PHYSICAL PROPERTIES OF FOODS

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FOOD SCIENCE TEXT SERIES

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TO OUR PARENTS

SEMİHA-ŞEVKET SAHIN

&

EMİNE-ERDOĞAN SUMNU

Who have given us our roots

Preface

We have been teaching an undergraduate course of Physical Properties of Foods in Department of Food Engineering in Middle East Technical University for four years. We have had difficulty in finding a suitable textbook for undergraduate students since standard physical properties of foods books do not cover all the physical properties such as size, shape, volume and related physical attributes, rheological properties, thermal properties, electromagnetic properties, water activity and sorption properties, and surface properties together. In addition, engineering concepts and physical chemistry knowledge are not combined in these books.

We tried to write a book to provide a fundamental understanding of physical properties of foods. In this book, the knowledge of physical properties is combined with food science, physical chemistry, physics and engineering knowledge. Physical properties data are required during harvesting, processing, storage and even shipping to the consumer. The material in the book will be helpful for the students to understand the relationship between physical and functional properties of raw, semi-finished and processed food to obtain products with desired shelf-life and quality.

This book discusses basic definitions and principles of physical properties, the importance of physical properties in food industry and measurement methods. Moreover, recent studies in the area of physical properties are summarized. In addition, each chapter is provided with examples and problems. These problems will be helpful for students for their self-study and to gain information how to analyze experimental data to generate practical information.

This book is written to be a textbook for undergraduate students which will fill the gap in physical properties area. In addition, the material in the book may be of interest to people who are working in the field of Food Science, Food Technology, Biological Systems Engineering, Food Process Engineering and Agricultural Engineering. It will also be helpful for graduate students who deal with physical properties in their research.

The physical properties of food materials are discussed in 6 main categories such as size, shape, volume and related physical attributes, rheological properties, thermal properties, electromagnetic properties, water activity and sorption properties and surface properties in this book. In the first chapter physical attributes of foods which are size, shape, volume, density and porosity are discussed. Methods to measure these properties are explained in details. In Chapter 2, after making an introduction on Newtonian and non-Newtonian fluid flow, viscosity measurement methods are discussed. Then, principle of viscoelastic fluids, methods to determine the viscoelastic behavior and models used in viscoelastic fluids are mentioned. Chapter 3 explains definition and measurement methods of thermal properties such as thermal conductivity, specific heat, thermal diffusivity and enthalpy. In the fourth chapter color and dielectric properties of foods are covered. In Chapter 5, equilibrium criteria and colligative properties are discussed. Then, information is given on measurement of water activity. Finally preparation of sorption isotherms and models are discussed. The last chapter is about surface properties and their measurement methods. Where appropriate, we have cited throughout the text the articles that are available for more information.

We are deeply grateful to Prof. Dr. Haluk Hamamci for encouraging us during writing this book and his belief in us. We would also like to thank our colleagues Prof. Dr. Ali Esin, Prof. Dr. Haluk Hamamci, Assoc. Prof. Dr. Nihal Aydogan, Assoc. Prof. Dr. Pinar Calik, Assoc. Prof. Dr. Naime Asli Sezgi, Assoc. Prof. Dr. Esra Yener, Assist. Prof. Dr. Yusuf Uludag, who read the chapters and gave useful suggestions. We would also like to thank our Ph.D student Halil Mecit Oztop and his brother Muin S. Oztop for drawing some of the figures. We would like to extend our thanks to our Ph.D students, Isil Barutcu, Suzan Tireki, Semin Ozge Keskin, Elif Turabi and Nadide Seyhun for reviewing our book. We are happy to acknowledge the teaching assistants Aysem Batur and Incinur Hasbay for their great effort in drawing some of the figures, finding the examples and problems given in each chapter.

Last but not the least; we would like to thank our families for their continuous support throughout our academic career. With love, this work is dedicated to our parents who have patience and belief in us. Thank you for teaching us how to struggle the difficulties in life.

Ankara-TURKEY
October 29, 2005

Serpil Sahin
Servet Gülüm Sumnu

Contents

Chapter 1

Size, Shape, Volume, and Related Physical Attributes

SUMMARY

In this chapter, the physical attributes of foods, which consist of size, shape, volume, density, and porosity, are discussed. Methods to measure these properties are explained in detail.

Size and shape are important physical attributes of foods that are used in screening, grading, and quality control of foods. They are also important in fluid flow and heat and mass transfer calculations. Sieve analysis can be used to determine the average particle diameter and specific surface area of granular material. Volume, which affects consumer acceptance, can be calculated from the measured dimensions or by using various methods such as liquid, gas, or solid displacement methods and image processing. Volume measurement methods can also be used for measuring the density of solids. Volume/density can be expressed in different forms such as solid, apparent, and bulk volume/density depending on pores. Porosity is a physical property characterizing the texture and the quality of dry and intermediate moisture foods. Total porosity of particulate materials includes the voids within and among the particles. Porosity can be determined from the difference between bulk volume of a piece of porous material and its volume after destruction of all voids by compression, optical methods, density methods, or by using a pycnometer or porosimeter. Internal pores may be in three different forms: closed pores that are closed on all sides, blind pores in which one end is closed, and flow-through pores that are open at both ends so that flow can take place.

1.1 SIZE

Size is an important physical attribute of foods used in screening solids to separate foreign materials, grading of fruits and vegetables, and evaluating the quality of food materials. In fluid flow, and heat and mass transfer calculations, it is necessary to know the size of the sample. Size of the particulate foods is also critical. For example, particle size of powdered milk must be large enough to prevent agglomeration, but small enough to allow rapid dissolution during reconstitution. Particle size was found to be inversely proportional to dispersion of powder and water holding capacity of whey protein powders (Resch & Daubert, 2001). Decrease in particle size also increased the steady shear and

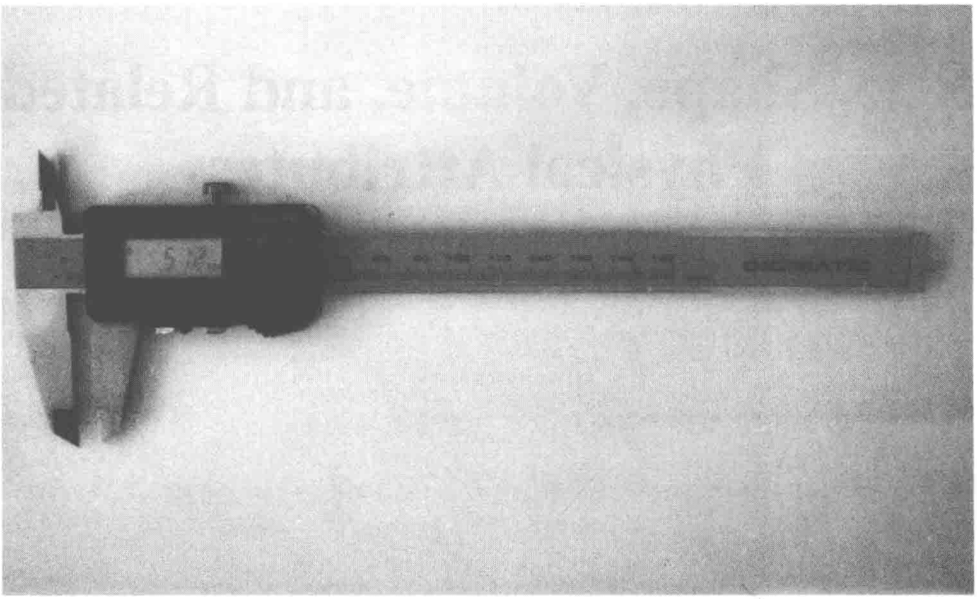

Figure 1.1 Micrometer.

complex viscosity of the reconstituted powder. The powder exhibited greater intrinsic viscosity as the particle size increased. The size of semolina particles was found to influence mainly sorption kinetics (Hebrard, Oulahna, Galet, Cuq, Abecassis, & Fages, 2003). The importance of particle size measurement has been widely recognized, especially in the beverage industry, as the distribution and concentration ratio of particulates present in beverages greatly affect their flavor.

It is easy to specify size for regular particles, but for irregular particles the term size must be arbitrarily specified.

Particle sizes are expressed in different units depending on the size range involved. Coarse particles are measured in millimeters, fine particles in terms of screen size, and very fine particles in micrometers or nanometers. Ultrafine particles are sometimes described in terms of their surface area per unit mass, usually in square meters per gram (McCabe, Smith & Harriot, 1993).

Size can be determined using the projected area method. In this method, three characteristic dimensions are defined:

1. Major diameter, which is the longest dimension of the maximum projected area;
2. Intermediate diameter, which is the minimum diameter of the maximum projected area or the maximum diameter of the minimum projected area; and
3. Minor diameter, which is the shortest dimension of the minimum projected area.

Length, width, and thickness terms are commonly used that correspond to major, intermediate, and minor diameters, respectively.

The dimensions can be measured using a micrometer or caliper (Fig. 1.1). The micrometer is a simple instrument used to measure distances between surfaces. Most micrometers have a frame, anvil, spindle, sleeve, thimble, and ratchet stop. They are used to measure the outside diameters, inside diameters, the distance between parallel surfaces, and the depth of holes.

Particle size of particulate foods can be determined by sieve analysis, passage through an electrically charged orifice, and settling rate methods. Particle size distribution analyzers, which determine both the size of particles and their state of distribution, are used for production control of powders.

1.2 SHAPE

Shape is also important in heat and mass transfer calculations, screening solids to separate foreign materials, grading of fruits and vegetables, and evaluating the quality of food materials. The shape of a food material is usually expressed in terms of its sphericity and aspect ratio.

Sphericity is an important parameter used in fluid flow and heat and mass transfer calculations. Sphericity or shape factor can be defined in different ways.

According to the most commonly used definition, sphericity is the ratio of volume of solid to the volume of a sphere that has a diameter equal to the major diameter of the object so that it can circumscribe the solid sample. For a spherical particle of diameter D_p, sphericity is equal to 1 (Mohsenin, 1970).

$$\text{Sphericity} = \left(\frac{\text{Volume of solid sample}}{\text{Volume of circumscribed sphere}}\right)^{1/3} \tag{1.1}$$

Assuming that the volume of the solid sample is equal to the volume of the triaxial ellipsoid which has diameters equivalent to those of the sample, then:

$$\Phi = \left(\frac{V_e}{V_c}\right)^{1/3} \tag{1.2}$$

where

Φ = sphericity,
V_e = volume of the triaxial ellipsoid with equivalent diameters (m^3),
V_c = volume of the circumscribed sphere (m^3).

In a triaxial ellipsoid, all three perpendicular sections are ellipses (Fig. 1.2). If the major, intermediate, and minor diameters are $2a$, $2b$, and $2c$, respectively, volume of the triaxial ellipsoid can be determined from the following equation:

$$V_e = \frac{4}{3}\pi abc \tag{1.3}$$

Then, sphericity is:

$$\Phi = \frac{(abc)^{1/3}}{a} \tag{1.4}$$

Sphericity is also defined as the ratio of surface area of a sphere having the same volume as the object to the actual surface area of the object (McCabe, Smith, & Harriot, 1993):

$$\Phi = \frac{\pi D_p^2}{S_p} = \frac{6V_p}{D_p S_p} \tag{1.5}$$

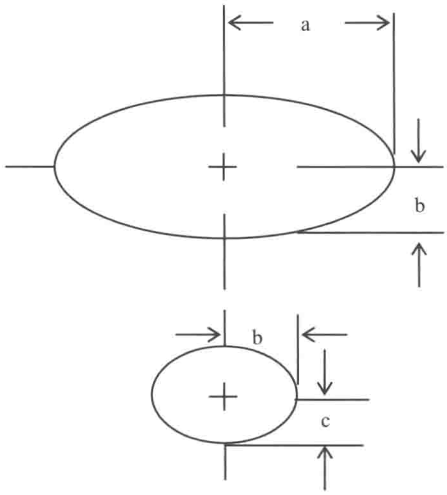

Figure 1.2 Triaxial ellipsoid

where

D_p = equivalent diameter or nominal diameter of the particle (m),
S_p = surface area of one particle (m^2),
V_p = volume of one particle (m^3).

The equivalent diameter is sometimes defined as the diameter of a sphere having the same volume as the particle. However, for fine granular materials, it is difficult to determine the exact volume and surface area of a particle. Therefore, equivalent diameter is usually taken to be the nominal size based on screen analysis or microscopic examination in granular materials. The surface area is found from adsorption measurements or from the pressure drop in a bed of particles.

In general, diameters may be specified for any equidimensional particle. Particles that are not equidimensional, that is, longer in one direction than in others, are often characterized by the second longest major dimension. For example, for needlelike particles, equivalent diameter refers to the thickness of the particles, not their length.

In a sample of uniform particles of diameter D_p, the number of particles in the sample is:

$$N = \frac{m}{\rho_p V_p} \tag{1.6}$$

where

N = the number of particles,
m = mass of the sample (kg),
ρ_p = density of the particles (kg/m^3),
V_p = volume of one particle (m^3).

Total surface area of the particles is obtained from Eqs. (1.5) and (1.6):

$$A = NS_p = \frac{6m}{\Phi \rho_p D_p} \tag{1.7}$$