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Some simplified geometrical properties of elephant grass and sugarcane trash particles

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A B S T R A C T

Two types of biomass solid particles, elephant grass ("*Pennisetum purpureum Schum.*" variety) and sugarcane trash have been studied in laboratory in order to obtain information about several geometrical properties. In both cases, the length, width, and thickness of fifty randomly selected particles from the fractions of each size class or group of particles, obtained by mechanical fractioning through sieves, were measured manually given their sizes. A geometric model of rectangular base prism type was adopted based on observations. It was demonstrated that most of the measured particles exhibited lengths significantly greater than width ($l \gg a$). From those measurements, average values for other geometrical properties were estimated; for example, shape factor, sphericity, particle specific surface areas, equivalent diameter, etc. A statistical analysis was done, and empirical and semi-empirical mathematical correlation models were proposed. These correlation models were obtained by non-linear regression analysis to describe the characteristic dimension of particle dependence on geometrical properties, which proved to be a good fit for the reported experimental data.

1. Introduction

A proper knowledge of the physical and chemical properties of the fuels is essential in order to design biochemical and thermochemical conversion processes and equipments. The lack of standards for characterizing solid biomass fuels makes it difficult to achieve an adequate understanding and meaningful comparison of the experimentally determined properties.

Most recently, some investigators have focused on elephant grass (a family of grasses) and sugarcane trash, which are lignocellulosic materials with potential value to biofuels and bioenergy production [1]. The energetic potential of these sources of lignocellulosic materials is comparable to that of wood, but with significantly lower moisture content in the initial condition of use. Also, early investigations of ethanol recovery from enzymatic hydrolysis by the National Renewable Energy Laboratory (NREL) in Colorado, United States, and Laboratório Nacional de Ciência e Tecnologia do Bioetanol (CTBE) in Campinas, São Paulo, Brazil indicate that switchgrass and sugarcane bagasse respectively are a very suitable substrate and produce high ethanol yields from current simultaneous saccharification and fermentation technology (SSFT). The materials above appointed may be considered as an agrofiber source for pulping and it appears to be a promising substitute for some woods in the production of paper. They have a relatively high cellulose content, relatively low ash content, and good fiber length to width ratios [2].

Research work involving fluid–particle interactions or both separated phases require knowledge of physical and geometrical properties. Solid phase is characterized by the knowledge of its density, particle size distribution and particle shape. These properties have a significant influence on some mechanical handling and processing operations, as well as developing technologies. Particularly, the sugarcane bagasse is a fibrous residue resultant from the sugarcane milling, composed basically by two types of particles; the fiber and the pitch [3,4]. The fiber is composed of fibrovascular bunches that give it hardness and are transport elements. The pitch is formed by spongy parenchyma cells where it accumulates the juice containing the sugars (sucrose). The sugarcane trash is a fibrous material constituted basically by green leaves, dry leaves and foliage of the plant. Bagasse and trash represent 2/3 of the sugarcane energy and 52% of the plant total mass.

Ponce et al. [3] have studied the particles apparent density as well as the geometrical properties of different sugarcane bagasse fractions. That study was based on the direct measurement of the three particle dimensions: length, width and thickness, having chosen a rectangular base prism as the geometrical model in order to characterize the particles.

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Geldart [5] compared several methods during the evaluation of physical and geometrical properties such as sphericity and apparent density of porous particles like those of glass, sand and calcareous. Bernhardt [4] and Ramirez and Lagunas [6] published their experimental results on the determination of volume and surface shape factors for each fraction of classifying sugarcane bagasse, and also of the total specific surface area of the sugarcane bagasse particles (m^2/g or mm^2/g) according to the following relation:

$$s_e = \frac{a_s}{a_v \rho_a} \int_0^\infty \frac{1}{X_i} \frac{dM_i}{dX_i} dX_i \tag{1}$$

Where:

s_e Total specific surface area of the particles (m^2/g or mm^2/g);
a_s and a_v Shape factors for area and volume in the respective size class of the particles of material, dimensionless;
ρ_a Particle apparent density, kg/m^3;
X_i Characteristic dimension in the respective size class of the particles of material, m;
M_i Mass fraction in the respective size class of the particles of material, dimensionless.

And the specific volumetric surface area of the material particles (or samples) in m^2/m^3 (or mm^2/mm^3), according to following relation:

$$s_v = s_e \rho_a (1-\varepsilon) \tag{2}$$

Where:

s_v Specific volumetric surface area of the material particles (m^2/m^3 or mm^2/mm^3);
ε mean conglomerate porosity, dimensionless.

The literature does not provide any information about physical and geometrical properties for elephant grass and sugarcane trash materials, that allows to evaluate its use as lignocellulosic feedstock on the fast pyrolysis and gasification processes, commonly conducted in packed and fluidized bed reactors to produce charcoal, liquid biofuels, biosyngas and ethanol by hydrolysis process, also on the pneumatic and hydraulic conveying systems, drying systems, pneumatic and mechanical classifying systems, and others.

Thus, the objective of this study was to develop a new and simplified methodology for approximately determining the shape factor, surface shape factor, volume shape factor, sphericity, specific surface area and other geometrical properties, totalizing eighteen geometrical properties determined for seven size fractions of elephant grass and sugarcane trash particles. For this purpose, a protocol for the experimental and theoretical determination of geometrical properties of biomass solid particles was developed. As a first approach this methodology can be applied to any biomass particle with several moisture contents.

Empirical mathematical models were proposed for ten properties of those determined and obtained through non-linear regression analysis. The determination coefficient for each empirical or semi-empirical model to verify a good fit for the reported experimental data was used.

Quantitative data values of these properties studied here are the basic data for designing different systems, such as, pneumatic classification systems, conveyor belts, storage silos and several biochemical and thermochemical reactors.

2. Theoretical approach

Usually, standard methods for physical and chemical analyses applied to coal and coke as well as those for wood have been adapted and utilized for characterization of polidisperse biomass fuels. However, the characterization results for such materials as sugarcane bagasse and trash, elephant grass, rice husk, coffee straw, and other biomass, are, most of the time, inconsistent and the yield results are difficult to interpret. In fact, ASTM (American Society for Testing and Materials) methods are applied to quite dense materials whose physical distribution characteristics are very different from those of renewable nature. On the other hand, polidisperse biomass fuels, such as sugarcane bagasse and trash, and those above cited, have low density and complex size and shape distributions of particles. For these types of biomass, the normalized techniques used for physical and geometrical analyses of biomass fuel particles are not usually mentioned.

It is necessary to understand the particle size distribution analysis (PSDA) for those materials, which constitute also a field of numerous and different reported results due to the complex nature of these solid materials and the lack of detailed description of the adapted methodology. It's said that there is not a unique opinion about the size and shape of the particles which can be represented using an exact probability density function to describe the distribution of particles of these materials according to their sizes.

The biomass particulate system models studied consist of porous particles having a wide size distribution and non-spherical shapes. Other characteristics of these particulate models of representative samples are often difficult to be obtained as well as the particle size distribution (PSD) experiments have commonly lower reproducibility and reliability because of the difficulty in handling biomass samples.

After obtaining each mass fraction, the material was replaced to direct handling in order to verify visually the particle morphological structure (shape and dimensions of particles). This observation process allows associating the shape of the particles to some simple geometrical model (Fig. 1), and by this way there is a space representation for the particle dimensions.

The literature presents the usage of the two applicable geometric models, in most cases, to sugarcane bagasse. These models are for the fiber particles, a model of elliptic/cylindrical base prism, and for the pitch particles a spherical model.

In this case, the geometrical and morphological behavior of particles on each examined size classes were obtained analyzing particles having high length/width ratios, which were approximated to a rectangular base prism with parallel flat faces (parallelepiped). Particles of regular shape type (cubic space model), commonly represented with length/width ratio near unity, and spherical particles were not noticed. So, linear measures for length, width and thickness were taken for each particle.

The relationships used and their preliminary definitions for the estimation of all physical and geometrical properties were the following:

- Characteristic dimension, X_i, mm [4]: The parameter used for identifying the characteristic dimension of the i-th mass fraction of the polidispersed particles.

$$X_i = \bar{X}_{i-th} = \left[\frac{\left(X_2^2 + X_1^2\right)(X_2 + X_1)}{4} \right]^{1/3} \tag{3}$$

- Projected area of the particle (rectangular base prism model), A_{proj}, mm^2 [3,4]:

$$A_{proj} = q.a.l \tag{4}$$

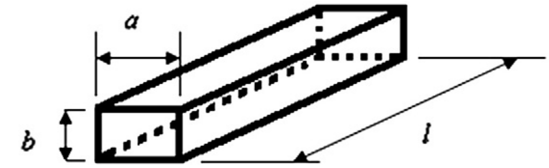

Fig. 1. Assumed geometrical model (rectangular base prism or parallelepiped).