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PARTICLE SIZE DISTRIBUTION OF DRIED SEWAGE SLUDGE

R. Kukla, P. Junga, J. Ševčíková

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Abstract

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The aim of this paper was to determine the basic granulometric curves related to the dried sewage sludge and particles size distribution according to Rosin-Rammler, which belongs to the most widely used methods for the statistical distribution of particles in the samples. For this purpose, series of accurate sieves have been chosen. In the next phase, gross calorific value of individual fractions of sewage sludge and subsequently mixed sample, have been determined. Individual measurements were statistically evaluated.

sewage sludge, particle size distribution, mathematical model, Rosin-Rammler, gros calorific value

For determination of the particle size variously complicated methods are used (Macías-García *et al.*, 2004). Particle size is one of the most important physical properties of solids which are used in many fields of human activities such as construction, waste management, metallurgy, production of fuels, etc.

Sewage sludge treatment is currently very relevant. An increasing attention is paid to this issue by both practitioners and from research institutions. The reason is that the management of sewage sludge is an essential part of the financial costs that is necessary for the operation of waste water treatment plant. The correct determination of the particle size distribution in a sample of dried sewage sludge has a significant influence on the development and construction of technology units associated with the sewage sludge utilization, such as special sludge incinerator, cement kilns, waste incinerator, etc.

A series of methods designed to determine the particle size (sieving, microscopy, etc.) were already described in the literature (Dierickx *et al.*, 2000). Using different methods to determine particle size distribution in the sample can be obtained quite different results (Rosin and Rammler, 1933, Ramakrishnan, 1994). What method will be used depends mainly on the final objectives of the characteristics of the material under consideration.

Result of analysis of particle size distribution can be expressed in different forms, by the diameter of particles, respectively by nominal mesh size or by size distribution of particles, in grams, in the weight proportion of each fraction (differential distribution, as a percentage of the cumulative particle size below this value – undersize – and as a percentage of the cumulative size of the value – oversize) (Ballester *et al.*, 2000). The most commonly used mathematical models for calculation of the particle size distribution in a given sample is a mathematical model based on Rosin-Rammler, Gates-Gaudis-Schumann or Nukiyama-Tanasawa. The mathematical model for the statistical particle size distribution of different samples according to Rosin-Rammler achieved good results (Vítěz *et al.*, 2011, Macías-García *et al.*, 2004) and it was also used in our work.

The aim of this paper was to determine the granulometric curves of dried sewage sludge samples: the cumulative weight over the sieve, the cumulative weight under the sieve, the frequency and distribution of particles of sewage sludge by Rosin-Rammler model. Sewage sludge was dried by using of indirect heating. For the purpose of determining granulometric curves particle size distribution by using a selected series of sieves has been used. Determination of gross calorific value and particle size distribution is a prerequisite for the design of technologies aimed at energy use of sewage sludge using fluidized bed combustion.

MATERIAL AND METHODS

The samples of the dried sewage sludge for the analysis has been taken from the sewage sludge dryer directly at the wastewater treatment plant. Collection of samples was performed in accordance with standard ISO 10381-6:1998 Soil quality – Sampling – Part 6. After the transport of the sample of the dried sewage sludge to the laboratory sieving analysis using a sieves of mesh size 0.04 mm, 0.063 mm, 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.71 mm, 1 mm, 2 mm and 3 mm have been performed. Totally six distribution analysis have been made. The portion of dried sewage sludge for analysis ranged between 100 g and 150 g. After weighing the sample has been placed on the top sieve. Individual fractions of dried sewage sludge were then separated by sieving analysis, respectively by shaking of vibration unit, on which set of sieves with diameter of 200 mm have been placed. The number of cycles was set to 150 per minute and the test duration was 15 minutes. After sieving analysis each fraction of dried sewage sludge has been removed from the sieve and has been weighed. Weighing has been done on analytical balances Radwag AS 220 / X with an accuracy of 0.0001 g. Based on the measured data granulometric curves have been constructed, the curve of the cumulative weight of particles over the sieve, curve of the cumulative weight of particles under the sieve, the frequency curve and particle size distribution by Rosin-Rammler.

The cumulative weight over the sieve

The curve of the cumulative weight over the sieve indicate the proportion by weight of grains x_z, that are larger than the size of the sieve mesh size x depending on the size of the mesh size x.

$$R(x) = \frac{\Delta m \times (x_z > x)}{m} \text{ [-]}, \quad (1)$$

where:
Δm... weight of particles with mesh size x and higher [kg]
m...... total weight of the sample [kg].

The cumulative weight under the sieve

Mass of grains whose size x_z is equal to mesh size x or smaller than the mesh size x, depending on the mesh size of the sieve x, is given by the curve of the cumulative weight above the sieve (Rosin and Rammler, 1933).

$$P(x) = \frac{\Delta m \times (x_z \le x)}{m} \text{ [-]}, \quad (2)$$

where:
Δm... mass particles of size x_z equal or smaller than the sieve mesh size x [kg]
m...... total weight of the sample [kg].

Frequency

The frequency curve is derived from the curve of the cumulative weight under the sieve. Frequency curve defines the mass proportion of particles dP(x), that seems in the unit interval.

$$y(x) = \frac{dP(x)}{dx} \text{ [m}^{-1}\text{]}. \quad (3)$$

Mathematic model by Rosin-Rammler

The distribution of particles according to Rosin-Rammler is often used for mathematical description of particle emissions resulting from the milling, grinding, etc. The mathematical model is given by (Rosin and Rammler, 1933):

$$Q = 100 \times \exp\left[-\left(\frac{D}{D_m}\right)^b\right] \text{ [-]}, \quad (4)$$

where:
D ...... particle size [mm]
D_m .... mean particle size [mm]
b....... coefficient of uniformity.

Calorimetry

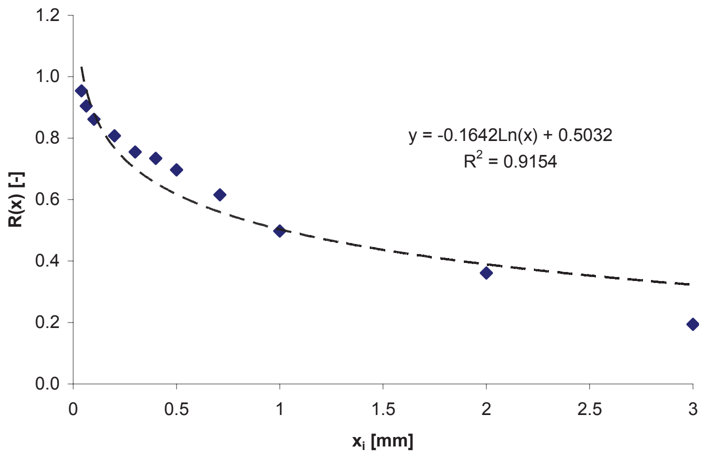
Gross calorific value of individual samples of dried sewage sludge has been carried out in accordance with CSN ISO 1928 Solid mineral fuels – Determination of gross calorific value by the bomb calorimetric method, and calculation of net calorific value. For each sample of dried sewage sludge gross calorific value has been performed in three replications. For the experimental measurements calorimeter Parr 6400 have been used. The samples have been weighed on an analytical balance Radwag AS 220 / X with an accuracy of 0.0001 g.

RESULTS AND DISCUSSION

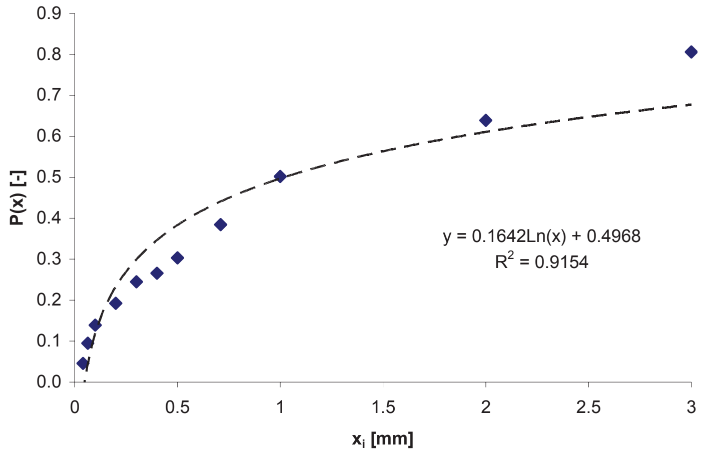
Course of the cumulative weight over the sieve and the cumulative weight under the sieve are shown in Figure 1, respectively in Figure 2. Both figures show that the trend line for the individual points is logarithmic. Logarithmic course of curve of cumulative process is typical for most of the analyzed materials (Otsuki *et al.*, 2010, Macías-García *et al.*, 2004, Vítěz *et al.*, 2010).

The coefficient of determination indicating the proportion of variance of measured values, which were explained by regression, is showed in Fig. 1 and Fig. 2 and it is identical $R^2 = 0.92$. This value is statistically relatively low, it shows that dispersion of measured values is high. For other materials of biological origin, such as a mixture of shavings and sawdust, the value of the coefficient of determination can be higher even 0.99 (Vítěz *et al.*, 2010).

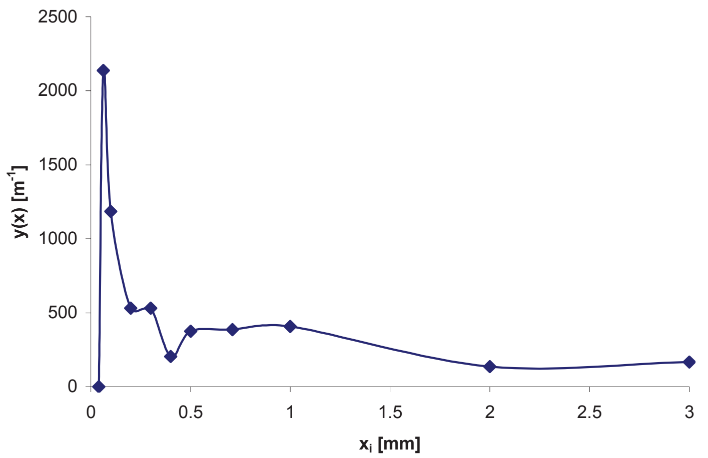
Figure 3 shows the frequency curve of each faction. The figure shows that the greatest frequency



1: *The cumulative weight over the sieve*



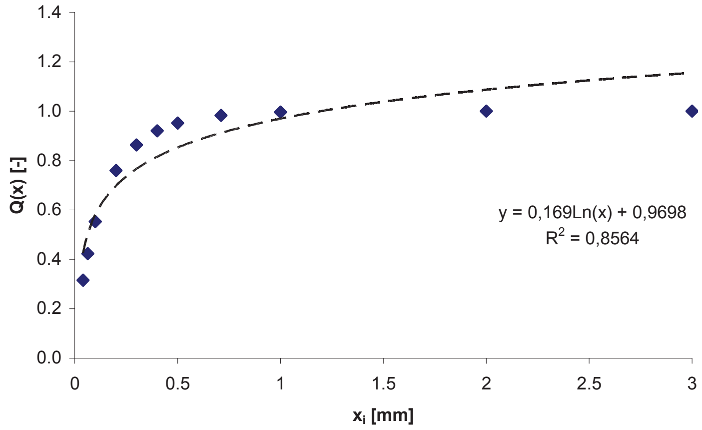
2: *The cumulative weight under the sieve*



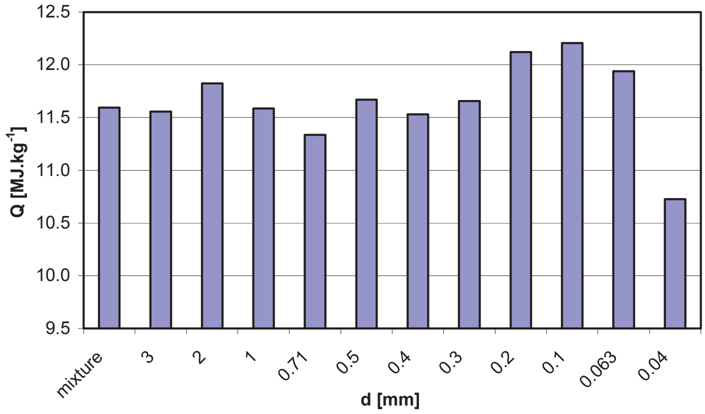
3: *The frequency of individual fractions*

of particles occurs in the range from 0.04 mm to 0.1 mm. From the frequency curve is also apparent that the analyzed material is heterogeneous.

Mathematical model of determination of particle size distribution by Rosin-Rammler is used for the analysis of many kinds of materials (Macías-García *et al.*, 2004; Allaire *et al.*, 2003). The mathematical model determines the distribution of particles in the sample of dried sewage sludge is shown in Figure 4. Trend line is characterized as in previous cases by logarithmic function. The coefficient of determination is $R^2 = 0.86$.



4: *Particle size distribution by Rosin-Rammler*



5: *The gross calorific value of individual fractions of sewage sludge*

Average value of gross calorific value of mixed sample of dried sewage sludge has been 11.6 MJ·kg^{-1}. This corresponded with work of other authors, where values for similar samples ranged from 10.5 MJ·kg^{-1} to 15 MJ·kg^{-1} (Werthera *et al.*, 1999, Weidong *et al.*, 2010).

Based on the particle size distribution six granulometric curves have been created, the coefficient of determination R^2 ranged from 0.86 to 0.92. The relatively low value of the determination indicated that the sample of thermally treated sewage sludge has been highly heterogeneous. This fact also indicated the frequency curve for the various factions, whose course has not been standard, which means that by investigating of the function more than one inflection point has been found. The gross calorific value of samples of dried sewage sludge has ranged in the interval from 10.73 MJ·kg^{-1} to 12.20 MJ·kg^{-1}. A mathematical relationship between the fraction and gross calorific value has not been approved. The lowest gross calorific value has been found for the 0.04 mm fraction and it has indicated a higher proportion of inorganic substances than in the other factions.

SUMMARY

This article deals with the influence of particle size distribution of samples of dried sewage sludge on its final gross calorific value. To determine the gross calorific value particle size distribution of dried sewage sludge has been made. The performed analysis shows, that the highest frequency of presence have been found for fractions from 0.04 to 0.1 mm. The coefficient of determination indicating the proportion of variance of measured values, which were explained by regression and it was $R^2 = 0.92$. Mathematical model of determination of particle size distribution by Rosin-Rammler used for the sample of dried sewage sludge have been characterized by coefficient of determination $R^2 = 0.86$. The gross calorific value of samples of sewage sludge ranged in the interval from 10.73 MJ·kg^{-1} to 12.20 MJ·kg^{-1}. A mathematical relationship between the fraction and gross calorific value has not been approved. The lowest calorific value has been found for the 0.04 mm fraction and it is indicate a higher proportion of inorganic substances than in the other factions.

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Address

Dr. Ing. Radovan Kukla, Ing. Petr Junga, Ph.D., Ing. Jana Ševčíková, Ústav zemědělské, potravinářské a environmentální techniky, Mendelova univerzita v Brně, Zemědělská 1, 613 00 Brno, Česká republika, e-mail: radekk@mendelu.cz