Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014: 2(150):55-63

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.150.032

ANALYSIS OF THE SIZE OF DUST PARTICLES WHICH WERE FORMED DURING PELLET PRODUCTION

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ARTICLE INFO

Article history:
Received: July 2013
Received in the revised form: November 2013
Accepted: January 2014

Keywords:
dust,
fractions,
size distribution

ABSTRACT

The objective of the paper was to analyse by means a laser diffraction method, the granulometric composition of dust which settled on various surfaces of factory floors, where pellet was produced. A laser analyser of the size of particles MASTERSIZER 2000 was used in the research. Based on the research, it was found out that the sample of dust contained a limited amount of fractions particularly dangerous for health, i.e. PM_4 and PM_{10} respectively 1.4% and 5.1%. The content of particles of dimension up to 100 µm did not exceed 60% of total volume of the analysed dust. Moreover, a shape of particles was analysed with the use of optic and scanning microscope and NIS – Elements BR software. Values of shape coefficients and histograms of their distribution were determined. Furthermore, relations between the size of particles and its shape were described.

Introduction

Dust is one of the main hazardous factors occurring in the work environment and causes many illnesses including pneumoconiosis and cancer (Koradecka, 1999; GUS, 2013). Pursuant to the Labour Code (Labour Code, Chapter 10) professional risk resulting from hazardous effect of dust should be limited. Inter alia, it should be carried out by encapsulation of production processes, which are the main sources of dust emission and the use of group or individual personal protection equipment (Koradecka, 1999). According to PN-N-18002:2000 a low professional risk is admissible, when the value of the exposition index is W ≤ 0.5 NDS – values of the highest admissible concentration of dust.

Influence of dust on human body is a resultant of the hardness of the performed physical work, concentration of dust, dimensions and the shape of fraction, their chemical composition and crystal structure as well as solubility in body fluids. Particularly hazardous is a fraction of a respirable dust determined as Particulate Matter, $PM_{2,5}$ – (Konieczyński, 2010) or PM_4 (Ordinance of the minister of labour and social politics of 29th November 2002) – which constitutes a collection of fractions which settle in air sacs. In case of PM_4 average value of an aerodynamic diameter of particles is 3.5 ± 0.3 µm. Also thoracic fraction of PM_{10} of an aerodynamic diameter of inhaled grains smaller than 10 µm, which may reach upper respiratory track and lungs (Konieczyński, 2010; PN-EN 482:1998). Acc. to a nomogram presented in the report (NEPSI) for a particle of an aerodynamic diameter of 4 µm there is 50% of chances that it will penetrate the region of air sacks and only 1.3% that a particle of 10 µm will penetrate through. According to this nomogram, among all particles which are in the air of dimensions ≤100 µm only 50% of them may get to a respiratory track.

Some of technological processes related to agricultural production are characterized with very intense emission of dust. Especially during harvesting and threshing, the concentration of dust may exceed 40 $mg \cdot m^{-3}$. It many times exceeds admissible concentration (Ordinance of the minister of labour and social politics of 29th November 2002). Constant exposure on organic dust activity results in toxic syndrome which is specific for this professional group (Dutkiewicz, 2006).

Production of pellets and briquettes especially from straw brings the same risks as dustiness which occurs in some works in agriculture (Maciejewska, et al., 1997). It particularly refers to small establishments which produce biofuels from solid biomass, in which encapsulation of production processes is less effective and fan systems functioning is weakened. No systematic removal of dust deposited on the surface of production halls favours concentration of dust in the air. Then, a professional risk and the risk of explosion or ignition of dust increases (Sawicki, 2003).

Concentration of dust in the work environment is determined with weight by reference to the mass of dust deposited on measurement filters to measurement fractions of dust particles which deposit in various fragments of a human respiratory track. In Poland, for determination of the content of a total dust PN-91/Z-04030/05 applies, whereas for respiratory dust PN-91/Z-04030/06. Dust measuring equipment and devices based on cascade impactor operation are used for measurement (Konieczyński, 2010).

As alternative for direct measurement of dust concentration, a method based on the analysis of the amount and the size of dust particles on surfaces of production halls was suggested. It was assumed that in the condition of saturation of air with volatile fractions which are in the air and dust which deposited on surfaces are similar.

The objective of this article is determination of the content of fractions, particularly dangerous for health, the so called fractions PM_4 and PM_{10} in dust deposited on the surfaces of production halls and determination of properties which characterize the shape of given particles.

Methodology

Determination of the PM_4 fraction content and PM_{10} was carried out through an analysis of results of the distribution of the size of particles of the tested sample at the laser analyser of the size of particles. The applied analyser by MALVERN Company, model MASTERIZER 2000 with an attachment SIROCCO 2000 enables the measurement within 20 nanometers up to 2 milimeters. Mastersizer device records distribution of the volume of particles and then calculating into the volumes of equivalent balls determines their diameters. The method for description of the sizes of a particle was described in the British Standard BS 2955.

The object of the research were samples of dust collected from three selected producers of pellet manufactured from the mixture of sawdust of hardwood and softwood as well as straw. In the shop floor of each company, samples of approx. 10 g of dust settled on various surfaces was collected from three spots located approximately 2 m from the source of dusting. Samples have been initially purified and sieved through a sieve of 0.25 mm meshes. For each sample, triple measurement of the size of particles was carried out at the assumed value of the residual error at the level of 1% and then the results of analysis were averaged and presented in the form of a histogram.

Moreover, properties which characterise their shape were analysed by means of measurement of specific particles. For this purpose the following microscopes were used: optic stereoscopic Nikon SMZ 1500 and a scanning microscope EVO LS 15 f. Zeiss. The obtained images were subjected to analysis with the use of software NIS-Elements BR. For each particle the following were measured: A – Area; P – Perimeter. Then, values of the following shape indices were calculated:

d_z – hydraulic diameter (Eqdia), diameter of a circle of the surface area equal to the object area

$$d_z = \left(\frac{4 \cdot A}{\Pi} \right)^{0,5} \tag{1}$$

w_K – circularity index (Circularity)

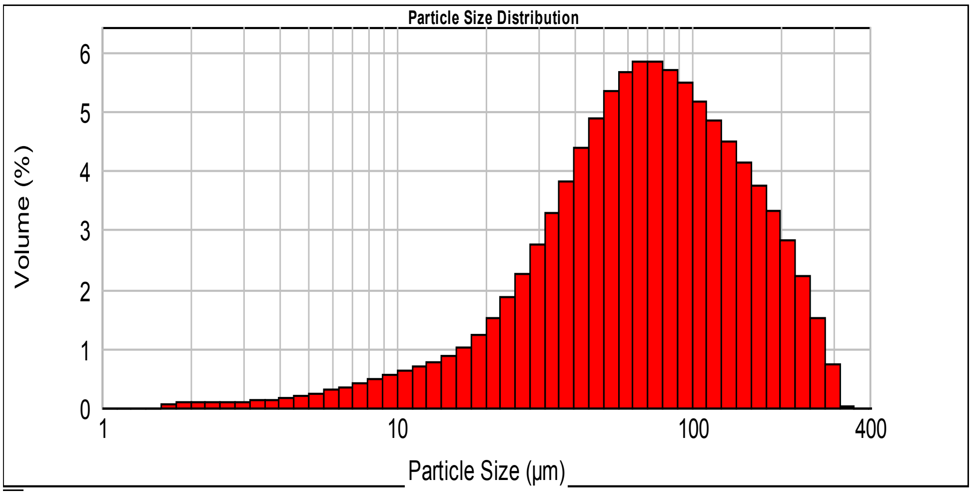
$$w_K = \frac{4 \cdot A \cdot \Pi}{P^2} \tag{2}$$

Values of the circularity index w_K were grouped according to ranges and then densities of number corresponding to them were determined. Moreover, values of the hydraulic diameters d_z corresponding to the particles assigned to a specific group of values w_K. were grouped Results were statistically analysed.

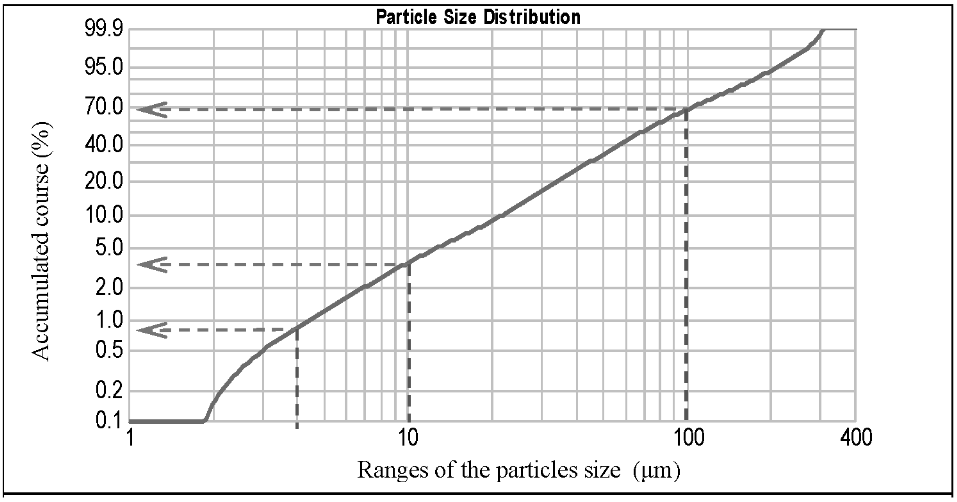
Results

Figure 1 presents exemplary results of the analysis of the distribution of sizes of dust particles, where at the cumulative curve, border interests of the volume of PM_4, PM_{10}, PM_{100} fractions were determined. Results of this determination carried out for 9 samples were listed in table 1.

Figure 2 presents a microscope image of the dust particles and the manner of their dimensioning. Results of measurements of the surface area A and the perimeter P was carried out for at least 300 particles and was listed in figure 3. Results of grouping the number of particles acc. to a range of values of the circularity index w_K were presented in figure 4. According to the value of this coefficient also values of hydraulic diameter d_z were grouped and the results were presented in figure 5.



a)



b)

Figure 1. Exemplary results of analysis of the particles size distribution, a) histogram of the distribution of classes of particles size; b) accumulated course, where axis y according to Rosin-Rammler scale

Table 1
Volumetric participations designated for border values of fractionsPM$_4$, PM$_{10}$, PM$_{100}$

No of a sample	Volumetric participation for fraction, (%)		
	PM$_4$	PM$_{10}$	PM$_{100}$
1	1.2	4.4	57.2
2	1.6	5.2	63
3	1.4	5	61.2
4	1.2	5.3	55
5	2.2	5.9	69.8
6	2.2	6.1	70
7	1.2	5.7	61.8
8	0.8	4.8	52.6
9	0.6	3.8	50
Average	1.4	5.1	60.1
Standard deviation, SD	±0,55	±0,73	±7,0
Coefficient V, (%)	40	14.3	11.7

Average value of respirable fraction PM$_4$ is 1.4%; of thoracic fraction PM$_{10}$ – 5.1% and a fraction to 100 µm – 60%. High value of index V for a fraction PM$_4$ proving considerable diversification of the content of this fraction in particular samples of dust is significant.

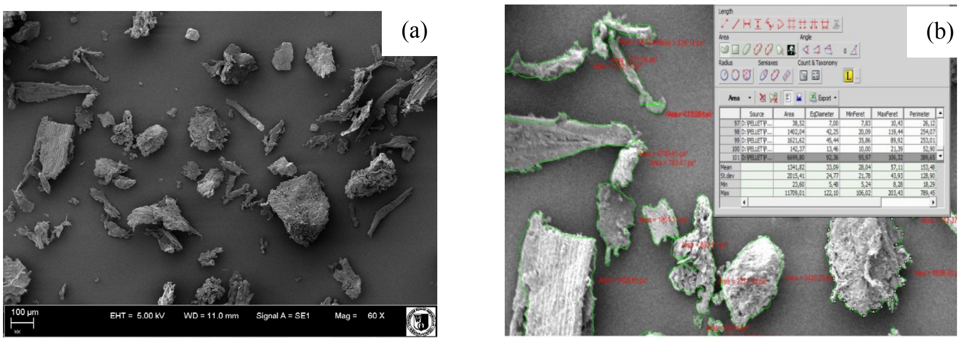


Figure 2. Image of dust particles: a – photo from a scanning microscope, 60x; b – manner of particles determination and their dimensioning

Analysis of the image of dust particles proves that their size and shapes are varied. Very small particles, of a hydraulic diameter d_z of 10 µm have regular shapes, considerably bigger particles d_z of 100 µm are very irregular.

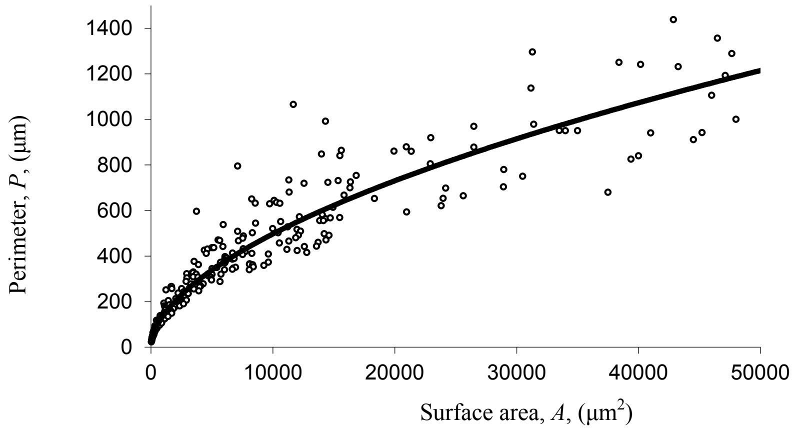


Figure 3. The list of results of measurements, A – Area, P – Perimeter

Relation between the values of particles perimeter P and its area A may be described with the following equation:

$$P = 3 \cdot A^{0{,}555}, R^2 = 0.966 \tag{3}$$

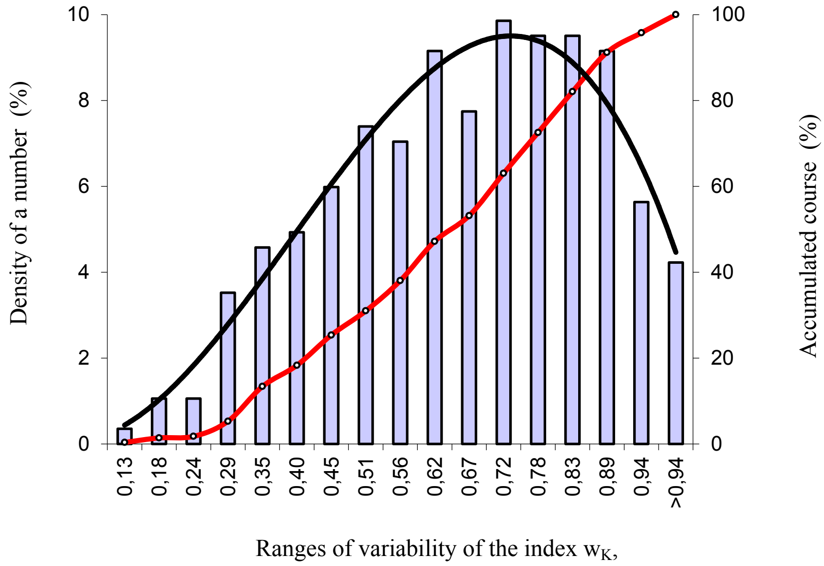


Figure 4. The list of statistical analysis results: histogram of the distribution of ranges of variability of the circularity coefficient w_K and the accumulated course

From the analysis of figure 4 follows that a modal value of the circularity index is value 0.72 and that 62% of all particles are within the value of this index 0.56–0.89. Values $w_K = 0.89$ and 0.56 are equivalent for an ellipse of the proportion of the length of the long semi-axis to a short one respectively 1.5:1 and 4:1. For ca. 5% of particles a very elongated shape of ellipse is characteristic.

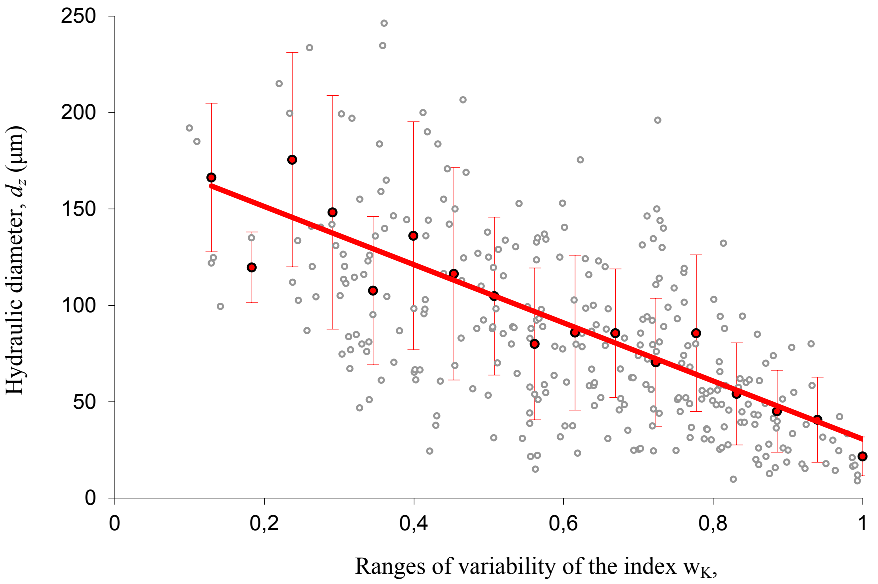


Figure 5. Relation between values of the hydraulic diameter d_z and the circularity coefficient w_K

Analysis of figure 5 shows that there is a correlation between the shape of a particle and its size. The smaller particles have more rounded shape. Relation between values of the hydraulic diameter d_z and the circularity index w_K may be described with an empirical coefficient:

$$d_z = -150.8 \cdot w_K + 181.1 \quad R^2 = 0.878 \tag{4}$$

Conclusions

1. Analysis of samples of dust collected from the surface of shop floors, where pellet was produced shows that the average content of respiratory fraction PM_4 is 1.4% and thoracic fraction PM_{10} – 5.1%. It was determined that 60% of total volume of the analysed dust comprises of a fraction of diameters up to 100 μm. Possibly a half of this amount may be inhaled so 30% of the dust settled on various surfaces of shop floors creates risk.

2. High value of the coefficient of variability V referred to PM_4 proves significant variability of the content of this fraction in particular samples. In case of the remaining fractions, for which $V < 15\%$, the content of particles of dimensions > 4 μm in particular samples was similar.
3. The shape of particles is correlated with their size. The smaller particles are the more regular and rounded they are. For big particles their considerably extended shape of an expanded area is characteristic.

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ANALIZA WIELKOŚCI CZĄSTEK PYŁU POWSTAŁEGO W PRODUKCJI PELETU

Streszczenie. Celem pracy była analiza metodą dyfrakcji laserowej składu granulometrycznego pyłów osiadłych na różnych powierzchniach hal, w których produkowano pelet. W badaniach wykorzystano laserowy analizator wielkości cząstek model MASTERSIZER 2000. Na podstawie badań stwierdzono, że próbki pyłu zawierały ograniczone ilości frakcji szczególnie niebezpiecznych dla zdrowia, tj. PM4 oraz PM10 odpowiednio 1,4% oraz 5,1%. Zawartość cząstek o wymiarach do 100 µm nie przekraczała 60% ogólnej objętości analizowanego pyłu. Analizowano również kształt cząstek z wykorzystaniem mikroskopu optycznego i skaningowego oraz oprogramowania NIS-Elements BR. Wyznaczono wartości współczynników kształtu oraz określono histogramy ich rozkładu. Określono również zależności zachodzące pomiędzy rozmiarem cząstek a jej kształtem.

Słowa kluczowe: pyły, frakcje, rozkład wielkości