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Determination of the sphericity of granular food materials

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Abstract

In the present study, a new dimensional method and equation were developed to calculate the sphericity (ϕ_s) of certain shapes (sphere, cubes, rectangular solid and cylinder) and some granular food materials (wheat, bean, intact red lentil, chickpea and coarse bulgur).

It was found that increase in ϕ_s value caused deviation from the absolute sphericity ($\phi_s = 0$). Sphericity was constant and independent of size for certain shapes at 0, 0.00271 and 0.00155 for sphere, cube and cylinder (length = diameter), respectively. Also, the sphericities of wheat, bean, intact red lentil, chickpea and coarse bulgur were determined as 0.01038, 0.00743, 0.00641, 0.00240 and 0.01489, respectively ($P < 0.05$). As expected, chickpea had the best and coarse bulgur had the worst sphericity due to their specific shapes.

Keywords: Sphericity; Wheat; Bean; Lentil; Chickpea; Bulgur

1. Introduction

The shape of an individual particle is conveniently expressed in terms of sphericity ϕ_s, which is independent of particle size. For a spherical particle of diameter D_p, $\phi_s = 1$; for a nonspherical particle, the sphericity is defined by the relation in Eq. (1). For a cylinder where the diameter equals to length, ϕ_s is calculated to be 0.874 and for a cube, ϕ_s is calculated as 0.806 (McCabe, Smith, & Harriott, 1985, 2001; Geankoplis, 1983; Perry, 1984; Holdich, 2002).

$$\phi_s \equiv 6V_p/D_pS_p \qquad (1)$$

where ϕ_s, V_p, D_p and S_p are sphericity, volume of one particle, equivalent or nominal diameter of particle and surface area of one particle, respectively.

The equivalent diameter is sometimes defined as the diameter of a sphere of equal volume. For granular materials, however, it is difficult to determine exact volume and surface area of a particle to obtain the equivalent diameter, and D_p is usually taken to be the nominal size based on screen analyses, visual length measurements or microscopic examination. The surface area may be found from adsorption measurements or from the pressure drop in a bed of particles and Eq. (1) used to calculate ϕ_s. For many crushed materials ϕ_s is between 0.6 and 0.8, but for particles rounded by abrasion ϕ_s may be as high as 0.95 (Geankoplis, 1983; Perry, 1984; McCabe et al., 1985, 2001; Holdich, 2002).

As explained above, the main problem in having irregular shape granular materials is the calculation of the exact volume and surface area. High-level mathematical formulas should be used to calculate the volume and surface area. Additionally, instead of a calculation method, advanced experimental methods can be used

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(Geankoplis, 1983; McCabe et al., 1985, 2001). Therefore, the determination of the solid mechanical and handling properties of any granular food material using sphericity is very difficult and also not very practical.

The present study deals with (1) the derivation of a sphericity equation, (2) the determination of the sphericity values of certain shapes i.e. sphere, cubes, rectangular solids and cylinders having different dimensions, (3) the application of the sphericity equation to some granular food products.

2. Materials and methods

2.1. Materials

Wheat (*Triticum durum*, Fırat-98, harvesting year 2003), bean (Tokat species, harvesting year 2003), red lentil (Kızıltepe species, harvesting year 2003), chickpea (Elbistan species, harvesting year 2003) and coarse bulgur (produced from *Triticum durum* "Fırat-98", harvesting year of wheat and processing year for bulgur 2003) were obtained from Arbel Legumes and Cereals Co. (Mersin, Turkey). The population of each sample was 10.

2.2. Measurement of dimensions

Dimensions were measured using a micrometer (Mitutoyo, No: 505-633, Japan) in millimetre. Measurements were carried out through crossing the origin of the materials by determining orifin with measuring the distance of a line through the origin.

2.3. Drawing of shapes

All drawings on a 1:1 scale were made using AutoCAD 2000 Engineering Drawing Software (AutoDesk, USA).

2.4. Calculation of sphericity

Sphericity was calculated using Microsoft Office Excel Software (Microsoft, USA).

2.5. Statistical analysis

An ANOVA analysis was performed for average diameters and sphericity value to determine significant differences ($P < 0.05$). Duncan's multiple range tests were

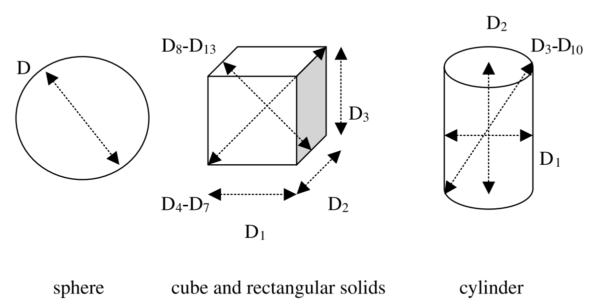

Fig. 1. Illustration of measuring sides for certain shapes. (For sphere: D is diameter. For cube and rectangular solid: D_1, D_2, D_3 are edges; D_4, D_5, D_6, D_7 are diagonals; D_8, D_9, D_{10}, D_{11}, D_{12}, D_{13} are cross-sides. For cylinder: D_1 is diameter; D_2 is length; D_3, D_4, D_5, D_6, D_7, D_8, D_9, D_{10} are diagonals.)

Table 1
Dimensional values and formulas for certain shapes

Shapes	Dimensional values and formulas	N	ϕ_s
Sphere	D as a given	1	0 (size independent and constant)
Cube	$D_1 = D_2 = D_3$ as given $D_4 = D_5 = D_6 = D_7 = (3D_1^2)^{1/2}$ $D_8 = D_9 = D_{10} = D_{11} = D_{12} = D_{13} = (2D_1^2)^{1/2}$	13	0.00271 (size independent and constant)
Rectangular solid	D_1, D_2, D_3 as given $D_4 = D_5 = D_6 = D_7 = (D_1^2 + D_2^2 + D_3^2)^{1/2}$ $D_8 = D_9 = (D_1^2 + D_3^2)^{1/2}$ $D_{10} = D_{11} = (D_2^2 + D_3^2)^{1/2}$ $D_{12} = D_{13} = (D_1^2 + D_2^2)^{1/2}$	13	Size dependent and changes with dimensions
Cylinder	D_1, D_2 as given $D_4 = D_5 = D_6 = D_7 = D_8 = D_9 = D_{10} = (D_1^2 + D_2^2)^{1/2}$	10	Size dependent and changes with dimensions
Cylinder (for length = diameter)	$D_1 = D_2$ as given $D_4 = D_5 = D_6 = D_7 = D_8 = D_9 = D_{10} = (2D_1^2)^{1/2}$	10	0.00155 (size independent and constant)

For sphere: D is diameter. For cube and rectangular solid: D_1, D_2, D_3 are edges; D_4, D_5, D_6, D_7 are diagonals; D_8, D_9, D_{10}, D_{11}, D_{12}, D_{13} are cross-sides. For cylinder: D_1 is diameter; D_2 is length; D_3, D_4, D_5, D_6, D_7, D_8, D_9, D_{10} are diagonals. N shows the number of measurement, i.e. the number of measured diameters.