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DETERMINATION OF SOME PHYSICAL PROPERTIES OF BIOMASS FOR THE PURPOSE OF PNEUMATIC TRANSPORT
ODREĐIVANJE NEKIH FIZIČKIH SVOJSTAVA BIOMASE ZA POTREBE PNEUMATSKOG TRANSPORTA

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ABSTRACT

The scope of the research presented in this paper is agricultural biomass which becomes more and more interesting as a fuel, especially for the production of heat. The easiest way to manipulate agricultural residues in the processes, either for production of pellets or in the system for boiler feeding, is to apply pneumatic transport. For the purpose of pneumatic transport, biomass should be grinded into smaller particles. In order to design pneumatic transport it is necessary to know some of the physical characteristics of these particles. There is not enough data in the literature on properties of agricultural biomass such as: bulk density, particle distribution, density, porosity and humidity. The aim of this paper is to show the application of methods for obtaining these parameters. The methods are applied to a sample of raw sunflower husks. The principal methods of determining the physical properties of biomass are experimental. A sample of raw sunflower husks is obtained from one Vojvodinian agricultural household and was prepared for testing.

Key words*: density, bulk density, porosity, humidity, agricultural waste, biomass, pneumatic transport of biomass.*

REZIME

Predmet istraživanja u ovom radu je poljoprivredna biomasa koja postaje sve interesantniji vid goriva, pogotovo za proizvodnju toplote. Najjednostavnija manipulacija poljoprivrednih ostataka, bilo da je u pitanju proizvodnja peleta ili dopremanje poljoprivredne biomase u dozatore ispred kotla, obavlja se pneumatskim transportom. Za potrebe pneumatskog transporta potrebno je usitniti biomasu kako bi se oblik dobijenih čestica približio sfernom. Pri projektovanju pneumatskog transporta potrebni su podaci o fizičkim karakteristikama biomase kao što su: gustina, raspodela čestica, nasipna gustina, poroznost i vlažnost. Ovi podaci su retko dostupni u literaturi. Cilj rada je prikaz primene metoda dobijanja navedenih parametara. Metode su primenjene na uzorku sirove suncokretove ljuske. Primenjene metode određivanja fizičkih karakteristika biomase su eksperimentalne. Uzorak sirove suncokretove ljuske dobijen iz jednog vojvođanskog poljoprivrednog domaćinstva pripremljen je za potrebe ispitivanja. Uzorak sirove ljuske semenki suncokreta samleven je pomoću malog ručnog mlina. Kod materijala nejednolike krupnoće i čestica različitog oblika, kao što je to slučaj sa ovim uzorkom, srednji ekvivalentni prečnik određuje se sitovnom analizom. Za određivanje nasipne gustine izmerena je masa uzorka m, kao i njena nasipna zapremina VBM. Sadržaj vlage u biomasi određen je pomoću uređaja za merenje vlažnosti. U ovom radu prikazan je metod koji koristi piknometar za merenje poroznosti gde se zapremina čvrste faze uzorka VS određuje merenjem pritiska.

Ključne reči*: gustina, nasipna gustina, poroznost, vlažnost, poljoprivredni ostaci, biomasa. pneumatski transport biomase.*

INTRODUCTION

Interest in biomass production is growing since it is carbon neutral and a sustainable resource for energy production *(Tumuluru et al., 2014)*. Agricultural biomass are actualy residues of annual plants such as: straw, stalks, cobs, shells, pits *(Babić, et. al., 2012)*. Policy-makers have set ambitious targets to increase the use of renewable energy. Energy producers have identified biomass as a potential for fulfillment of this goal, relatively quickly and cost-effective if it is burned in existing coal-fired power plants *(Neville, 2011)*. Some engineering chalanges like handling, transportation, storage and processing, have identified physical properties of biomass as problem for power producers *(Wright et al., 2006, Knauf and Moniruzzaman, 2004; Sokhansanj et al., 2006; Rentizelas et al., 2009)*. The structure of agricultural biomass is inhomogeneous and its bulk density and energy content are low compared to conventional fossil fuels.

The use of biomass for energy is either direct - burning biomass in boilers, or indirect - pellet production or biofuels. In both cases, one of the ways of manipulating the biomass, and very often the most convenient, is the pneumatic transport. There are many reasons why pneumatic transport is used for unloading and reloading of different materials. For all these applications the particle size of the material has to be reduced. Reducing the size of particles is considered to be a significant step in the conversion process *(Tumuluru et al., 2014)*.

Pneumatic transport involves the wide variety of particulate and granular solid materials in a gas stream. Size and shape of the particles and their surface roughness depends exclusively how they were formed. In the case of biomass particles are mainly shells of unequal size, different shape and roughness. Therefore, it is important to adopt an "equivalent particle", which spatial shape will represent all of the particles in the mixture. This is not an easy task, and the most elegant solution was to adopt sphere as "equivalent particle".

Nomenclature:

f_i - mass of fraction i [%]
h (-) - humidity
m (kg) - mass
p (Pa) - pressure
V (m^3)- volume
Greek symbols
ρ (kg/m^3) - density
ε (-) - porosity

Subscripts
1 – chamber 1
2 – chamber 2
b – bulk
BM - biomass
C - callibration object
S - solid
ave - average

MATERIAL AND METHOD

Bulk density, particle size distribution and porosity are three important and closely related parameters in pneumatic transport. Porosity ε is the ratio of volume of fluid within the area comprised by the material (the difference of bulk volume of biomass V_{BM} and the volume of the solid phase biomass V_S) and bulk volume of material V_{BM}:

$$\varepsilon = \frac{V_{BM} - V_S}{V_{BM}} = 1 - \frac{V_S}{V_{BM}} \tag{1}$$

Porosity is a dimensionless property and its size ranges from 0 to 1.

In this paper are investigated physical properties of raw sunflower husks obtained from a household in Vojvodina. The material was stored in a covered indoor storage.

There are a many test standards relating to the bulk solid materials handling [1,2]. Although some of the standards were developed by the individual countries (for example, Austria, Sweden, Germany), the majority of the test standards for biomass material in EU are still in the developing stage. Some characteristics of solid biomass hinder or prevent the application of the existing standard test methods. For instance, particles are too large to use the traditional methods of testing (Jenike method [1]), or non-homogeneity of biomass aditionaly hinder the use of conventional tests. Nevertheless, the principles of various commonly used experiments can still be used as the background knowledge for testing solid biomass fuels. *(Wu, et al., 2011)*.

The particle size distribution in the sample is an important physical property of solid biomass since it, together with the moisture content influence the flow properties of the material in transport and storage systems. The understanding of particle size distribution will also help to deploy suitable handling and storage equipment *(Wu, et al., 2011)*. The simulations *(Hilton, et al. 2009)* have shown that altering the shape of a particle by a small amount can significantly affect the bulk dynamics of a pneumatic conveying system. The change in shape of a particle causes the packing fraction to change, altering the bulk density of the particle bed. This, in turn, alters the fluidization velocity and can cause slugs to become unstable.

A sample of raw sunflower husks was grinded using a small hand mill. For materials of uneven particle sizes and shapes, as is the case with the sample, average equivalent diameter can be determined by sieve analysis. For this purpose were used standard sieves made from wire with a square mesh of dimensions: 0.46 mm, 0.96 mm, 2.75 mm, 4.5 mm and 5.7 mm. The sample was passed through the sieves, which were shaken for 10 minutes with a low amplitude (approximately 1 cm). A series of five vertically arranged and connected frames enabled the preparation of 6 fractions. Each of the fractions was measured, and the total mass was obtained as mass share of each of the fractions Δm_i. Sieve analyzes provided information on participation of each fraction f_i in the total mass of material m.

$$f_i = \frac{\Delta m_i}{m} \cdot 100\,[\%]\,. \tag{2}$$

According to cumulative distribution $N(d)$ and density function $n(d)$ was determined average diameter of equivalent particle d_{ave};

$$d_{ave} = \frac{\int_0^\infty n(d) \cdot d \cdot d(d)}{N}\ \text{[mm]}. \tag{3}$$

Bulk density was determined by measuring sample mass m and bulk volume V_{BM}:

$$\rho_b = \frac{m}{V_{BM}}\ \left[\frac{\text{kg}}{\text{m}^3}\right] \tag{4}$$

The mass was measured on laboratory scale and bulk volume in menzura. A series of four measurements was conducted and finally was calculated mean bulk density.

The moisture content of the biomass was determined with the device for moisture measurement according to "oven dry" method [3].

There are various methods in the literature for the porosity determination. It is known that the porosity of the grains of different cereals *(Chang, 1988)*, sediments, as well as various filters *(Sreedhara, et al., 2014)*, can be measured by a gas pycnometer *(Chang, 1988)*. This paper describes a method that uses pycnometer to measure porosity, where the volume of the solid phase of the sample V_S is determined by pressure measuring.

The gas pycnometer is a device which consists of two chambers with a valve between. The measurements consist of three stages. In each stage are measured pressures in two different cases. In the first case (Fig. 1), the measurement is performed as follows: valve 6 between the source of compressed air (compressor) 5 and chamber 2 is closed, valve 4 between chambers 1 and 2 is opened. Chambers 1 and 2 are initially at atmospheric pressure p_1 (valve 3 between the chamber and ambient is open). Valve 4 between the chambers is closed. Valve 6 between the compressor 5 and chamber 2 (volume V_2) is opened. Valve 6 between two chambers and compressor 5 is closed and pressure p_2 is measured. It is considered that the chambers and their contents are at the same temperature T. In the second case, the measurement is performed when the valve 3 between chamber 1 and ambient is closed and valve 4 between chambers 1 and 2 is opened. Gas flows between the chamber and soon is reached pressure equilibrium which is measured (p_3).

In the second stage of the measurement the same procedure is repeated. The only difference is that inside the chamber 1 (volume V_1) is put biomass 8 with known bulk volume V_{BM} and unknown volume of the solid phase V_S (Fig. 2). Pressures p_5 and p_6 are measured. In the third stage, again the procedure is repeated, but in the chamber 1 is now put calibration object 9 with known volume V_C (Fig. 3). Pressures p_8 and p_9 are measured.

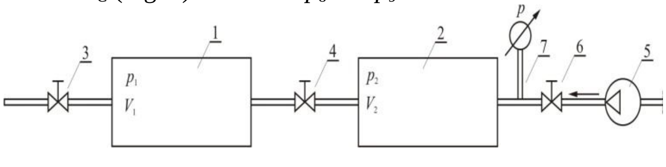

Fig.1. First stage of measurments

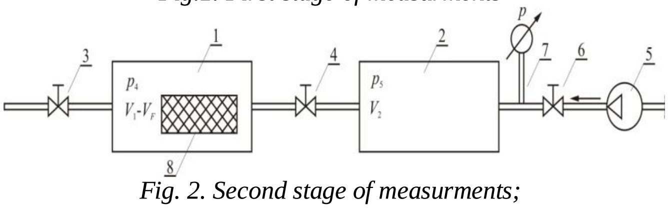

Fig. 2. Second stage of measurments; in chamber 1 is put biomass

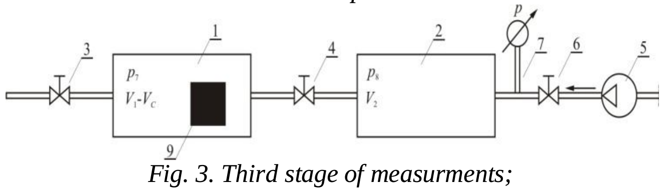

Fig. 3. Third stage of measurments; in chamber 1 is put calibration object

Applying ideal gas equation of state and equation of isotherm, following equations are:

$$V_2 = \frac{p_3}{p_2 - p_3} V_1 \quad (5)$$

$$V_{BM} = V_1 - \frac{p_5 - p_6}{p_6} V_2 \quad (6)$$

$$V_1 = \frac{V_C}{1 - \frac{p_8 - p_9}{p_9} \frac{p_3}{p_2 - p_3}} \quad (7)$$

Porosity is calculated according to formula (1).

RESULTS AND DISCUSION

The results of investigation of physical characteristics of raw sunflower husks are presented in tables. In Table 1 are presented results of sample bulk volume determination. In Table 2 is presented sample mass distribution. In Table 3 is presented porosity of sample. In Table 4 are given physical properties of sample, such as: average bulk volume, humidity, bulk mass, bulk density and average porosity.

Table 1. Bulk volume of sample

No. of measuring	I	II	III	IV
Bulk volume V_b [ml]	230	225	220	225

Table 2. Sample mass distribution

Diameter range of particle [mm]	0 - 0.46	0.46-0.96	0.96-2.75	2.75-4.5	4.5-5.7	5.7-10	Total
Mass of particles Δm_i [g]	0.8	4.03	20.90	15.56	1.24	1.1	43.63
mass of fraction i f_i [-]	1.83	9.23	47.9	35.6	2.84	2.52	100
Number of particles N_i [-]	19429	10768	2375	403	16	13	33004
Particle distribution n_i [-]	42237	17322	4688	1127	323	16	-

Table 3. Porosity of sample

p_2 [Pa]	2.18	2.26	2.17	2.17
p_3 [Pa]	1.13	1.17	1.12	1.12
p_5 [Pa]	2.17	2.26	2.16	2.16
p_6 [Pa]	1.16	1.2	1.15	1.15
p_8 [Pa]	2.17	2.26	2.17	2.17
p_9 [Pa]	1.13	1.18	1.13	1.13
V_C [cm^3]	3.808	3.808	3.808	3.808
V_b [cm^3]	70	70	70	70
V_1 [cm^3]	399.9	216.7	208.2	208.2
V_2 [cm^3]	430.3	232.6	222.1	222.1
V_s [cm^3]	25.18	11.23	13.15	13.15
ε [-]	0.64	0.839	0.812	0.812

It can be noted that particle distribution of sample corresponds to log - normal distribution what was expected (Fig. 4). Average particle diameter is determined according to Eq. (3) and it is d_{ave}=1.32 mm. This diameter should be used for calculations as a diameter of equivalent particle.

According to measured data of bulk volume and porosity it can be concluded that more measuring points should be provided, since the repeatability of measuring is not high enough.

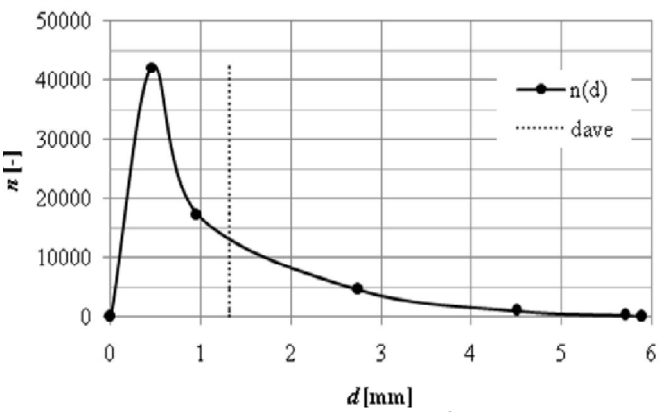

Fig. 4. Particles distribution of sample

Although, the value which was calculated with this method can be used as an input data for the needs of pneumatic conveying and combustion calculation.

Table 4. Physical properties of sample

Ave. bulk volume V_{bave} [ml]	Moisture Content h [%]	Bulk mass m_b [g]	Bulk density ρ_b [kg/m^3]	Average porosity [-]
225	15.37	43.63	194	0.764

Porosity should be given together with particle size distribution and bulk density, otherwise information on porosity is not complete.

CONCLUSION

In this paper are presented methods for determining the parameters that describe the biomass sample and that are necessary in any calculation (pneumatic transport, calculations of combustion). In order to determine physical parameters of the biomass it had to be grinded first. Than, its bulk volume, bulk density, size distribution of particles, porosity and moisture content were determined. In this way all the necessary parameters that are included in the calculations of pneumatic transport or combustion are provided.

The average diameter of equivalent particle was determined according to particle size distribution. This average diameter is a baseline information for pneumatic transport or biomass combustion calculation.

Finding porosity is the most complex part of the physical properties determination. Presented method is easy to use although the apparatus requires some specific features characteristic for pressurized air. The data can be easily processed and together with the bulk density and particle size distribution represent valid data for calculation.

The bad repeatability of the results indicates that a larger number of measurements is required in order to get more accurate calculation of arithmetic mean of bulk density and porosity of the sample.

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