

Encapsulation in the food industry: a review

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Encapsulation involves the incorporation of food ingredients, enzymes, cells or other materials in small capsules. Applications for this technique have increased in the food industry since the encapsulated materials can be protected from moisture, heat or other extreme conditions, thus enhancing their stability and maintaining viability. Encapsulation in foods is also utilized to mask odours or tastes. Various techniques are employed to form the capsules, including spray drying, spray chilling or spray cooling, extrusion coating, fluidized bed coating, liposome entrapment, coacervation, inclusion complexation, centrifugal extrusion and rotational suspension separation. Each of these techniques is discussed in this review. A wide variety of foods is encapsulated – flavouring agents, acids, bases, artificial sweeteners, colourants, preservatives, leavening agents, antioxidants, agents with undesirable flavours, odours and nutrients, among others. The use of encapsulation for sweeteners such as aspartame and flavours in chewing gum is well known. Fats, starches, dextrans, alginates, protein and lipid materials can be employed as encapsulating materials. Various methods exist to release the ingredients from the capsules. Release can be site-specific, stage-specific or signalled by changes in pH, temperature, irradiation or osmotic shock. In the food industry, the most common method is by solvent-activated release. The addition of water to dry beverages or cake mixes is an example. Liposomes have been applied in cheese-making, and its use in the preparation of food emulsions such as spreads, margarine and mayonnaise is a developing area. Most recent developments include the encapsulation of foods in the areas of controlled release, carrier materials, preparation methods and sweetener immobilization. New markets are being developed and current research is underway to reduce the high production costs and lack of food-grade materials.

Introduction

Approximately 30 years ago, encapsulation processes were developed. It involves the coating or entrapment of a pure material or a mixture into another material. The coated or entrapped material is usually a liquid but can be a solid or gas. This material is also known as the core material, actives, fill, internal

phase or payload. The coating material can also be called the capsule, wall material, membrane, carrier or shell. The purpose of encapsulation is to protect its contents from the environment which can be destructive while allowing small molecules to pass in and out of the membrane. Natural examples

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include birds' egg shells, plant seeds, bacterial spores, skin and seashells.

Early versions of microcapsules were impermeable and were broken apart, most often by mechanical means, for the inner ingredients to become active. Examples included controlled release of flavours and aromas, perfumes, drugs, detoxicants, fertilizers and precursors in textiles and printing (Seiss & Divies, 1981). Enzymes, plant, animal or microbial cells could be encapsulated to allow substrates to enter the membrane and products to leave. This concept was instrumental in the development of artificial kidneys since detoxifying enzymes could be placed in semipermeable membranes (Chang, 1978) and perform the function of the kidney. Nylon membranes have been used by Desoize (1986) to encapsulate and cross-link enzymes such as casein and pepsin. Examples of enzyme encapsulation include juice clarification with pectin esterase, sucrose inversion by invertase and milk coagulation with rennet (Lee, 1996).

An important bacteria used in the industry, lactic acid bacteria, was first immobilized in 1975 on Berl saddles and *Lactobacillus lactis* was encapsulated in alginate gel beads years later (Linko, 1985). Seiss and Divies (1981) suggested that immobilized lactic acid bacteria could be used to continuously produce yoghurt. However, the alginate beads of *L. lactis* susp. *cremoris* leaked large quantities of cells. Other membranes such as poly-L-lysine, nylon and polyethyleneimine to coat alginate beads have also recently been examined (Larisch, 1990) but did not show any improvement in lactic acid production as compared to free cells.

Encapsulation involves the incorporation of various ingredients within a capsule of approximately 5 to 300 micron in diameter (Lee, 1996). The capsule can be made of sugars, gums, proteins, natural and modified polysaccharides, lipids and synthetic polymers. The advantages of encapsulation include improved flow properties and easier handling since they are solid instead of liquid. Stability of the encapsulated material can be improved due to protection from moisture or heat.

Encapsulation can be of many different forms such as a simple membrane coating, a wall or membrane of spherical or irregular shaped, a multiwall structure with walls of the same or varying compositions or numerous cores within

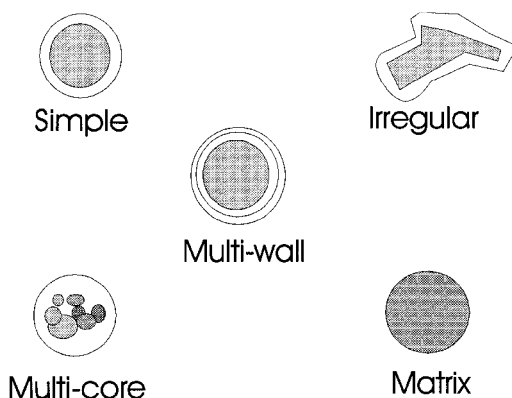


Figure 1. Various forms of capsules.

the same walled structure as shown in Figure 1. Currently, almost any material can be encapsulated for the purpose of isolation, purification or slow release.

For many years, this technique has been used in the pharmaceutical industry for time-release, enhanced stability of formulations and flavour masking. Prescription drugs, over-the-counter drugs, vitamins and minerals have been encapsulated. Therefore, these applications, in addition to many others, would be useful in the food industry.

Applications have been slower in increasing since the technique was thought to be too expensive and highly specific. However, since production volumes have increased and more cost-effective preparation techniques and materials have been developed, the number of encapsulated food products has significantly increased. Microcapsules can improve nutrition since the extensive storage of many products can result in the loss of nutritional value by enabling the addition of oxidation-sensitive vitamins, minerals and proteins to various products.

Manufacturing techniques

Various techniques are used for encapsulation (Dziedzic, 1988). In general, three steps are involved: formation of the wall around the material, ensuring that leakage does not occur, and ensuring that undesired materials are kept out. These encapsulation techniques include spray drying, spray chilling or spray cooling,

extrusion coating, fluidized bed coating, liposome entrapment, coacervation, inclusion complexation, centrifugal extrusion and rotational suspension separation. Each of these methods will be discussed in the following sections.

Spray drying

Since spray drying is an economical, effective method for protecting materials and specialized equipment is not required, it is most widely employed, particularly for flavours. It is also used for dehydration of materials such as powdered milk. For encapsulation purposes, modified starch, maltodextrin, gum or others are hydrated to be used as the carrier or wall material. The material for encapsulation is homogenized with the carrier material usually at a ratio of 1 : 4. The mixture is then fed into a spray dryer and atomized with a nozzle or spinning wheel. Water is evaporated by the hot air contacting the atomized material. The capsules are then collected after they fall to the bottom of the drier.

Recent developments have been in the use of new carrier materials and a newly designed spray dryer. Colloides Naturels (Thevenet, 1995) and TIC Gums (Reineccius *et al.*, 1995) have developed new combinations of gum arabic starches to increase the retention of volatiles and shelf-life of the microcapsules. In particular, Risch and Reineccius (1988) enhanced the retention of orange oil and decreased oxidation by using gum arabic. Bhandari *et al.* (1992) showed that a new type of dryer called the Leafish spray dryer, which uses a high air velocity with a temperature of 300 to 400°C, was effective for encapsulating citral and linalyl acetate without degradation. A disadvantage is that a separate agglomeration step is required to prevent separation or to render the obtained powder soluble. A chief advantage is that this technique can be used for heat-labile materials.

Spray chilling or spray cooling

In spray chilling, the material to be encapsulated is mixed with the carrier and atomized by cooled or chilled air as opposed to heated air as in spray drying (Risch, 1995). The outer material is usually vegetable oil in the case of spray cooling (45 to 122°C) or a hydrogenated or fractionated vegetable oil in the case of spray chilling (32 to 42°C). The disadvantage of the

latter method is that special handling and storage conditions could be required (Taylor, 1983). Spray chilling is usually used for ferrous sulfate, vitamin, mineral or acidulent encapsulation. Frozen liquids, heat-sensitive materials and those not soluble in the usual solvents can be encapsulated in this manner. These materials are then released as the wall material is melted. Applications of spray chilling can include: dry soup mixes, foods with high fat contents and bakery products (Blenford, 1986).

Extrusion

Extrusion was first patented in 1957 (Swisher, 1957) and further developed by the same group. At this time, citrus oils were dispersed in corn syrup solids and glycerine at 125°C as heated by steam, poured into a chamber pressurized by nitrogen and extruded into a dehydrating liquid such as isopropyl alcohol. The solidified material is then separated into small pieces (1 mm) and vacuum-dried. Several factors were later found to improve the quality of the microcapsules including the dextrose equivalent of the corn syrup, emulsifier and flavour oil content and emulsification pressure (Crocker & Pritchett, 1978). The advantage of extrusion is that the material is totally isolated by the wall material and that any core is washed from the outside. It is mainly used for visible flavour pieces, vitamin C, colours and extension of shelf-life up to at least 2 years. Dry food applications include drink, cake, cocktail and gelatin dessert mixes since the encapsulated materials are soluble in hot or cold water. Numerous flavours have also been encapsulated by this method (Risch, 1988).

Fluidized bed coating

Solid particles are suspended in a temperature and humidity-controlled chamber of high-velocity air where the coating material is atomized (DeZarn, 1995). Optimal results are obtained with particle sizes between 50 and 500 microns. Particle size distribution should also be narrow. The amount of material that coats the particles is dependent on the length of time that the particles are in the chamber. This technique is applicable for hot-melt coatings such as hydrogenated vegetable oil, stearines, fatty acids, emulsifiers and waxes or solvent-based coatings such as starches, gums, maltodextrins. For hot melts, cool air is used to harden the

carrier, whereas for solvent-based coatings, hot air is used to evaporate the solvent. Hot-melt ingredients release their contents by increasing the temperature or physical breakage, whereas water-soluble coatings release their contents when water is added. Fluidized bed encapsulation can be used to isolate iron from ascorbic acid in multivitamins and in small tablets such as children's vitamins. Many fortified foods, nutritional mixes and dry mixes contain fluidized bed-encapsulated ingredients. Citric acid, lactic acid, sorbic acid, vitamin C, sodium bicarbonate in baked goods, and salt added to pretzels and meats are all encapsulated.

Liposome entrapment

One type of capsule with more versatile properties and less fragility than those made of fat are liposomes. They have been used for delivery of vaccines, hormones, enzymes and vitamins in to the body (Gregoriadis, 1984). They consist of one or more layers of lipids and thus are non-toxic and acceptable for foods. Permeability, stability, surface activity and affinity can be varied through size and lipid composition variations. They can range from 25 nm to several microns in diameter, are easy to make and can be stored by freeze-drying. Kirby and Gregoriadis (1984) have devised a method to

encapsulate at high efficiency which is easy to scale-up and uses mild conditions appropriate for enzymes.

Phospholipids make up the outer layer or layers of liposomes (Figure 2A). The hydrophilic portion of the lipids is oriented towards the aqueous phase and the hydrophobic groups associate with the hydrophobic ones of other lipid molecules. Folding of the lipid sheet into a spherical shape forms a very stable capsule due to there being no interaction of the lipids with water (Figure 2B). Aqueous or lipid-soluble materials, but not both, are entrapped in these membranes. Mainly flavour agents are encapsulated in this manner. Liposomes can range from a few nanometers to micron. They were initially developed for medical purposes (New, 1990) and then were used for cosmetics (Ghychy & Gareiss, 1993). Food applications of liposomes in cheese-making were described by Kirby (1993).

The most common phospholipid in lectin, phosphatidyl choline, is insoluble in water and is inexpensively isolated from soy or egg yolk. The composition of the phospholipids and the process used determine if a single or multiple layers are formed (Martin, 1990). Fatty acids also make up liposomes and their degree of saturation is dependent on the source. Animal

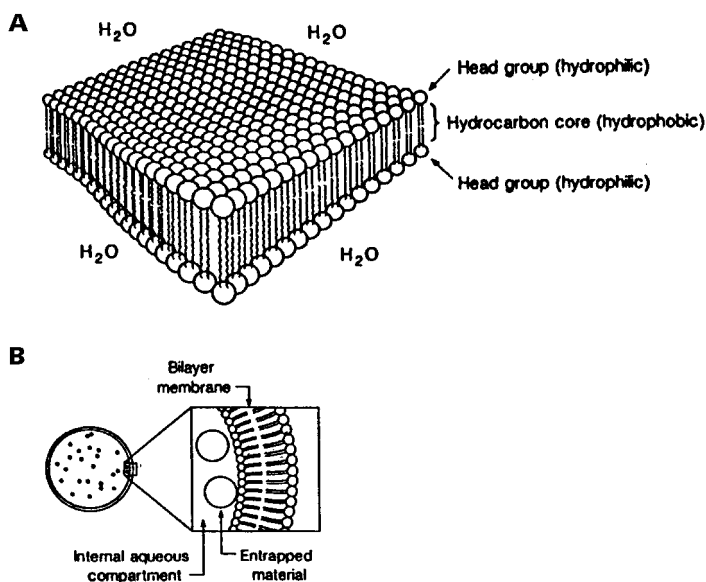


Figure 2. Schematic diagram of a sheet of lipid bilayer (A) and the liposome formed from the lipids (B) (adapted from Reineccius, 1995).

sources provide more saturated fatty acids. They influence the transition temperature which is the conversion from a gel to the more leaky liquid form.

Although sugars and large polar molecules cannot permeate through a liposome bilayer, small lipophilic molecules can. They will only permeate through the membrane, though, if they are soluble in the outside liquid. Hydroxyl ions, protein, and molecules potassium ions permeate very slowly.

Liposomes are made by three different procedures. The lipid formulation is mixed with a solvent system such as 2 : 1 chloroform : methanol. The volume of solvent is decreased and the film of lipids/solvent is then redispersed in an aqueous phase. This step forms the liposomes and it can be done in different ways including physical, two-phase and detergent solubilization. The liposomes are then recovered from the water (New, 1993).

The phospholipids in the liposomes oxidize or hydrolyze over time. Maximum stability can be ensured by using freshly prepared lipid and solvents to prepare the liposomes, avoiding exposure of the liposomes to oxygen as much as possible, limiting excessive temperatures, adding antioxidants and metal chelators to avoid charge neutralization by metals and using proper storage conditions. Hydrolysis can be minimized by using pure solvents and removing as much of the water as possible.

Holding the temperature above the phase transition temperature helps to avoid annealing or fusion. Liposomes smaller than 40 nm are more likely to fuse than larger ones. Since neutral liposomes will still aggregate due to van der Waals forces, addition of 5% phosphatidic acid or phosphatidyl glycerol can reduce this.

Coacervation

National Cash Register Company patented this technique for carbonless paper in the 1950s (Risch, 1995). Particle sizes of a few sub-microns to a centimeter are obtained. Food-grade materials have only recently been used as the carrier. This method, although efficient, is expensive. It consists of dissolving a gelling protein, followed by emulsification of a material such as a flavour oil into the protein. The coating in liquid form is removed from a polymer solution, coats the material to be encapsulated, solidified and collected by cen-

trifugation or filtration. Drying can be accomplished by spray or fluidized bed drying. The factors, pH, temperature and composition are all important in making the microencapsules.

Coacervation can be simple with only one colloidal solute such as gelatin, or complex, with, for example, gelatin and gum acacia (Luzzi & Gerraughty, 1964). Gelatin and gum acacia are used together since at low pH, each has an opposite charge, causing attraction and the formation of an insoluble complex. This viscous solution is more common and can be used to coat flavour oil droplets suspended in an aqueous medium (Bakan, 1969). Lowering the temperature hardens the wall material but it can be softened again by addition of bases, acids, heat or dilution. This process is irreversible if divalent salts or aldehydes are added.

Hydrophilic coatings such as gelatin can be used to microencapsulate hydrophobic substances including citrus or vegetable oils or vitamin A. Hot water, pressure or chemical reaction can be used to release the contents. The coating can also be hydrophobic and the core may be water soluble or immiscible (Balassa & Fanger, 1971).

Inclusion complexation

In this technique, beta-cyclodextrin is used since the centre is hydrophobic while the outer surface is hydrophilic due to its seven glucose units linked 1 to 4. In the centre of the cyclodextrin, water molecules are replaced by less polar molecules (Risch, 1995). The complex then precipitates out of solution (Reineccius & Risch, 1986). Only water can serve as the suspension medium. The precipitate is recovered and dried by conventional means. Binding by the cyclodextrin can occur up to 200°C. The moisture and temperature conditions of the mouth, however, allow release of the bound material.

Garlic and onion oils can be complexed as odour less compounds by cyclodextrin. Vitamins A, E and K which are fat-soluble can also be stabilized in this manner. Cyclodextrin, however, is only approved for use with foods in Japan and Eastern Europe (Dziezak, 1988).

Rotational or centrifugal suspension separation

The steps in rotational suspension separation, which is a relatively new technique (Sparks,

1989), involve mixing the core and wall materials and then adding to a rotating disk. The core materials then leave the disk with a coating of residual liquid. The capsules are then dried or chilled after removal from the disk. The whole process can take between a few seconds to minutes. Solids, liquids or suspensions of 30 microns to 2 mm can be encapsulated in this manner. Coatings can be 1 to 200 microns in thickness and include fats, polyethylene glycol (PEG), diglycerides and other meltable substances. Since this is a continuous, high-speed method that can coat particles, it is highly suitable for foods. One application is to protect foods that are sensitive to or readily absorb moisture such as aspartame, vitamins or methionine (Sparks *et al.*, 1993).

Types of encapsulated food ingredients

The types of food ingredients (Kirby, 1991) that can be encapsulated are shown in Table 1. Most of the uses of encapsulation in foods are for masking odours or tastes. The capsules are usually water-soluble and are dissolved when water is added. Flavour oil encapsulated in a food-grade hydrocolloid is such an example. Microencapsulation also enables ingredients such as enzymes to maintain their viability for extended periods of time as shown in Figure 3. Addition of enzymes unprotected to foods exposes them to ions, protons, radicals, inhibitors, etc. that cause instability and inactivity.

Table 1. Various food ingredients that have been encapsulated

Type of ingredient
Flavouring agents such as oils, spices, seasonings and sweeteners
Acids, alkalies, buffers
Lipids
Redox agents (bleaching, maturing)
Enzymes or microorganisms
Artificial sweeteners
Leavening agents
Antioxidants
Preservatives
Colourants
Cross-linking and setting agents
Agents with undesirable flavours and odours
Essential oils, amino acids, vitamins and minerals

Source: Adapted from Kirby (1991).

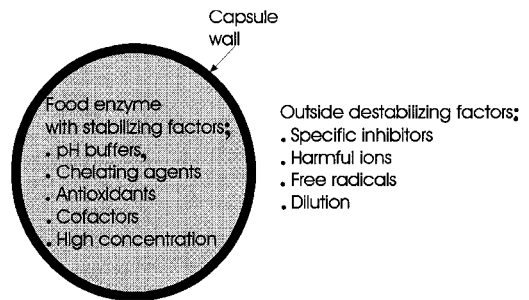


Figure 3. Benefits of encapsulating enzymes in the food industry.

The capsule can shield the enzyme from these factors.

Acidulents are added to processing and preservation aids, and flavour modifiers. Since they interact with gums, starches, proteins and pectins, they can develop a wide range of textures. Encapsulation of these agents can increase the shelf-life of citrus flavours and starch-containing foods and prevent loss of flavour and colour since their release is controlled (Dziezak, 1988). Hygroscopicity and dusting can also be reduced.

Adipic, fumaric, citric, lactic and ascorbic acids have all been encapsulated. Ascorbic acid is added to bread to improve its quality. The encapsulated form can protect this acid from the water and oxygen in the bread which causes degradation (Dziezak, 1988). Citric acid is added to tea (Dziezak, 1988) to increase tartness but it can react with the tannins and cause discolouring of the tea bag. Encapsulation can avoid this problem while maintaining the function of the citric acid. In cured meats such as pepperoni, hard salami and summer sausages, lactic and citric acids enhance the flavours of these meats. Usually this is accomplished by fermentation which is hard to control. Direct addition is not an option since the acids react with the foods. An alternative is to use encapsulated acids. Bielski (1988) found that production times of cured ground beef are significantly reduced. Glucono-delta-lactone (GDL) is used to cure meats. Encapsulation with fat avoids premature acidity and meat stiffening, and bypasses the fermentation step. Other potential applications include desserts, baking mixes and pet foods.

Beta-carotene, turmeric and other natural colours are not very soluble and can cause dust

problems during handling. The advantages of encapsulating these materials include: extending shelf-life from 6 months to 2 years (Lanzoff, 1988), easier handling, improved solubility and stability.

Encapsulation of citrus oils, other flavouring agents and spices enhance stability. Menthol, peppermint, spearmint, and other flavours in their encapsulated forms are gaining popularity in microwavable and extruded foods because of their stability at high temperatures for short periods of time. Fat-encapsulated cinnamon does not allow this flavour to interfere with yeast growth in baked goods.

Sodium bicarbonate used as a leavening agent can be encapsulated to reduce its reaction with acid or water and provide uniform performance. Fat and oil coatings are typical to encapsulate leavening agents in pizza doughs.

The advantage of encapsulating sodium chloride with partially hydrogenated vegetable oil is to increase ability to flow and reduce clumping and caking. Sodium chloride decreases colour degradation, rancidity, and helps to control water absorption and the growth of yeast. This is particularly applicable for yeast doughs, pretzel snacks and pulverized meats.

Sweeteners can be degraded by temperature and moisture. Sugar and the artificial sweetener, aspartame, is encapsulated with fats in chewing gum. These sweeteners are released slowly during chewing and moisture in the mouth. Aspartame (NutraSweet) can be protected from high temperatures in baking goods by encapsulation. Sweetness would normally be lost as the aspartame breaks down to aspartic acid and phenylalanine (Gibbs *et al.*, 1996).

Vitamins and minerals are usually added to breakfast cereals, dairy products, infant and pet foods. By encapsulating both water and fat-soluble vitamins, off flavours can be avoided and stability can be increased. Flow properties are also enhanced.

Materials of encapsulation

The use of gum arabic as an encapsulating matrix is common due to its characteristics of viscosity, solubility and emulsification. Risch and Reineccius (1988) have reported on the encapsulation of orange oil. Its main disadvantage is its expense due to frequent shortages. Therefore other materials are being investigated. Since

starch derived from potatoes, corn, wheat, rice and others is very plentiful, its derivatives could be used for encapsulation. Unmodified starch is too viscous when mixed with water.

Dextrin is formed by the heating of dry starch with acid or base, forming highly branched polymers. Different products can be obtained depending on the conditions utilized. Compared to unmodified starch, water solubility and viscosity is improved; however, they are unsuitable for oil-based ingredients due to their contribution to flavour and colour.

Starches can also be reacted with 1-octenylsuccinic anhydride to form amphiphilic groups. The concentration of this agent is limited by law to 3% of the starch (US Code of Federal Regulations). The formation of hydrophilic groups enables encapsulation of lipids almost as well as gum arabic. There has been some evidence, though, that the shelf-life of citrus oils encapsulated in this manner is inferior to gum arabic (Westing *et al.*, 1988).

Maltodextrins are formed by partially hydrolysing corn starch with acids or enzymes, whereas corn syrup solids are dried glucose syrups. Both contain glucose polymers of various lengths. The molecular weight of 10 DE (dextrose equivalent) is approximately 1800 daltons. Their viscosities are lower than gum arabic and they have no lipophilic groups. Therefore their emulsification properties are poor. Their advantages include low flavour, use at high solids concentrations and improvement of the shelf-life of citrus oils.

Blending of corn syrup solids, maltodextrins and modified starches may lead to optimal encapsulating materials. Spray-drying and extrusion processes of the individual components has been used as water-soluble coatings.

Alginates are hydrocolloids extracted from kelp which can react with calcium ions and form a stable gel. They can then be used to entrap or encapsulate flavour oils at ambient temperatures (King, 1983). The alginates are polymers of 12,000 to 180,000 molecular weight composed of D-mannuronic acid and L-guluronic acid connected by 1–4 glycosidic linkages. To make the beads, alginate is emulsified with the flavour oil and then added dropwise to a calcium chloride solution. The bead can be of 200 to 5000 microns in size. Molecules greater than 5,000 daltons are retained by the gels.

Protein-based materials such as polypeptone, soy protein, milk-derived and gelatin derivatives are able to form stable emulsions with volatile flavourings. However, their solubilities in cold water, the potential to react with carbonyls, and their high cost limit potential applications (Bangs & Reineccius, 1988). Other materials such as cyclodextrin and lipid components (liposomes) have already been mentioned.

Methods of release of ingredients from capsules

The release of components can be diffusively controlled either by the capsule wall or by a membrane covering the wall. The former is called matrix controlled and the latter, membrane controlled. The permeability through the matrix and the solubility of the component of the capsule wall influence the rate of diffusion. In general, the compound to be diffused should be soluble in the matrix. However, this is not necessarily the case, since the vapour pressure of a volatile substance on each side of the matrix can become the major driving force influencing diffusion. The volatility of aromas can vary substantially. For example, octanol has a vapour pressure of 0.18 mm compared to methyl acetate which is 170 mm.

Selection of an appropriate matrix or membrane is thus very important. Chemical nature,

morphology and glass transition temperature, all influence diffusion. However, the selection is limited since food safety is an additional consideration. Less information is available to the food scientist since few databases exist regarding food-compatible matrices or membranes. The degree of swelling is controlled by water absorption or presence of solvents such as glycerin or propylene glycol. The higher water activity, the faster the rate of release. Cross-linking also influences diffusion and is possible by coacervation. Thies (1992) discussed the use of glutaraldehyde as a cross-linker in coacervates. Higher degrees of cross-linking decrease release rates. Aroma release into bulk containers of dry drink mixes of chewing gums is a possible application. Further work using coacervates should be evaluated.

Pressure-activated release has been used for carbonless paper and scratch-and-sniff cards but has not been used frequently for food applications. Aromas could be released by opening a jar. Another application has been developed by Parliament *et al.* (1989) where a package is microwaved, heated and releases aromas during the process.

The most commonly used method of controlled release in the food industry is solvent-activated. Flavour is released from dry products such as dry beverages or cake mixes as water is added. Coatings based on sugars, gelatin, starches, PEG and others are used. In these cases,

Table 2. Encapsulation techniques used in chewing gum

Attribute	Encapsulation technique			
	Extrusion	Spray drying	Fluidized bed	Coacervation
Acidulent				
Long lasting	×		×	
Few reactions with colour	×	×	×	
Low sucrose inversion	×	×	×	
Flavour				
Immediate	×	×		×
Delayed			×	
Long-lasting				×
High concentration				×
Sweetener				
Immediate	×	×		
Delayed	×		×	
Sustained release	×		×	
Temperature	×	×	×	

Source: Adapted from Cherukuri (1992).

release is immediate, unlike for chewing gum where release over a long period of time is preferred. Other components such as sweeteners and acidulents must also be released from the chewing gum gradually. Numerous patents have been obtained. Various techniques are used as shown in Table 2.

One method that is used to control the release of flavours in chewing gum is to perform an initial spray-drying step and then coat the particle with a gum, wax or other water-insoluble substances. Acidulents are encapsulated for slow release and to avoid reactions with colours and sugars. Sweeteners such as aspartame or acesulfame K are encapsulated with an extra fatty or waxy coating to add stability (Song, 1990) and allow release over an extended period of time. As shown in Table 1, several techniques are used. One difficulty with this method, though, is that the flavour concentration is diluted by addition of the additional coating which can make up to 50% of the weight of the capsule. Higher concentrations of flavour must be used but this can change the flow properties of the gum. Release of enzymes through a change in pH is possible with liposomes (Karel & Langer, 1988) which can be destabilized. A preservative, sorbic acid, has been concentrated at the surface at a different pH than the bulk solution by mixing with an anionic polyelectrolyte, carrageenin. This can extend the shelf life of foods from hours to weeks.

Another mechanism of release is by melt-activation. The membrane on the wall or the wall itself made of lipids or waxes is destroyed by melting and components such as salts, leavening, flavourings and nutrients are released. Spray chilling is frequently used in this case. This technique is limited to water-soluble flavourings since those which are hydrophobic will pass through the wall material. Low-viscosity coatings are useful to release products upon stirring.

The release of the enzyme from the enzyme/substrate complex can be site-specific, time/stage-specific or signalled by changes in pH, temperature, irradiation or osmotic shock. Alteration of the surface properties of the microcapsule is performed so that the capsules will accumulate at a certain location for release at the specific location. Selection of more-stable microcapsules will delay the release of the

enzyme. Microcapsules made of hardened fats are insoluble in water and can release the contents when subjected to shear or increased temperature which melts the fat. This type is widely used in soup mixes, bakery products or high-fat products (Dziezak, 1988).

Other materials such as the antioxidant *butylated hydroxytoluene* (BHT), however, are encapsulated to improve handling. Normally, it is very sticky but encapsulation with methyl cellulose enables it to be easily added to fatty materials which then dissolve the capsule wall and release the antioxidant. Studies (Karel & Langer, 1988) have also indicated that ultrasonics and surfactants (e.g. Triton X-100) can also induce enzyme release in cheese-ripening from microcapsules such as liposomes. Chewing can release flavours such as herbs or garlic in pizza which are encapsulated in 1000 micron particles.

Applications of liposomes

Liposomes are being developed for use in cheese-making for reducing ripening time and preventing spoilage (Figure 4). Addition of protease enzymes is commercially used in the United States and other countries since ripening times can be reduced from a year to half a year. The use of liposomes would allow the enzymes to be dispersed uniformly in the milk and avoid the brine environment in hard cheeses which is normally too harsh for the enzymes. The liposomes are added to the milk after coagulation and will break down within the next few hours, releasing the enzymes (Kirby & Law, 1986).

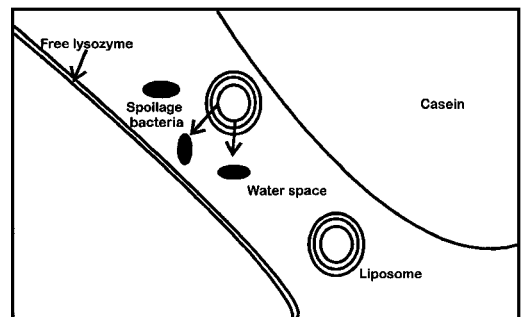


Figure 4. Microencapsulation of lysozyme in liposomes to prevent spoilage in cheese by bacteria (adapted from Kirby, 1991).

Cheeses such as Gouda, Edam and Emmental can be spoiled by butyric acid fermenting bacteria. Nitrate can be used to control this problem but there are some health concerns. Liposomes can be used to encapsulate the enzyme, lysozyme (Thapon & Brule, 1986) or the antibiotic, nisin, which could be used to prevent spoilage by bringing these components to the areas where spoilage is most likely.

Another promising area for liposomes is the prevention of oxidation of unsaturated fats in food emulsions such as spreads, margarines or mayonnaise. This is a new application since saturated fats are now being replaced by unsaturated ones which are susceptible to oxidation. Natural anti-oxidants are preferred since many synthetic varieties are banned. One approach is to entrap Vitamin C in the interior and alpha-tocopherol (Vitamin E) in a liposome layer (Kirby, 1990). Currently lipid-soluble, chemical derivatives of vitamin C are used.

Encapsulation patents

Recent developments in the encapsulation of foods have been mainly in the areas of controlled release, carrier materials, encapsulation methods and sweetener encapsulation. Most patents are concerned with controlled and sustained release. Their main objective is to lead to new and improved products. For example, the release of flavours and sweeteners from chewing gum has received considerable attention. International Flavours and Fragrances (IFF) developed a mixture of polyethylene and polyethylene glycol to encapsulate and provide sustained release of 2-methyl-2-pentenoic acid, the strawberry flavour in gum (Rutherford *et al.*, 1992). Wm Wrigley Jr Co. and Warner-Lambert Company have been actively involved in the development of chewing gums. Wrigley obtained a patent that concerned mixing sweetener with a wax coating (Zibell, 1989), incorporation of the encapsulated sweetener Alitame into the liquid part of gum (Song, 1990) and many other patents.

Since aspartame is sensitive to heat, methods to protect it are being developed. Encapsulation with ethyl- or methylcellulose (Redding *et al.*, 1992) or a mixture of lecithins, fatty acids, waxes, glycerides and an anti-foaming agent (Bodor & Dokuzovic, 1992) have been examined. Nabisco Brands has developed processes

for liposomes. The liposome capsules are added to water, flour and shortening at 150°F in an extruder so that the liposomes remain intact to provide the required dough texture upon baking (Finley *et al.*, 1991), while another application involves encapsulation of an unsaturated lipid by liposomes into margarine (Haynes *et al.*, 1992).

Conclusions

Numerous developments have been made in the field of encapsulated food ingredients. Manufacturing techniques include spray drying, spray chilling or spray cooling, extrusion coating, fluidized bed coating, liposome entrapment, coacervation, inclusion complexation, centrifugal extrusion and rotational suspension separation. There are many requirements for the controlled and sustained release of food ingredients. New markets will be developed as advances in encapsulation continue. Coacervation seems to be particularly promising since the cost can be reduced due to the requirement for lower levels of food ingredients. In addition, flavours are more stable after processing with microwave, heat, oven drying and frying.

Limitations in many of the encapsulation techniques have occurred due to high costs of production and the lack of food-grade available materials. Research is necessary to eliminate these limitations. Encapsulation currently is an art that is difficult for the food scientist to master. The food scientist does not have the information available in databases to enable him to make informed choices concerning the most appropriate material and encapsulation process. For example, the appropriate blends of starches and maltodextrins as encapsulating materials could prove highly beneficial. The development of cyclodextrins has led to new products with longer shelf-life, reduced volatility and protection of heat-labile substances.

Preliminary indications are that liposomes have many benefits for the food industry including protection of materials until desired release or targeted delivery. There is a great deal of research that needs to be done concerning the use of liposomes in the food industry. Unlike the pharmaceutical industry, which can tolerate high costs, manufacturing costs will have to be reduced for food applications.

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