
1 Food Materials Science and Engineering: An Overview

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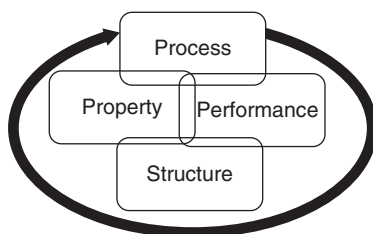
1.1 INTRODUCTION

Materials science deals with the relationships of processing, performance, properties and structures of materials. It covers chemical, physical and engineering areas of almost all materials used in industries and includes practical and theoretical aspects of materials from atomic to molecular and bulk levels. Originally materials science covered metallurgy and solid-state physics. Various metals and metal alloys and ceramics were manufactured to provide materials with diversified properties and strengths. The developments of science and engineering have led to the introduction of materials science concepts to almost every field of science and engineering. It is adapted from metallurgy to polymers, ceramic, bio-medical implants materials, textiles, paper, pharmaceutical, agricultural and food materials. Some common fields of materials science are described in Table 1.1. Material scientists and engineers improve traditional materials, develop new materials and produce them efficiently and economically. Thus they need knowledge of science and engineering or can be a part of a multidisciplinary team. In fact, gastronomy is often the artwork of food materials science.

In human civilisation, materials science started to develop during the Stone Age when humans began to use tools and weapons made from stone. This development grew through the bronze and steel ages, and now in the twenty-first century materials science has been revolutionised by new technologies in plastic, semi-conductors and biomaterials manufacture. The early focus of materials science prior to the 1960s was on the relationship between the structure and properties of materials. During the past two decades processing has become a major concern of materials science (National Research Council, 1989; Bensaude-Vincent and Hessenbruch, 2004). This development has established modern materials science with its four major interdependent components: process, structure, properties, and performance (Figure 1.1). It may be stated that a process for a material will determine its structure; the structure and the process contribute to the properties of the material; and the properties will dominate the performance of the material. In many industries, including the food industry, the process-structure-properties relationship may be altered by an intelligent selection of the formulation or the composition of raw materials. In food process and product development and design, materials science is essential in guiding the specific process selection for sensitive materials to produce a desirable product because, as in other areas, science and engineering

Table 1.1 General materials science areas.

Materials Science field	Descriptions
Ceramography	High temperature ceramics and silicons and their microstructure.
Crystallography	Crystal structures, defects and physical properties.
Electronic and magnetic materials	Fabrication of semiconductors, sensors, electrical integrated circuits, etc.
Materials characterisation	Thermal analysis, NMR, X-ray diffraction, electron and neutron spectroscopies, Raman spectroscopy, energy-dispersive spectroscopy (EDS), electron microscope analysis, atomic force microscopy, x-ray photoelectron spectroscopy, Small angle neutron scattering (SANS), Small angle X-ray scattering (SAXS).
Metallurgy	Study of metals and their alloys, and their structure and mechanical strength.
Microtechnology	Manufacturing processes of 'micron' size materials, ink-jet printers, electrical devices, transistors, integrated circuits.
Nanotechnology	Materials fabrication in nanoscale, nanocomposites to improve mechanical properties and hygiene of materials (such as packaging materials).
Surface science	Interactions of materials and structures of gas-solid, solid-solid, solid-liquid and liquid-gas dispersions.
Tribology	Study of friction, lubrication and wear of a materials in motion.

**Figure 1.1** Four interacting components of materials science and engineering.

are interwoven as *food materials science and engineering* (Shackelford, 2004, Callister, 2007). A significant recent development in materials science across all its areas has been the development of nanoscience and nanotechnology, which expand materials science to the nanostructural level of understanding and engineering materials, including foods. Materials science and engineering have a wide impact on the control of processes producing materials, either by controlling properties and composition of original raw materials, or changes occurring in materials during specific processes. This requires a deep physicochemical and structural characterisation of the materials. Several material science areas are dominated by physical and structural aspects of solid materials. However, the physicochemical properties of biological materials are significant determinants of food processing, performance and structural characteristics. These properties are also temperature and water content dependent.

Solid materials have been classified into three basic groups: metals, ceramics and polymers (food is a multicomponent mixture of these three basic groups). Materials that are typical of the 'high-technology' fields are termed as advanced materials: such as semiconductors, biomaterials and future materials (composites, smart and nanoengineered materials). Composites of base materials have been used to improve the mechanical, electrical and magnetic properties of solid materials. Materials science has allowed the increase of the strength of the materials by thousands of times as a result of the development of composite metallic materials (alloys) and fibres (such as aramid and carbon fibres). Superalloys and

Table 1.2 Food materials science and engineering areas.

Food Materials Science area	Examples of attributes
Food gels and soft-materials Solid foods (e.g., food powders, dried foods, extruded foods) Interfacial science	Gel formation and gel structures. Crispness, crunchiness, dispersion properties, flowability, cracking, friability, reconstitution properties, stickiness. Adhesion-cohesion and fouling mechanisms, colloidal dispersions, emulsification, foams, interfacial migration of surface active components.
Material characterisation techniques Nanotechnology	Chemical, microscopic, nutritional, physical, rheological, sensory and thermal property characterisation of food materials. Nanoparticle formation, nanoparticles for nutrient delivery, textural modification.
Oral processing and Tribology	Physics, physiology, and psychology of eating, lubrication, deformation and sensory perception.
Phase transition and separation	Crystallisation, glass transition, melting, phase separation in multi-component systems (composites), size fractionation and vitrification.
Restructuring and product design Rheology	Texture modification, texturised products. Flow and deformation properties of solid and semi-solid foods.

special ceramic composites are newly developed materials which are stable at very high temperatures and improve the energy conversion efficiency of heat engines (such as thermal power engines and automobiles) (Nitta, 1999; Mileiko, 2005). Magnetic strength of the newly developed composite metallic material has been increased by more than 100 times (Shackelford, 2004). The strength of tools and abrasive materials has been improved exponentially owing to the development of new materials. Similarly, there are great achievements in the development of superconductor and superelectronic materials (Johrendt, 2011).

Materials science requires new levels of understanding and control of the basic building blocks of materials: atoms, molecules, crystals, and noncrystalline single and multiphase systems (glassy matrix). The whole spectrum of novel materials in bioscience includes soft-gels, colloids, emulsions and dispersed particulate suspensions and their manufacturing processes and structure. Since the quality and functionality of food products are highly dependent on their components and component properties their structure needs to have a robust design to achieve the desired quality and sensory properties. Food materials science and engineering is also expected to contribute significantly to the development of advanced nutrient delivery systems with specific structural, sensory and nutrient release properties. Thus, 'Food Materials Science and Engineering' is an interdisciplinary field involving the properties of food materials and its applications, for example, to food process engineering and product manufacturing, product design, sensory properties, quality enhancement and shelf-life extension. In food materials science, the major food components of foods, such as starch and proteins, are considered as food polymers. Their molecular and structural properties are related to those of many other polymers (such as plastics). The mechanical and rheological properties of foods are considered important not only because they contribute to sensory properties but also because of their effects on physical stability and shelf-life. Food materials science has developed along with the introduction and wider availability of several frontier technologies, such as Atomic Force Microscopy, Electron Microscopy, Confocal Laser Microscopy, Nuclear Magnetic Resonance spectroscopy, X-ray Diffractometry and thermal analysis. Various fields within food materials science are evolving (Table 1.2) as the importance of the food materials science approach in food product manufacturing and quality is growing.

The present chapter introduces the area of food materials science and highlights developments and achievements in applying the materials science principles across the disciplines of food science and engineering.

1.2 MOLECULAR BASIS OF FOOD MATERIALS

Materials consist of molecules with various physical states. These exhibit diverse levels of energy and molecular mobility. Molecular mobility may include translational (three-dimensional displacement from one location to another), rotational (movement around an axis), and vibrational (stretching and bending of the bonds between the atoms, which changes the shape of the molecules) mobility. Translational and rotational motions relate to the movement of the entire molecule, whereas vibrational motions occur within the molecule. The magnitude of these motions depends on the physical state of the matter whether it is in a liquid, solid, or gaseous state. These states exhibit different degrees of intermolecular interactions and free volume (intermolecular space) between the molecules. The possible interactions between atoms are covalent and noncovalent bonds. *Noncovalent bonds* involve electrostatic forces such as hydrogen, ionic, and dipole interactions and van der Waals forces. Noncovalent bonds exist more in macromolecules and are common in biological molecules, such as proteins and carbohydrates. Noncovalent bonds are important in forming the secondary and tertiary structures of the molecules. *Covalent bonds* involve the equal or unequal sharing of one or more pairs of electrons between atoms. *Nonpolar bonds*, a term which signifies an equal sharing of electrons, are described as nonpolar because of the nonaccumulation of electrons and the absence of dipole movement. Covalent bonds are stronger than the noncovalent bonds. The state of the matter determines the extent of these intermolecular forces and molecular mobility. Therefore, the melting and phase transition temperatures of the materials are dependent on the strength of these bonds. Material properties are thus highly dependent on these molecular level differences and their relative molecular mobility.

Food materials science and engineering is a sub-area of biological materials science which belongs to the field of general materials science rather than having an independent identity. Components of food materials exist in gas, liquid and solids states. The reactivity of the molecules, shelf-life and properties is often related to their relative mobility. Table 1.3 depicts how various physico-chemical and nutritional properties of food materials are related to molecular mobility. Food can be a mixture of a number of components present in different phase or state with different degrees of molecular mobility; such as, in simple terms, rigid (solid), mobile (liquid) and very mobile (gas) components. The fraction of each of the components and reactivity of each of these components within food systems is important for an overall stability/shelf-life of products. Addition of small molecules or plasticisers can increase food system mobility influencing the physical properties and shelf-life.

Table 1.3 Properties of materials (including food materials) that are related to molecular mobility.

Attributes	Properties
Physical	Softness, hardness, crispness, fracture properties, fluidity, viscosity, sensory
Chemical	Reaction rate/degradation- collision of molecules
Nutritional	Bioactivity, bioavailability, viability

As food materials could be converted from one form to another, their molecular mobility and stability will change depending on their physical state and the fraction of each of these components present as well as their molecular level interactions.

1.3 OBSERVATION OF MATERIALS AT VARIOUS SIZE RANGES AND SIZE-PROPERTY RELATIONSHIP

From atomic or molecular to bulk particulate level the food components can exist in a solution (independent molecules) or colloidal (self-assembled molecules) or in particulate forms (emulsion or bulk particles). The size spectrum of various food components at molecular to particulate levels is depicted in Figure 1.2. While molecules are the elements for the formation of food components, actual formation of matter begins with the aggregation of few or several molecules. Depending on the size, the molecular systems can be divided into nano-, micro- or macrostructural systems. The nanoparticles are like nuclei or clusters of molecules prior to crystal formation. They can also be called an embryo of matter (Figure 1.3). Once the size is grown towards the micro and macro scales, the material starts to behave like bulk matter. Thus, nanoparticles effectively bridge the atomic or molecular structure and bulk. These materials in the nanometer size are of current interest because

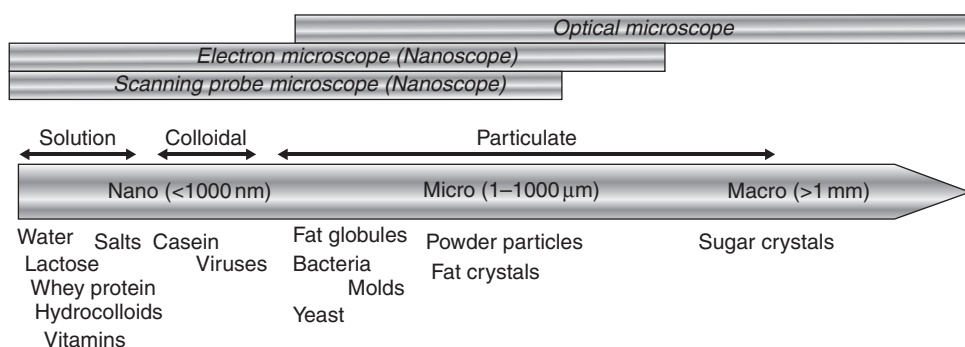


Figure 1.2 Size classification of various components of food, including microorganisms found in milk (indicative only – not to the scale).

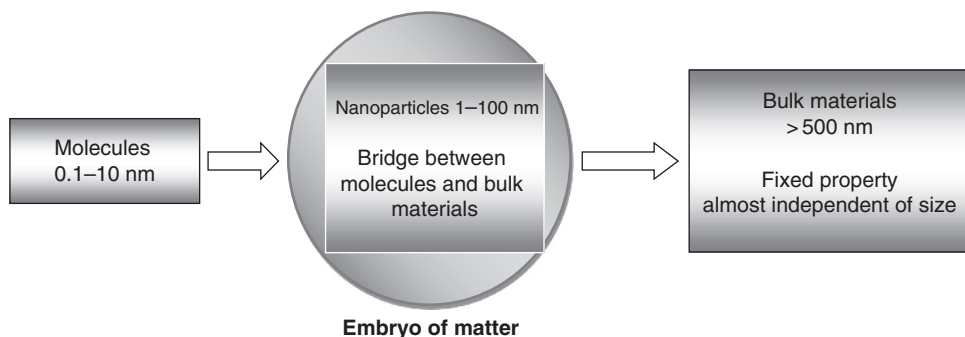


Figure 1.3 Schematic illustration and definition of nanoparticles.

their properties differ from those of molecules and bulk. Nanoparticles possess very high van der Waal forces and exhibit peculiar light scattering and magnetic properties (Lue, 2001; Guo, 2011).

The nanoparticles can be produced by ‘bottom-up’ process (atomic/molecular level cluster formation) or ‘top-down’ process (size-reduction from bulk). The study and exploitation of materials from the size range of 1 to 100 nm is called nanotechnology. However, particles with sizes ranging below the submicron size (usually <500 nm) are often known as nanoparticles. In a liquid suspension if the nanoparticles are less than 200 nm and provided there are enough repulsive forces to avoid aggregation, they are thermodynamically stable due to the dominance of Brownian motion against gravity (Zhu et al., 2007). There are four types of nanoparticles that can be prepared from food materials: nanoemulsion, micelles, liposomes, biopolymeric nanoparticles, and cubosomes (Chen et al., 2006). Amphiphilic molecules (e.g., surfactants, lipids, and copolymers that have both polar and nonpolar characteristics) when dispersed in a polar solvent, spontaneously self-assemble to micelles and liposome forms due to hydrophobic interactions. These particle arrays are thermodynamically stable, lyotropic, liquid crystalline phases of the size range of nanometers.

In food systems, there are colloidal particle suspensions that already exist in nanometer scales, such as casein micelles (sizes range from 50–500 nm, average 300 nm) (Figure 1.4a). The dispersion rate of milk powders in water is affected by the release of these nanoparticles from the parent powder particles (Mimouni et al., 2010). At present, nanoemulsion particles of a size below 200 nm have been prepared for efficient active compound delivery and also better stability against component separation (Chen et al., 2006). Enormous increase in interfacial area also improves the solubility of sparingly water soluble compounds, such as polyphenols, due to the interaction of the apolar molecular entity of the polyphenols with enormous droplet surface area provided by the lipid nanoparticles (Barras et al., 2009). High shear processes, such as microfluidiser or ultrasonic systems, can be used to prepare such nanoemulsions (Jafari et al., 2007). Nanoemulsions have been found to deliver the active components efficiently in the digestive tract. Nanosize particles have also been found to enhance the antimicrobial properties attributed to the high surface energy and fusion

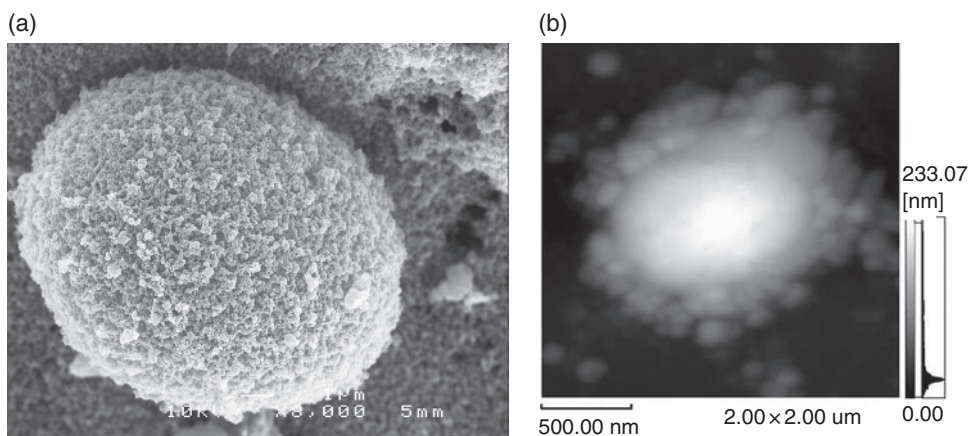


Figure 1.4 (a) Dairy milk powder particles composed of aggregates of casein micelles (casein micelles size is 50–500 nm). (b) Chitosan nanoparticles attached to bacteria, eventually causing damage in the cell wall and death.

Source: Qi et al., 2004, with permission from Elsevier.

Table 1.4 Examples of particle sizes and quality attributes of selected food product systems.

Food product system	Size of the particles	Desirable attributes
Chocolate	18–25 μm	Clean snap, creaminess, melting temperature and rate, smooth surface and taste.
Condensed milk	Lactose crystals <10 μm	Smoothness.
Creamed sugar-rich products (cake icing, creamed honey)	Crystal size <30 μm	Creaminess, spreadability.
Food powders	50–300 μm	Bulk density, dispersability, flowability, wettability, etc.
Ice-cream	Ice crystals 30–35 μm , Lactose crystals <10 μm	Creaminess.
Milk	Fat emulsion 500 nm–1 μm	Stable against separation.
Spreads (butter, margarine)	Fat crystals <10 μm	Spreadability.
Yoghurt (stirred)	Gel particles <30 μm	Creaminess.

ability on the cell membrane of many pathogenic bacteria (Hamouda et al., 2001; Teixeira et al., 2007). The antimicrobial property of biopolymers (such as chitosan) as nanoparticulates was found higher than in traditional dispersions (Qi et al., 2004) (Figure 1.4b).

The bulk food systems can be constituted with discrete particles at molecular, colloidal or particulate levels. The structure of the food materials and their property (such as viscosity and texture) will depend on their component size and distribution. Some examples of components in food systems are: micron size fibres of meat, nanometer size casein micelles, micron size crystals in the icing sugar in creamed honey, micron size water and lactose crystals in ice-cream, micron size fat crystals in chocolate, etc. (Table 1.4). Many quality parameters and functional properties of a food material system, such as creaminess, flowability, graininess, smoothness, spreadability, and other textural properties are dependent on the particles' size and distribution in a food system. The bulk properties of the materials and their sensory perception will depend on their particle size distribution, orientation and shape. For an optimum food quality the particulate size needs to be controlled.

1.4 AMORPHOUS AND CRYSTALLINE STRUCTURES OF MATERIALS

Solid materials can exist in crystalline or amorphous states. Food materials in solid states may be crystalline, partially crystalline or amorphous (Figure 1.5). The crystalline state possesses defined and repetitive molecular alignment in the long-range order. The molecules are tightly packed; therefore, only radical or functional molecular groups on the external surface of the crystals can interact with external materials, such as water (adsorption). Thermodynamically, the crystalline form is in the lowest energy level or forms the stable equilibrium state (Hartel, 2001). Molecules in the amorphous state are in anarchy, tangled, more open and porous; therefore, an individual molecule possesses more sites for external interactions, and, as a result, for example, an amorphous structure can adsorb water easily. Amorphous powder components are more hygroscopic than crystalline components. They tend to be sticky and cake when they sorb water, which has an adverse effect on flowability (Bhandari and Hartel, 2005). Powders with amorphous components also tend to be more porous and bulky than powders with crystalline components. The microstructure of an

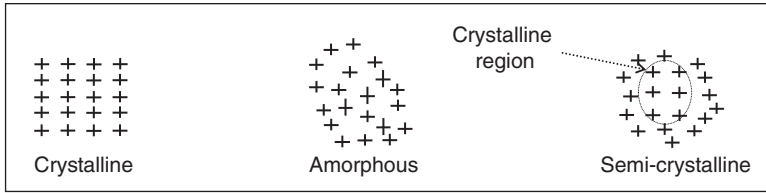


Figure 1.5 Indicative crystalline, amorphous and semi-crystalline structures of solids (+ indicates a molecule).

Table 1.5 Differences in relative physical properties between crystalline and amorphous states of materials.

Properties	Crystalline state	Amorphous state
Chemical reactivity	Low	High
Compressibility	Poor	Good
Density	High	Low
Hygroscopicity	Low	High
Interaction with solvent	Slow	Rapid
Heat of solution	Endothermic	Exothermic
Internal porosity	Low	High
Mechanical strength	Strong	Brittle
Softening temperature	High (called melting)	Low (called glass transition)

amorphous solid may consist of short-range order and regions of high and low densities, and have higher entropy than the corresponding crystals (Yu, 2001). The physical and functional properties of food materials will be highly dependent on the proportion of these two states present in the system (Table 1.5). It is, therefore, necessary to control these structures to produce the food with desired microstructure and sensory properties (some of the examples are given in Table 1.4).

Many food processes, such as drying and extrusion, etc., produce powders with amorphous components. The raw materials used could be crystalline, amorphous or semi-crystalline. In some cases, the processes produce crystalline forms, such as from crystallisation of sugars and salts, freezing of foods (crystallisation of water), crystallisation of lactose in skim milk, whey and lactose prior to powder manufacturing.

Crystallisation prolongs the shelf-life of food materials, and controlled crystallisation reduces the graininess or grittiness of the products. However, in many situations it is important that the microstructure of the product is maintained in an amorphous state and crystallisation has to be totally prevented; otherwise the flavour, colour and taste of the product will be altered during the storage period (Hartel, 2001; Roos, 1995).

The physical state of powder components influences functionality and handling properties of the powder (Table 1.5). Hardness, cohesiveness and compressibility of powders with amorphous components are different from those of powder with crystalline components. The particle density and hardness of powders with crystalline components are high and the powder may be less compressible under stress (Table 1.5). Powders with amorphous components deform and compact more, and tend to cake under stress (Yu, 2001). For example, a bag of powder at the bottom of a bin or stack in the bulk storage room is more prone to caking.

Rehydration properties, such as dispersibility and rate of dispersion, can be influenced by the form of the powder components. Powders with crystalline components typically

dissolve slowly because dissolution of crystals occurs only at their outer surface exposed to solvent. The particles are impermeable to solvent, because the molecules are bonded strongly and density is high; therefore, the dissolution proceeds from outside to inside. In contrast, powders with amorphous components rehydrate rapidly, because the bonding between the molecules is weaker as compared to the crystalline part and the particles are in the dissolved state of the components, which are hygroscopic and the solvent can be easily reintroduced (Hancock and Parks, 2000; Marabi et al., 2007). As a consequence, the crystalline materials show endothermic enthalpy of dissolution, while the amorphous state of the same materials shows an exothermic response. This difference is often attributed to the higher entropy and internal free energy of the metastable amorphous material, leading to enhanced dissolution rate and chemical reactivity, relative to the thermodynamically more favourable and stable crystalline state (Marabi, et al., 2007). However, some vitrified powder components (least porosity and structure fully relaxed) can be as tough to rehydrate as crystals. Powders with amorphous components (such as gum and milk powders) tend to lump during rehydration due to particle swelling. The particle size is also responsible for this lumping and rate of rehydration. The amorphous state also positively influences the rehydration and melting behaviour of the mixed form powder, such as in starch granules, where the sorption of water by amorphous starch enhances the melting of the crystalline fraction by weakening the intermolecular bonds in the crystals.

Encapsulation is a process whereby an active and non-compatible ingredient (such as a flavour, vitamin, enzymes or lipid) is entrapped within a matrix of a carrier material. Powders with components forming amorphous structures are often used for encapsulation. The amorphous form is essential for the entrapment of the active or non-compatible component; an example being fat in whole milk powder, which is entrapped within the amorphous matrix of lactose. The crystalline form, however, often excludes other components. Since crystallisation is a process in which molecules of the same species are tightly bound, they do not accommodate foreign molecules, except that some impurities from similar size molecules can be found. During the storage of powder the amorphous form of components should be maintained. If there is a phase change of a powder component from the amorphous form to crystallised form, the encapsulated material is ejected and the quality is rapidly degraded. Another form of encapsulation involves the agglomeration of tiny crystals that entrap other non-compatible molecules within the inter-particulate space. This method is employed during the encapsulation of active components by co-crystallisation of sugars (Bhandari et al., 1998).

Amorphous components exhibit the glass transition which has many processing and self-life implications (Roos, 1995). The glass transition temperature (T_g) indicates a temperature range value for the softening or vitrification of an amorphous material. In many food processing situations, glassy structures are produced during drying (removal of water) or cooling the food products (such as in extrusion and candy making). In these processes, the materials are converted to the glassy state by rapid dehydration or cooling. The glass transition coincides with the cessation of mobility of the back-bone structure of molecules and is referred to as α -relaxation in mechanical and dielectric measurements. This transition in vitrification produces the non-equilibrium glassy state. Amorphous solids may continue to relax over the time towards a lower energy level below T_g (Figure 1.6). The lowest energy that can be theoretically achieved at a given condition is equivalent to the corresponding equilibrium solid line as depicted in Figure 1.6. The β -relaxation is believed to be caused by the further micro-level alignment of the side chain or groups of the molecules which still remained relatively mobile during α -relaxation (or glass transition). The β -relaxation is

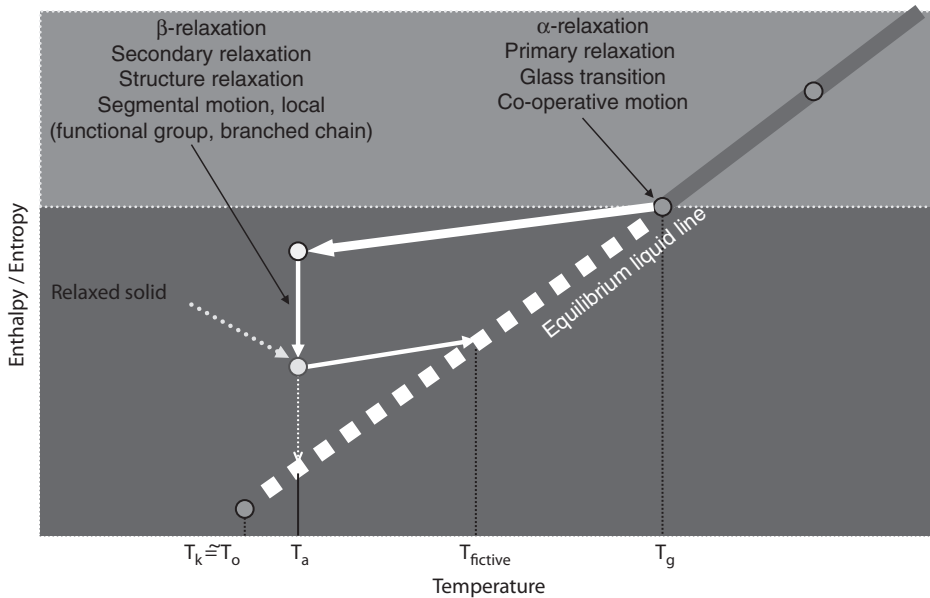


Figure 1.6 Glass transition (alpha-relaxation) and enthalpy relaxation of an amorphous solid.

accelerated by water, provided that the product is still below T_g . Water toughening of various snack foods (such as cheese balls, cocoa puffs and pork rinds) due to macroscopic structural relaxation (also known as molecular or stress relaxation) effect has been reported (Corradini and Peleg, 2008). In a number of pharmaceutical systems the effect of β -relaxation on the stability of drugs/bioactives has been reported. Chemical reactions (such as Maillard reaction) have also been found to take place (Karmas et al., 1992), but at a slower rate below T_g , probably contributed to by β -relaxation (Schebor et al., 1999).

As the solid materials with limited molecular mobility are converted to relatively mobile states above T_g , many physico-chemical changes are observed to take place rapidly, such as stickiness, caking of powders, Maillard reaction, crystallisation, etc. Stickiness has been an on-going issue on the drying and agglomeration of sugar-rich materials, such as fruits juices, honey and low molecular weight systems, such as protein hydrolysates, mainly because of their low glass-transition temperature (lower than the drying temperature) (Roos, 1995; Jouppila et al, 1997; Bhandari et al., 1997).

1.5 GEL STRUCTURES OF FOOD MATERIALS

Gels are semi-solid materials in which a molecular network entraps the liquid continuous phase (water in the case of food materials). In materials science, gels are categorised as 'soft-materials'. They are liquid but behave like pseudo-solids due to their three dimensional cross-linked structure entrapping the liquid. Gels do not flow in a steady state condition. Gels may be weak, soft or hard depending on the extent of cross linking and the water content. Examples of different types of food gel structures are presented in Table 1.6. The soft gels can have a water content up to 99% (w/w), but the hard gels normally have lower water contents. The water content is reduced by gelation at low water contents (usually at

Table 1.6 Classification of gels based on their firmness.

Gel categories based on the firmness	Food product systems
Soft gel	Yoghurt, soft cheese, soft soy tofu
Firm gel	Soy tofu, jelly (confectionery)
Hard gel	Cheese, paneer, jelly beans, liquorice

high temperature, such as in the case of starch), forced expulsion or syneresis (such as in cheese manufacturing).

Many 'soft-materials' including gels, pastes, concentrated emulsions, foams and solid colloids are disordered, out-of-equilibrium systems. Because the mobility of their constituents is extremely reduced, these systems are frozen (or 'jammed') in configurations far from thermodynamic equilibrium (Sollich et al. 1997; Ovarlez et al., 2010). This jamming is a transition phenomenon from liquid to solid state below a yield stress. As a result, they exhibit unusually slow relaxations and aging effects. Therefore, their properties continuously evolve with time. Structures of these soft materials show some analogy to glassy solid materials, therefore these materials are also called 'soft glassy materials' (Cipelletti and Ramos, 2002; Stokes and Frith, 2008; Ovarlez et al., 2010). After the initial gelation process has taken place bonds between the particles in gels may change during the observation time, either spontaneously or due to external forces. The dynamic character of the bonds may also lead to gradual changes in the structure that, in turn, changes the rheological properties. This may result into coarsening, increased hardness and syneresis (Renard et al. 2006).

The network structure in gels is a result of physical and/or chemical interactions. The cross linking of the gelling compound could be hydrophobic, ionic, covalent or microcrystalline. Covalent bonds are formed due to S-S bridges in proteins due to heating or by addition of reagents. Ionic bonds are formed due to the formation of bridges, such as in the presence of ions in hydrocolloids. Polymers may crystallise and form microcrystallite regions that act as cross-links (Walstra, 1996). The particle gels are normally formed by aggregation induced by pH change or ionic strength, such as in casein micelles typical of gelation in yoghurt. The particles in gels possess fractal behaviour. Fractal is a geometric pattern that is repeated at every smaller scale to produce irregular shapes and surfaces.

The texture of a gelled food system can be as important as its flavour. In food systems, there are a number of food polymers that form gels, such as plastic fat, casein, gelatin, alginate, carrageenan, globular proteins, starch and composite gels (Walstra, 1996). The plastic fat gels are formed due to the aggregation of fat crystals by van der Waals attraction between crystals. Caseinate gels are formed due to electrostatic forces by decreasing the electric repulsion by lowering the pH. Gelatin gels are formed due to the formation of triple helices of which the third helix is a part of other molecules that develops cross-links. Gelatin exhibits a coil-to-helix or disordered to ordered transition upon cooling. The triple helices align forming microcrystalline region. A higher temperature unfolds the triple helices (called melting). The globular proteins form heat-setting gels, mainly when the protein structure unfolds and gels due to formation of covalent bonds (-SH and -S-S- linkages) and hydrophobic forces and hydrogen bonds. At a high concentration of protein it may also form a fine-stranded gel due to hydrophobic interaction and hydrogen bonds of protein particulates (Renard et al., 2006). These gels are formed close to the isoelectric point.

The polysaccharides are cold-setting gels. The hydrocolloid k-carrageenan forms double helices between two molecules and the microcrystalline regions are formed between the

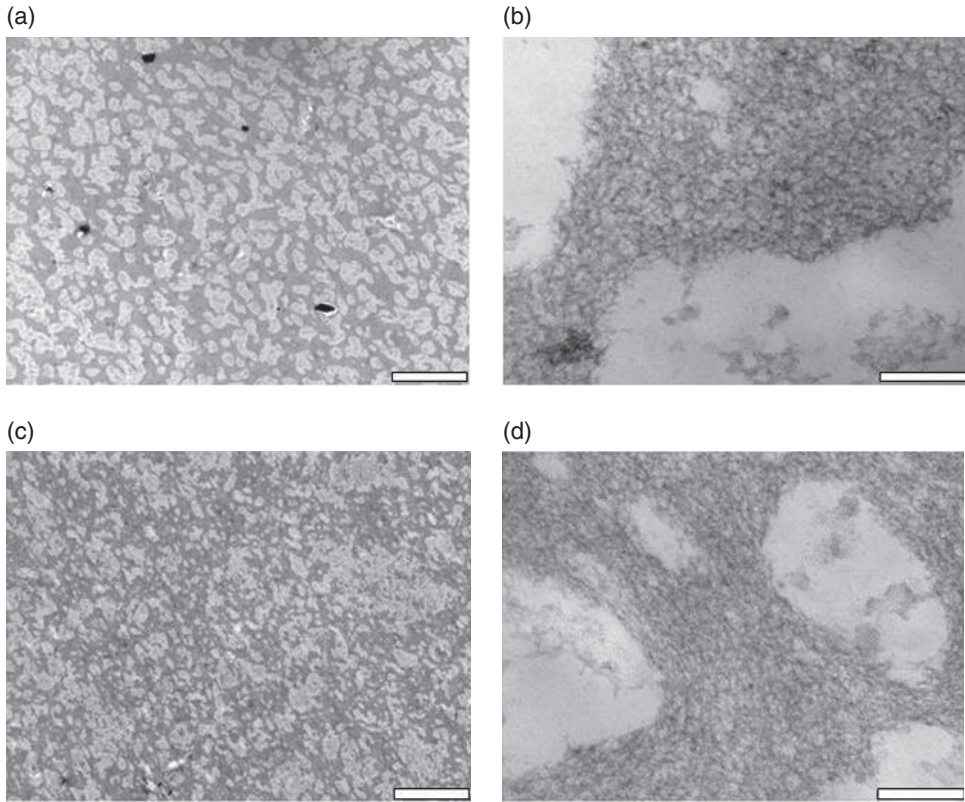


Figure 1.7 Microstructure of composite gels of sugar, starch and gelatin (a), (c) low magnification, (b), (d) high magnification. Scale bars 5 μm for low magnification, 200 nm for high magnification (starch/sugar rich domains (lighter grey with a textured appearance) and gelatin-rich domains (dark)).
Source: Sukha, 2005, with permission.

double helices of different molecules. The helical conformation is promoted by the addition of salts or by lowering the temperature. Monovalent cations (e.g., K^+) promote the aggregation of k-carrageenan double helices to form so-called aggregated 'domains'. Melting of gel signifies the disruption of double helices. The 'Egg-box' model is introduced for alginate gels when a cation (such as Ca^{++}) complexes between the alginate molecules forming egg-box like junctions by ionic bonding. The junctions are believed to form a microcrystalline region. Normally alginate gels are rigid and irreversible (Burey et al., 2008).

Amylose and amylopectin can form single helices and arrange themselves to microcrystalline regions and gel formation is initiated at higher concentrations (Yuryev et al., 1995). Starch can form gels due to swelling of the starch granules when the granule occupies all the volume. The swollen and partly deformed starch granules may interlock each other forming gels. Retrogradation (crystallisation) of starch during storage can also form stiffer gels.

The composites of biopolymers (such as starch and gelatin) can also form gels at lower concentrations. Fracture properties of these gels vary greatly based on the processing conditions, pH, ionic strength, temperature, etc. Phase separation of these composite gels may occur if the system is thermodynamically incompatible (Figure 1.7). The fracture and rheological (flow) properties will alter due to this effect (Sukha, 2005).

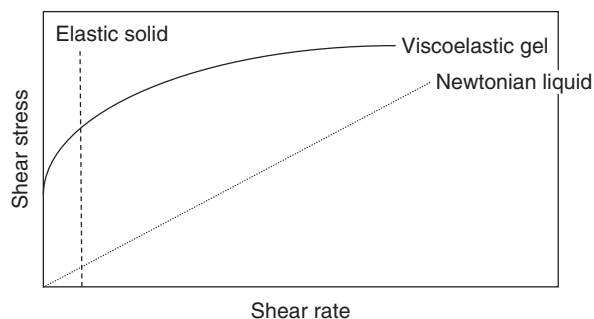


Figure 1.8 Rheological property of a gel structure.

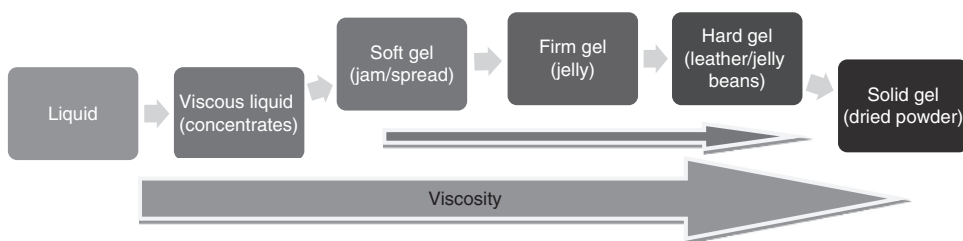


Figure 1.9 Possible forms of food products manufactured through sol-gel-solid transformation mainly by removal of water and addition of gelling agent if necessary.

In rheological definition, gels are viscoelastic materials with a yield stress (Figure 1.8). The gel consists of both solid and liquid behaviour. The firm and hard gels fracture after certain force is applied. The elastic modulus (stress/strain of gels) is normally less than 10^6 Pa. Many different food products are based on gelation. The eating characteristics are related to the yield and fracture properties. In sensory terms, the stiffness of the gel is related to its elastic modulus, and the hardness correlates with the fracture stress. The strain at the fracture can be related to brittleness or shortness (inverse of strain at fracture). The lower the strain at fracture, the more brittle is the gel. The area under the curve is called toughness. The polymer gels are more dominated by elastic behaviour whereas the particle gels are more dominated by viscous behaviour.

Sol-gel transformation occurs in many food materials systems. Depending on the concentration, processing conditions and presence of reagents, the sol-gel transformation will take place through increased viscosity. The structure of the material can be changed from a thin liquid to hard gel particles to produce new food products as depicted in Figure 1.9. Addition of gelling agent may be necessary during the process of making the gelled products. One example is fruit juice which can exist as a simple thin liquid (drinking consistency) to concentrate, gels and powders.

In food applications, gels can be produced as discrete particles or bulk gels. The discrete gel particles are used for encapsulation of actives and also to encapsulate water insoluble particles, such as fat (emulsion filled gels). Weak gels may be used to prevent sedimentation of particles, because the yield stress is enough to prevent the sedimentation. This property has applicability in salad dressings. Emulsion-filled gels are also the gels that will have different rheological properties and provide a stable emulsion (Sala et al., 2007).

The sensory evaluation of food texture involves the force and deformation required to cause fracture and the viscous flow response of the food when masticated. A basic understanding of food texture can be gained by determining the molecular mechanisms responsible for fracture, flow and rheological properties (Foegeding et al., 1994). Texture profile analysis can also be performed to determine the textural property of gels, such as hard cheese gel or soft yoghurt gel (Tunick, 2000). Various fundamental and empirical textural properties (adhesiveness, cohesiveness, factorability, gumminess, hardness, stiffness and sponginess) that are related to sensory properties can be determined by this texture profile analysis method. The textural property of the food gels may change due to the loss of the weak bonds by increase of the temperature of mechanical shear force. The stress at fracture may not vary with temperature, suggesting that the force required to rupture a covalently bonded gel matrix is temperature invariant while normal viscoelastic food gels are temperature dependent (Foegeding et al., 1994).

1.6 INTERFACIAL PROPERTIES OF THE FOOD MATERIALS

All materials or objects have interfaces that are surrounded by some other materials. The property of the materials at the interface or boundary surface is always different from the bulk, either due to rearrangement of the interface forming components to reduce the energy or due to contamination during their manufacturing. This property change could be at a single molecular layer (monolayer) in a nanometer scale. Interfacial science involves the behaviour of surface active materials at molecular level, fine particle dispersion, thin films and fibres and other systems that are strongly influenced by their interfaces. Surface tension, surface energetics and adhesion are all interfacial properties. Table 1.7 presents the list of fields in food processing and product systems where an understanding of interfacial science is important. The interfaces could be solid, liquid or gases. If it is a particulate dispersed system, the particles could be solid, liquid or gas and the continuous phase could also be solid, liquid and gas. The interfaces could be liquid-liquid (oil-water), solid-liquid (equipment surface-food liquid), liquid-gas (water-air), or solid-solid (glass-plastic), gas-solid (air-equipment surface). There is an excess of free energy in the phase boundary of the materials. Substances that lower the interfacial tension are adsorbed onto the interfaces in order to lower the total free energy. Any system at equilibrium will have a minimum free energy. The adsorption processes are time-dependent, because the molecules that are

Table 1.7 The Food materials and processing systems where interfacial science is important.

Systems	Examples of food materials and processes
1. Aerosols of liquid or solid particles	Spraying, spray drying of foods.
2. Cleaning compounds	Detergents, wetting of the surfaces during cleaning.
3. Colloidal dispersions	Infant formulas, milk (casein micelles), dairy liquids.
4. Emulsion	Milk, mayonnaise, sausages.
5. Food powders	Wetting during reconstitution of powders.
6. Liquid foams	Whipped cream and butter, cappuccino, egg white, ice-cream.
7. Product-equipment surface	Fouling, food adhesion on packaging, product stickiness on the equipment surface.
8. Solid foams	Extruded expanded foods, bread.
9. Suspension	Salad dressings.

adsorbed on the interfaces need to be transported or diffused from the bulk. The substances that are amphipathic (have hydrophilic and hydrophobic groups in the molecular structure) and reduce the free energy at the interface are called surfactants (short form of 'surface active agents').

1.6.1 Emulsions and surface active compounds

Emulsions are the most common engineered food systems that involve the applications of interfacial science. There are natural emulsions such as milk, while a number of food products are made by emulsification. Surfactants are used extensively in food material systems to stabilise emulsions by reducing the surface energy and increasing repulsion of particles. The emulsions and colloids have dispersed particles with very large interfacial surface areas. As the size of the dispersed particles decreases, the total surface energy increases significantly due to the increase in the interfacial surface area (Langevin, 2000). For example, the surface area of a droplet with a volume of $1\ \mu\text{L}$ ($10^{-9}\ \text{m}^3$) and surface area of about $5\ \text{mm}^2$ initially will increase to $10\text{--}50\ \text{m}^2$ when it is broken in to particles with nanoscale diameters. The Laplace pressure ($P_L = 2\gamma/r$; P_L =Laplace pressure, γ =surface tension, r =radius of droplet) explains the surface pressure of dispersed particles (Barnes and Gentle, 2005). The applied mechanical shear has to overcome this pressure to break the particles. Thus, the amount of surfactant required to reduce the surface tension of nanoscale droplets will be very high as compared to the $1\ \mu\text{l}$ droplet size. Nanotechnology including the technology to form nanoparticles has become very important due to the large interfacial surface of materials at that size range.

In food systems, common surfactants are of three types: small molecular surfactants (e.g., aliphatic alcohols, monoacyl glycerol, Tweens 80, phospholipids), macromolecules (e.g., gum arabic) and proteins. The surfactant molecules are bipolar, which means they have a 'polar head' and an 'apolar tail' (Figure 1.10). When the surfactant is added to an aqueous system it will be adsorbed at the water-air or water-lipid interface by projecting the apolar

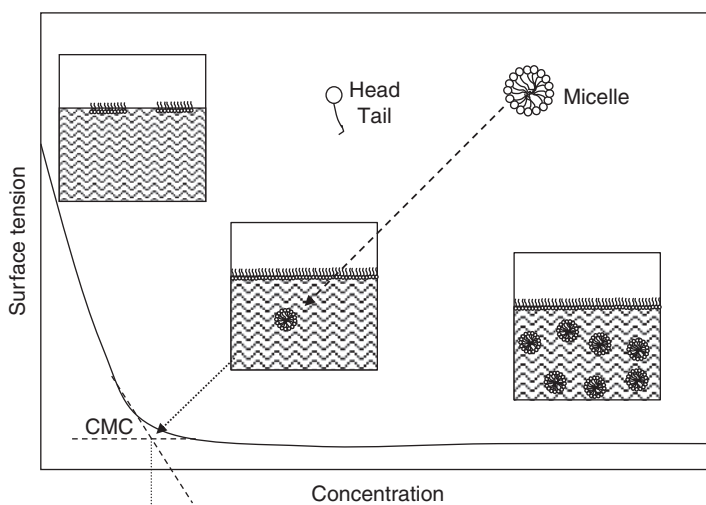


Figure 1.10 Diagrammatic representation of surface tension as a function of surfactant concentration, adsorption of surfactant at the water-air interface and formation of micelles.

tail towards the air or lipid interface reducing the surface tension of water. When the surface is saturated with a monolayer of hydrophobic tail, there is no more adsorption. At this point, the hydrophobic part of the molecule must be sequestered away from the water. Therefore, the surfactant molecules start to form micelles which are the aligned structures of hydrophobic (tail) and hydrophilic (head) groups (Figure 1.10). Thus if the surfactant is added in excess over the amount required for surface coverage at the interface, micelle formation occurs (Barnes and Gentle, 2005). These micelles can incorporate the insoluble species into their core (such as in cleaning process or in encapsulation process). There are some food materials, such as electrolytes and sugars (sucrose), which may increase the surface tension. This is due to their strong interaction with water; thus they prevent surfactant from being adsorbed at the interface or push the molecules back to interior from the surface. This phenomenon is called negative adsorption or depletion (Figura and Teixeira, 2007).

Proteins are surface active due to the presence of hydrophobic moieties in their structures. The hydrophobic groups are normally buried inside their secondary and tertiary structures. The conformation of the protein is changed during the adsorption at the interface due to the projection of hydrophobic group towards the apolar phase, such as to air or fat. Thus, proteins can be used as emulsifiers. The surface tension at the interface is reduced until the surface is saturated with protein molecules. Because of this effect, the surface tension of the liquid remains constant above a certain concentration. The diffusion from bulk solution to the surface, unfolding of the protein structure to expose the hydrophobic group at the interface and spreading of the unfolded part of the molecules are all time-dependent. Therefore, the surface tension will be reduced continuously until equilibrium is reached. Based on the property of the dispersing medium and the polymers, the time to equilibrium can be from a few minutes to a number of hours (Barnes and Gentle, 2005). There is also competing effect of low (such as tween 80) and high molecular weight surfactant molecules (such as proteins) to reach the surface. The migration of proteins to the droplet-air interface during the formation of droplets in the spray-drying process has been found to increase the surface coverage of proteins in the resultant food powder particles (Faldt & Bergenstahl, 1996; Adhikari et al., 2009). The effect of change in the conformation may be irreversible reducing the solubility of the proteins located at the interface. Some enzymes may lose their activity as a result of this effect (Maa and Shu, 1997).

1.6.2 Colloids

Colloids hold a greater significance in material property due to their large interfacial surface per unit volume. Colloids are micron or submicron size particle dispersions in a fluid. Aerosols and hydrosols (sols) are the terms used if the dispersing medium is air or water, respectively. Aerosols are formed by the dispersion of solid or liquid in the air (such as mist, smoke). The particle diameter may vary from a few nanometers to up to 1 mm. The suspended colloidal particles can be in solid, gel or semi-solid forms. The interfacial area of colloids is very large due to their small size. The casein (50–500 nm size range) in milk is present in colloidal form. Many other foods may be in colloidal form. Many water pollutants can be in colloidal form. Colloidal suspensions are commonly used in the pharmaceutical, cosmetic and paint industries. The colloids are divided into two classes, lyophilic (solvent loving) and lyophobic. Lyophilic colloids are simple large molecules of the size of colloids, such as proteins or hydrocolloids. These are in fact solutions of large molecules. Hydrophobic colloids are not soluble in solvent (de Kruif and Tuinier, 2004).

Most particles in an aqueous solution possess an electric charge due to adsorbed ions or ionic surfactants. Most food systems are negatively charged (Walstra, 1996). The particles are accompanied by oppositely charged ions known as counterions to bring the system into net electroneutral charge. When electrically charged particles with the same charge come close to each other the electrical double layer overlap that results into repulsion between the particles. This theory on the stability of colloids was firstly explained by DLVO (Deryagin-Landau-Verwey-Overbeek) theory (Barnes and Gentle, 2005). All these factors avoid flocculation/coalescence, sedimentation or creaming. It is possible to coagulate the particles by the addition of electrolytes (salts) and acids that neutralise the surface charges. Colloids remain in suspension with separate identity in the fluid also due to Brownian motion and steric hindrances. Brownian motion is caused by the impact of the constantly moving solvent molecules on the colloidal particles. Steric hindrances occur when the amphiphilic polymers cover the surface of the particles projecting in the hydrophilic part into the solution providing the same charge at the particle surfaces. An example is a casein micelle particle where the κ -casein provides such steric hindrances and also through double layer repulsion arising from the charges on the κ -casein hairs. The stability of hydrocolloids is achieved by the balance between the attractive van der Waals forces originating from induced-dipole interactions and the repulsive forces due to a charged electric double layer surrounding particles. In relatively concentrated food systems, such as ice cream, cream, toppings and other deserts the emulsions are stabilised by colloidal proteins [such as casein in a colloidal particle form, which acts as the main stabiliser in milk based emulsions (Darling and Birkett, 1987)].

1.6.3 Foams

Foam is a substance that is formed by trapping gas bubbles in a liquid or solid. This is also a dispersion of a hydrophobic gas (air) in a hydrophilic liquid. Foams have similarities with oil-in-water type emulsions. However, the stability of a foam is very low due to fast separation because of the large density difference of the phases and large gas particle diameters (Walstra, 1996). Fine foams can be called colloids. The foam makes a network of interconnected films called lamellas. At the junction of films in a foam there is a region of greater thickness known as the plateau border. The connected lamellas radiate out at 120° from the connection points (Figure 1.11). The Laplace pressure at the plateau border is low due to surface curvature. Therefore, the liquid tends to flow from the lamella into the plateau border causing drainage thinning of the films and eventual stability of the foam. Osmotic

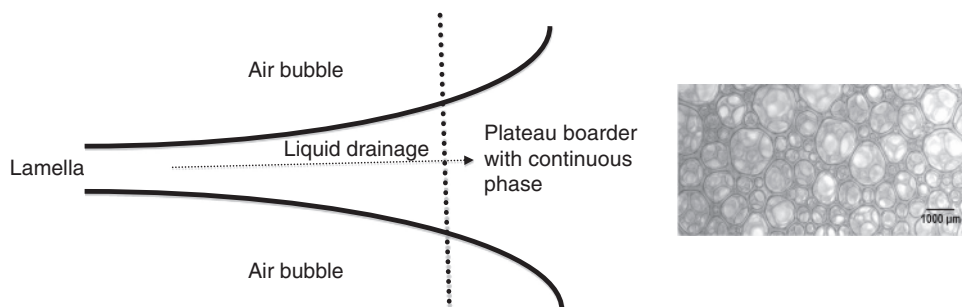


Figure 1.11 Structures of food foams.

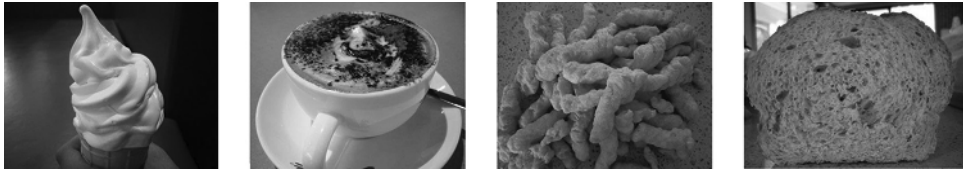


Figure 1.12 Food liquid foams (ice-cream and cappuccino) and solid foams (extruded snack and bread).

pressure can also promote drainage from the lamellas to the plateau borders due to internal concentration differences in the foam. Ostwald ripening effect (growth of bigger bubbles at the expense of smaller ones) driven by Laplace pressure difference (diffusion of small bubbles to the bigger one) cause diffusion of gas from small to large bubbles due to a higher internal pressure in the smaller bubbles. This is also known as disproportionation. Coalescence of bubbles due to instable film (poor surfactant coverage and drainage) will also destabilise the foam. The solubility of gases in water will also cause shrinkage of the bubbles and promote the Ostwald ripening effect (Langevin, 2000; Wilde, 2000).

Foam is stabilised by van der Waals forces between the molecules in the foam, electrical double layers built by dipolar surfactants and Marangoni effect which acts as a restoring force of the lamellas. Marangoni effect (or Marangoni convection) describes flow of liquid from low to high surface tension regions. This is also called ‘tears of wine’, that means when the alcohol in the wine evaporates from the wet surface above the wine level causing a higher surface tension region (high water concentration) above the wine level resulting in the pulling of the wine from below (Barnes and Gentle, 2005). In a bubble, the surfactant molecules are dragged to a high surface tension weaker region that helps to stabilise the bubbles.

There are a number of food systems that have foamed structure. These may be liquid or solid foams (Figure 1.12). Some of these products are whipped cream, ice-cream, bread and some confectionery products. The foam enhances the increase in volume (bread), contributes to brittleness and crunchiness (extruded food), lightness (cream and butter), scoopiness (ice cream), softness (bread, cakes) and froth (cappuccino). The carbonated beverages have dissolved CO_2 and N_2 at a high pressure. When the pressure is released, the gas gets super-saturated and starts diffusing to the wall of the container where there are already some air pockets. The bubbles grow and rise. Foam may form at the top of liquid.

The foams are normally made by a mechanical force. Small bubbles are formed by beating air into the liquid. The bigger bubbles are broken into fine bubbles depending on the shear force applied. The foams are normally stabilised by the surfactant, by adsorption of proteins and solid fats (such as in whipped cream).

Solid foam structures are also obtained in many food processes, and mainly in extrusion, puffing and after freeze-drying. A mix of ingredients may be expanded due to the sudden drop of pressure of plasticised ingredients at the die. The rapid evaporation of the water, vapour release and cooling forms the puffed solid structure of the extruded products. The structures of many cereals, such as puffed rice, wheat flakes and popcorn, are formed by this method. The direct immersion of food into the hot oil (180–200 °C) also causes pressure build-up, evaporation of water and puffing or forming a bubble structure, such as that of potato chips. In baked foods, the bubble formation may occur during mixing and proving due to fermentation of sugar by yeast, but these bubbles are stabilised (and expanded) when starch gelatinisation is induced by high temperatures in the oven (Niranjan and Silva, 2008). The foam stability in solid foods will depend on the balance between its

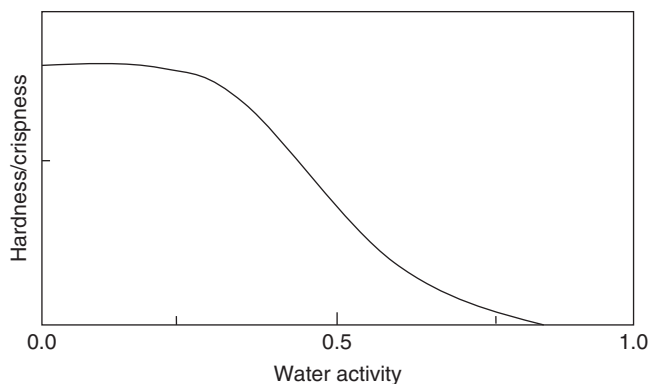


Figure 1.13 Schematic representation of loss of hardness/crispness of the solid foam structured baked or extruded products (e.g., crisp bread, chips) as a function of water activity.

formation while in viscous state and collapse before solidification of the structures. Unlike in a liquid foam, a solid foam holds its structures for years, so stability of a foam is not an issue in solid-foam systems unless there is some moisture adsorption and related physical changes in the structure. In these processes, the process variables, bubble size and distributions and structures have direct relationships. Structure will interplay with the mouth-feel. The loss of crispness (hardness in the instrumental test) of an extruded solid foam product is a function of water activity (Figure 1.13). It has also been found that the crispness of an extruded snack food is lost above the monolayer moisture content (Labuza et al., 2004). This also corresponds to glass transition temperature. The increased toughness of extruded snack foods was explained earlier in section 4.

1.6.4 Stickiness and fouling

Surface energetics describes other properties that are relevant to food materials and processing. Stickiness is driven by the surface property of a material. It is the ability of adhesion or cohesion of two dissimilar or similar surfaces. It is influenced by the adhesive balance between contacting surfaces. It can be a desirable or undesirable property of a material and is noticed in various ways, such as in sticking or adhesion to processing equipment, cohesion of powders, sticking to packages etc. Although, the term ‘stickiness’ usually has the connotation of a poor quality characteristic, it is a required sensory property in some food products. It is a term very commonly used in describing such food commodities as rice, chocolate, caramel, candy, bread/dough and dried fruits. In some processing situations, stickiness is a required property, such as in granulation, instantisation and tableting of powders.

In fact the stickiness property is directly related to the interfacial surface energy of contacting materials. Some materials may have a high water content and/or low viscosity yet do not exhibit strong stickiness behaviour, even in response to a finger touch. The adhesion of food materials is important in terms of recycling of packages and cleaning of industrial equipment (Michalski et al., 1999). Adhesion can cause losses and if there is adhesion to the packaging materials the food product can deteriorate (Nielson and Olafsson, 1995). The adhesion of food to packaging material surfaces is not desired from a consumer perception of quality.

Table 1.8 Surface wetting tension of various solid materials.

Surface	Wetting tension (mN/m)
Aluminium	90
Nylon-6,6	46
Polydimethyl silioxane (silicone)	21
Polyethylene	31
Polyethylene terephthalate (PET)	43
Polystyrene	33
Polytetrafluoroethylene (Teflon)	18
Polyvinyl chloride	39
Stainless steel	71

The surface energy of various solid materials is listed in Table 1.8 (Pocius, 2002). Normally inorganic materials have higher surface energies than organic materials; this means that organic materials have poor wettability (fewer tendencies to cause sticking of materials). Metals have high surface energies; therefore materials tend to stick more on a metal surface. Polymers have low surface energies therefore are difficult to wet. One polymer, Teflon, has very low surface energy. Since water is a very high energy material and Teflon has a very low surface energy, these events are energetically incompatible; therefore the wetting angle is very large. Therefore, Teflon coating has been practiced in many items of cookware. In general the higher the surface wetting tension of a material the higher is the tendency to adsorb hydrophilic materials on the surface.

In some food processing situations, food adhesion can be of significant concern, particularly in cases of foods that are more adhesive than others. One of the important processes where stickiness has been an issue is drying of high sugar and high fat products (Bhandari et al., 1997). This causes difficulties in drying equipment design and in processing, resulting in frequent down time and high losses of products, which stick on to the equipment surfaces or form a cake. Selection of equipment with an appropriate low energy surface of contact can minimise the stickiness caused by adhesion. Because of hygiene, ease of cleaning, durability and thermal stability, stainless steel is the material used in much food drying equipment. But stainless steel has a high surface energy (Table 1.8) that results in very easy fouling. The development of self-cleaning materials that do not foul is under development using the coating of hydrophobic nanomaterial surfaces which is a 'lotus-leaf' inspired technology (Mozumder et al, 2011). Lotus leaf grows in muddy water, but its leaves are seemingly never dirty. Drops of water on a lotus leaf have an unearthly sparkle, and rainwater washes dirt from that leaf more readily than from any other plant. This is due to the microscopic scale of waxy bumps on the surface of the leaves reducing the contact angle of water significantly. Development of this type of food grade materials will revolutionise food processing equipment that will not foul easily and also not need severe cleaning.

When a material sticks with the equipment surface, during its removal there will be adhesive or cohesive failures. During an adhesive failure the material will leave the surface neat, while if there is cohesive failure only part of the material will be removed. Figure 1.14 depicts interfacial property of a drying droplet on the stainless steel surface. In this illustration, the adhesive failure occurs at the interface of a food and the stainless steel surface. Thus a thin layer remains on the probe surface. Cohesive failure indicates that the product is stuck onto another surface. When the adhesive bond is limited by the adhesive material property there is a cohesive failure. The cohesive failure is influenced by the viscoelastic

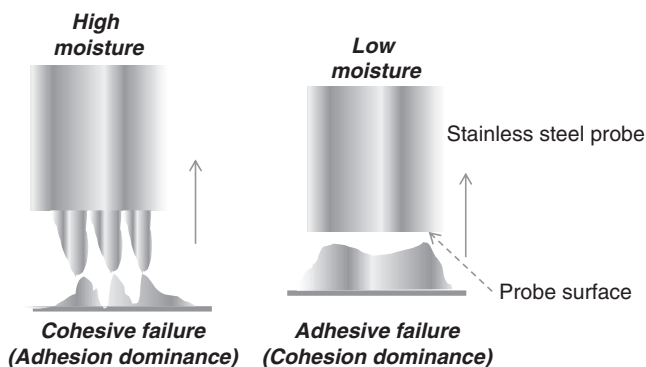


Figure 1.14 Interfacial property of a material with two different moisture levels on the stainless steel probe surface.

property of the material (Adhikari et al., 2007). During drying a continuous change from cohesive failure to adhesive failure of a drying droplet occurs at the probe surface. Just to note that the type of failure and the stage of failure will depend on the type of both materials (adherent and adhesive) as determined by the surface energies of both materials. To avoid the sticking of the product on the side wall of the dryer or on the packaging container wall, adhesive failure should occur. Normally increase in water content of a product may make it less cohesive and more adhesive.

1.7 APPLICATION OF MATERIALS SCIENCE IN FOOD DESIGN AND DEVELOPMENT OF ENGINEERED FOOD MATERIALS

Food is normally a composite in terms of composition and structure. It means that it constitutes a number of components, and there could be many macro- and micro-level structures of the food within a food system. The structure and properties of a food are important to food materials science and engineering (Figure 1.15). As discussed in the previous sections, the primary structures of the food are liquid, semi-solid, gel, foam, emulsion, powder, etc. The desired sensory properties could be crispness, chewiness, flowability, firmness, softness, smoothness, creaminess, hardness etc. One requires a good knowledge of science, engineering and food components to develop a product based on the materials science approach. Although, it has been a practice to design and develop a product based on the experience, the mechanism of changes occurring in the food system during processing, storage and consumption could not be understood in-depth without a proper knowledge of food materials science. The processing and performance are two other important aspects of food designs based on the material science approach. Thus, the same basic principles of materials science described in Figure 1.1 earlier in this chapter can be used while designing a new food product. The structure of food will depend on how it is processed. The food material performance in terms of eating quality, stability and nutritional quality will be a function of its properties. The data base of each ingredient that contributes to a microstructure or a combination of microstructures should be known and the processing methods and conditions should be designed and experimented. Thus the processing, structure, properties and performance are interdependent properties that can be considered while designing a food.

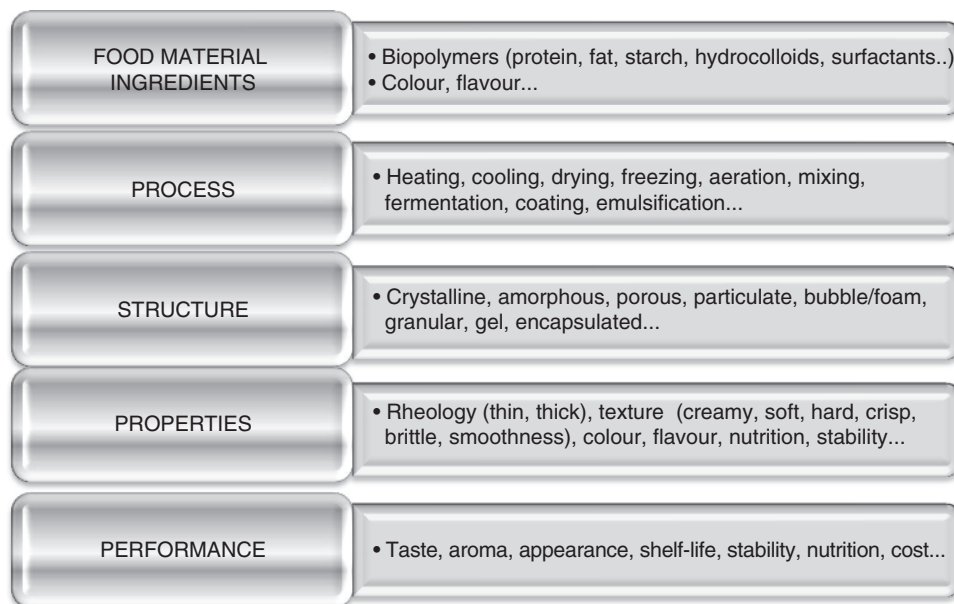


Figure 1.15 Materials science approach on food design and development.

An example of a product development based on the food materials science approach could be described during the development of a date powder (see Sablani et al., 2008 for more details). At first we should know the raw material properties (chemical and physical). Date is a sugar-rich sticky product. The powder from date should be free flowing. The conversion of date to powder form is not possible due to its components and their low glass transition temperatures; this means that even if it is dehydrated to very low water content it will be in a rubbery or sticky state (see section 4). The powder should be in a solid state (crystalline or amorphous) for a proper flowability. Crystallisation of date sugars is not possible due to the presence of a number of sugars (such as fructose) that inhibit crystallisation of each other. Due to the low glass transition temperature of the date solids it will not be possible to convert it to free flowing powder without adding a carrier. The role of the carrier will be to raise the glass transition temperature of the mixture. Then, we need to find an existing process or develop a new process that can convert date to powder (particulate structure) form. One of the common methods of converting the food into powder form is spray drying. For this, we can disperse or solubilise the date solids in water and add some miscible solid carrier (such as maltodextrin) to raise the glass transition temperature. Since date contains very high content of water-insoluble solids (cellulosic fibres) it may cause a problem (blockage or fast wearing) during atomisation. Although the fibres can be removed by filtration or micronisation, it will add another cost, and to retain the nutritional value it is beneficial to keep the fibre in the product. Another major cost-related concern is that the redispersing of already dried date in water and evaporation of that water to convert it to powder form will also be very expensive. Therefore, we can think of an alternative process. We need to find a process that can raise the T_g of the date. So, a simple mixing operation of additives (maltodextrin) that raise the T_g with the minced date may be possible. The water present in the date or a small amount of added water will assist dissolution of the carrier and blend it with the date. After a simple mixing operation the mixture will still be in rubbery

(sticky) state. Therefore, it should be dried in order to remove the water. A low cost hot air drying system can be used to remove the water. The dried product coming out of the drier may be in a chunky form, so further grinding is required to reduce the particle size in order to achieve free flowing solid powder. This example demonstrates how knowledge of raw materials properties, processing and performance are interwoven aspects in a new product development.

1.8 CONCLUSION

Food materials science and engineering is a new thought process for the improvement and development of new products. This also helps understanding various mechanisms involved during food manufacturing and quality control. Materials science is well developed in other areas, such as biotechnology and pharmaceutical materials. This new way of thinking and approach is required in food systems in order to improve the quality and shelf-life of existing products, and develop new food products and processes. To fully apply materials science in food systems, sufficient knowledge in basic science and engineering concepts from molecular to micro and bulk levels is needed. Although materials science research activities are on-going independently in various sectors, there is no integration of knowledge from various areas into one field. Novel food materials need safety, reliability, extended shelf-life, and improvement on functional properties. The understanding of materials science and engineering will assist in bringing these outcomes.

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