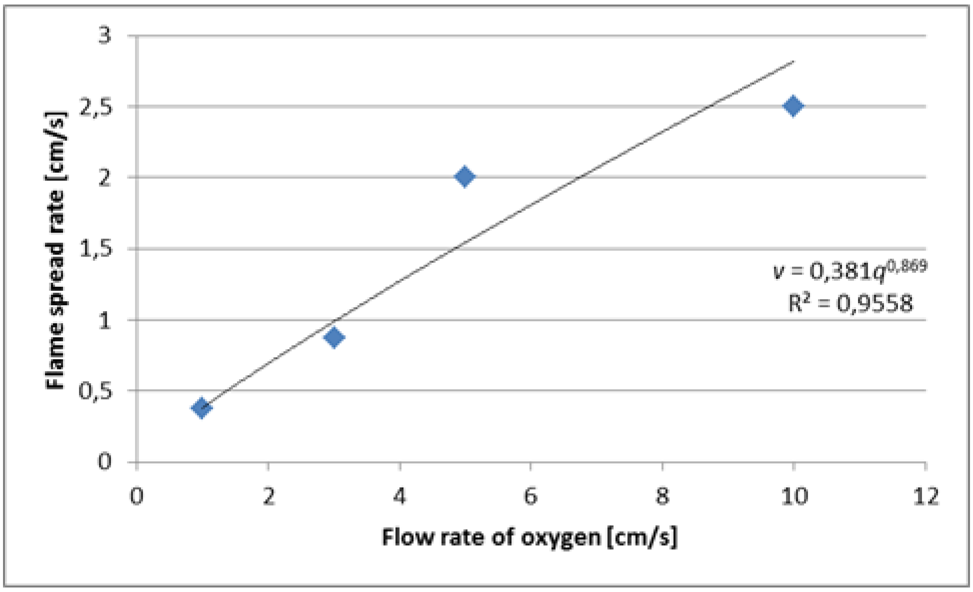


Fig. 7 *Relationship between the flame spread rate on the surface of the whole grain rye flour and the flow rate of oxygen that ranged from 1 to 10 cm/s*

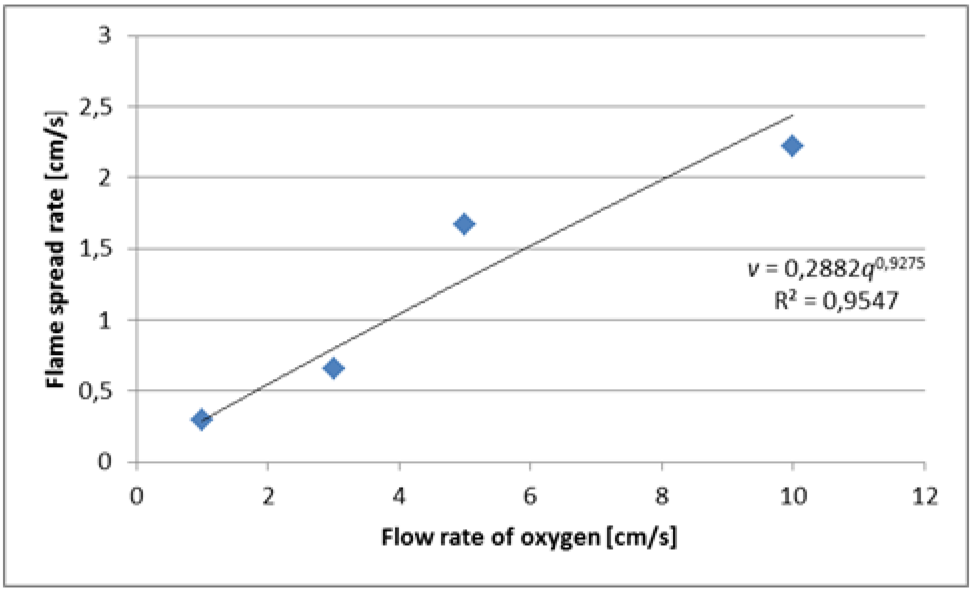


Fig. 8 *Relationship between the flame spread rate on the surface of the spelt flour and the flow rate of oxygen that ranged from 1 to 10 cm/s*

The analysis of the measured data revealed the power relationship between the flame spread rate and the oxygen flow rate. On the basis of the visual observation we presume that, in the range of oxygen flow rate from 1 to 5 cm/s, the relationship between the flame spread rate on the surface of the materials and the oxygen flow rate could be exponential. However, for clear conclusion, it will be necessary to make multiple measurements (for flow rates of oxygen 1, 2, 3, 4 and 5 cm/s). The decrease of growth dynamics of flame spread rate with flow rate of oxygen increase was identified between oxygen flow rate from 5 to 10 cm/s. This effect can be explained by different effect of oxygen flow rate to flame spread rate along the material surface (not only settled dust layer). At the low flow rate in the oxygen atmosphere, each increase of flow rate will cause enhancement of the amount of oxygen on burning. Amount of release rate during burning is proportional to the consumed oxygen. According to Lyon (10), amount of heat release is equal to (13.1 ± 0.7) kJ heat on 1 gram of the oxygen consumed. Therefore, each increase of oxygen flow rate causes increased heat release rate and higher heat release rate subsequently causes the higher flame spread along the surface of material (settled dust). However, the (counter current flame spread) flowing oxygen atmosphere causes heat removal. Heat removal also increases with the oxygen atmosphere flow rate increase. Therefore, the flame spread along the settled dust surface will be increasing with increasing the flow rate of oxygen atmosphere only up to a certain (first) critical value of the flow rate. This (first) critical value is defined as the flow rate at which the flame spread begins to decline. Further increase of flow rate causes further increase of heat removal until equality between heat release by burning and heat removal by flowing of oxygen is achieved. This (second) critical flow rate is accompanied by extinguishing flame. The values similar to those for the oxygen flow rate equal to 1cm/s, were published by e.g. (9, 11-12). For example according to Slosiarik (9), the flame spread rate along the surface of 5 mm thickness layer of smooth flour with 14 % wt. water content at the oxygen atmosphere flow rate 0.85 cm/s was 0.76 cm/s.

Conclusion

The method described above is suitable to compare dusty materials from the point of their ability to spread the flame on the surface of the settled layer. In contrast to the classical oxidation rate test, our method allows to determine the influence of the oxidant´s flow rate on the flame spread rate along the surface of the settled dust.

We demonstrated the strong dependence of flame spread rate on oxidising atmosphere flow rate at counter current flow of oxidising atmosphere.

Further research should focus on determining the influence of particle size distribution on flame spread rate along the settled dust surface and discovering the fraction with the maximum flame spread rate. Furthermore, future research should determine the dependence of the flame spread rate along the settled dust surface on the oxidising flow atmosphere rate at the oxygen atmosphere flowing current flow of flame spread. It should also determine the critical flow rate of oxygen atmosphere at which decrease of flame spread rate along the settled dust surface could be observed, and the critical flow rate of oxygen at which flame spread on settle dust surface extinguishing could be observed.

Acknowledgements

The research was supported by the Scientific Grant Agency of the Slovak Republic (VEGA) within the project No 1/0446/12 and the project ITMS 26220120048 under the Research & Development Operational Programme funded by the ERDF.

References

1. DAMEC, J. 1998. *Protivýbuchová prevence (Anti-explosion prevention).* Ostrava: Sdružení požárního a bezpečnostního inženýrství v Ostravě, 1998. 188 p. ISBN 80-86111-21-0
2. DAMEC, J. et al. 1999. *Protivýbuchová prevence v potravinářství a zemědělství (Anti-explosion prevention in food industry and agriculture).* Ostrava: Sdružení požárního a bezpečnostního inženýrství v Ostravě, 1999. 182 p. ISBN 80-86111-41-5
3. MARTINKA, J. et al. 2011. Effect of whirled teak wood dust particle size to the minimal ignition temperature. In: *New trends in research of energetic materials. NTREM: Proceedings*. Pardubice: Univerzita Pardubice, 2011. pp.833-838. ISBN 978-80-7395-390-4
4. EDABAT, V. 2010. Dust explosion hazard assessment. In: *Journal of loss prevention in the process industries*., 2010, Vol. 23, issue 6, pp. 907-912. ISSN 0950-4230
5. JOSEPH, G. 2007. Combustible dust: A serious industrial hazard. In: *Journal of hazardous materials*, 2007, Vol. 142, issue 3, pp. 589-591. ISSN 0304-3894
6. SLABÁ, I. 2007. Plameňová a bezplameňová iniciácia a propagácia procesu horenia prachov: autoreferát dizertačnej práce (Flame and flameless initiation….). Trnava: Slovenská technická univerzita v Bratislave – Materiálovotechnologická fakulta so sídlom v Trnave, 2007. 27 p.
7. KASALOVÁ, I., BALOG, K. 2011. Minimum ignition temperatures of food dust clouds determined by planned experiment. In: *Annals of the Faculty of Engineering Hunedoara,* Tom IX, Fas. 1, pp. 97-102. ISSN 1584-2665
8. TUREKOVÁ, I., BALOG, K., SLABÁ, I. 2008. Štúdium požiarno-technických vlastností potravinárskych prachov (Study into fire and technical properties of food duts). In: *Vedecké práce MtF STU v Bratislave so sídlom v Trnave*, 2008, No. 25, pp. 161-167. ISSN 1336-1589
9. SLOSIARIK, J. 2006. *Lineárna rýchlosť šírenia plameňa po vrstve usadených organických prachov (Linear rate of flame spreading along the layer of settled organic dusts).* Zvolen: Technická univerzita vo Zvolene, 2006. ISBN 80-228-1524-1. 68 p.
10. LYON, R. E. 2004. Plastics and rubber. In HARPER, CH. A. *Handbook of building materials for fire protection*. New York: McGraw-Hill, 2004. ISBN 978-0-07-138891-7, pp. 3.1-3.51.
11. SLOSIARIK, J. 2004. Vplyv výšky, vlhkosti a náklonu usadenej vrstvy prachu z drevotrieskových dosák na lineárnu rýchlosť šírenia plameňa (Impact of height, moisture and leaning of the settled dust layer…). In: *Wood and fire safety*. Zvolen: Technical University in Zvolen, 2004. ISBN 80-228-1321-4
12. SLOSIARIK, J. 2005. Testing of the flame spread linear speed on foodstuffs and agriculture dust layers. In: *Komunikácie: vedecké listy Žilinskej university,* 2005, Vol. 7, No. 3/2005, pp. 57-59. ISSN 1335-4205

Reviewers:

Prof. Ing. Anton Osvald, CSc.
Doc. Ing. Ivana Tureková, PhD.