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Review Paper

Application of Various Chemical and Mechanical Microencapsulation techniques in Food Sector-A Review

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Abstract

Microencapsulation is mainly concerned with encapsulation. which is the process of forming a continuous thin coating around encapsulant (solid, liquid, gas). The active ingredients may be a food additive, medicine, biocide, adhesive or any other specialty material. Different methods of encapsulation design the wall to permit controlled release of core material at specific time and place. The first microencapsulation technique was coacervation which was developed and patented by National Cash Register Company in U.S. in 1950. Microencapsulation started from 1950 in the research of pressure sensitive coatings for the manufacture of carbon less copying paper. Microcapsules can be described as micron-size packages, composed of a polymer wall (coat or shell), and an active ingredient referred to as core or nucleus. This technique is applie not only to protect the core material (flavour, enzyme, bacteria, and drugs) from light, air, moisture and heat but also change or modify the physical property and flow ability of core material. Microencapsulation includes various techniques like co acervation, co crystallization, molecular inclusion, spray drying, spray cooling, chilling, extrusion, fluidized bed drying etc. Microencapsulation sector is growing at @10% annually. Microencapsulation finds applications in different field like pharmaceuticals, microbiology, dairy, bakery and meat industry etc. Extensive ongoing research in microencapsulation is also boosting the popularity of microencapsulated products.

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Keywords: Microencapsulation, coacervation, co-crystallization, molecular inclusion, spray drying, spray cooling.

1.0 Introduction

Microencapsulation is a technique which emphasizes on encapsulation i.e. a process of forming a continuous thin coating around encapsulant. Encapsulant may be flavour, drugs, vitamin, enzyme and aroma producing compound. The core material is the material over which coating has to be applied to serve the specific purpose (Chien, 1982). Core material may be in the form of solids or droplets of liquids and dispersions. For encapsulation of the compounds, the carrier material must have no reactivity with the core material, it should be present in a form that is easy to handle (i.e. with low viscosity at high concentrations; allow a complete elimination of solvent in any processes requiring a phase of desolvatation; give the maximum protection of the active ingredient against the external factors), ensure good emulsion-stabilization properties and effective redispersion behavior in order to release the flavor at the times and the place desired (Bakan, 1986). The simplest of the microcapsules may consist of a core surrounded by a wall of uniform or non-uniform thickness varying from few mm to <1 mm. these encapsulated products vary in shape and size (Fig. 1). If the size is > 1mm, it is known as nanoparticle, nanocapsule or nanosphere but, if it is between 1um-1000nm it is

referred as microparticles, microcapsule or microsphere (Crouzet, 1998). Microcapsule protects the core material from degradation by reducing its reactivity, evaporation or transfer rate and hygroscopic nature to outside environment (e.g. heat, moisture, air, light). It can modify physical property of the original material and can be made easier to handle without lump formation (e.g. liquid component can be converted to solid particles). The core can be distributed more uniformly throughout a mix by giving it an optimum size and surface area due to good flowability and compression property. Dustiness can be reduced and density can be modified by microencapsulation. The product can be tailor-designed to either release slowly, over time or release at a certain point (i.e. to control the release of the core material) so as to achieve the property delay until the right stimulus. The core material can be diluted when only very small amount is required yet still to achieve a uniform dispersion. It can be employed to separate components within a mixture that would otherwise react with one another. It was employing pressure- sensitive coatings for the manufacture of carbon less copying paper where it was first done in 1950s (Green and Schleicher, 1955).

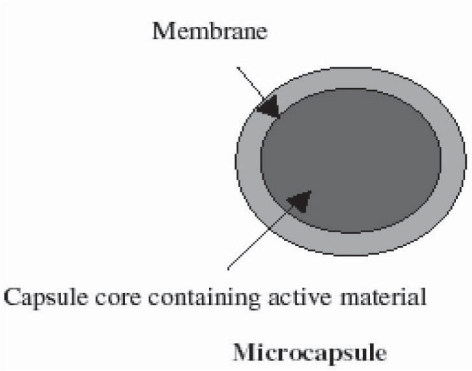

Fig. 1. Structure of Microcapsule

2.0 Morphology of Microcapsules

The morphology of microcapsules depends mainly on the core material and the deposition process of the shell. Microcapsules may have regular or irregular shapes and classified as follows :

Classification 1: On the basis of their morphology, microcapsule can be classified as monocore, polycore, and matrix types (Rama, *et al.* 2009) (Fig. 2).

1. **Monocore**: microcapsules have shell around the core material
2. **Polycore**: microcapsules have many cores enclosed within the shell.
3. **Matrix:** the core material is distributed homogeneously into the shell material.

Classification 2: On the basis of core and wall material microcapsule can be divided as: Single particle structure, Aggregate structure, Multi-walled

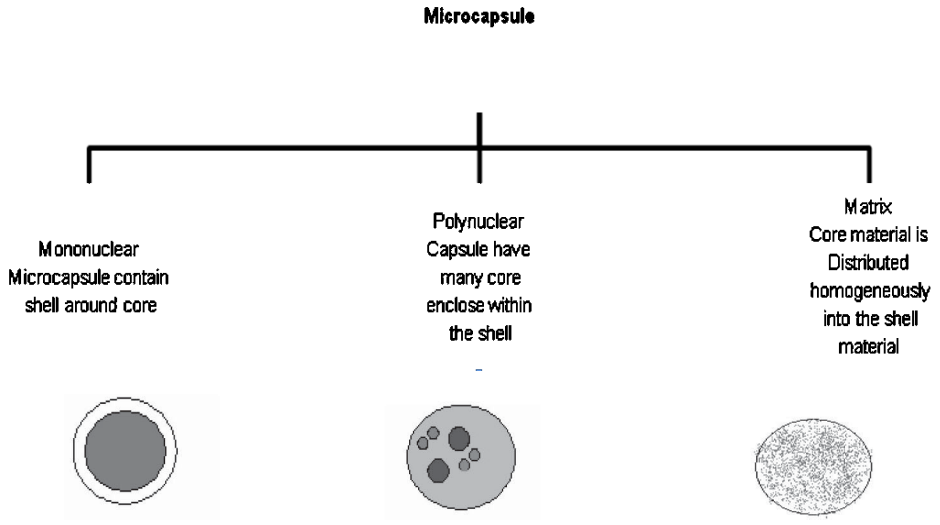

Fig. 2. Classification of microcapsule on the basis of morphology

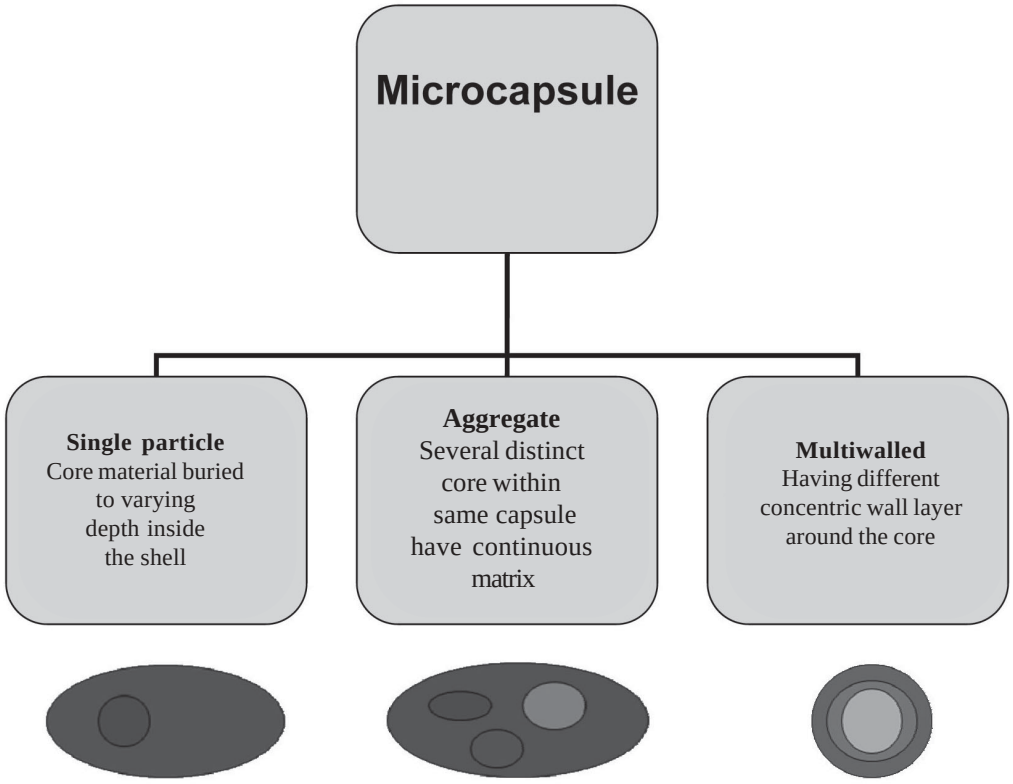

Fig. 3. Classification of microcapsule on the basis of core and wall material

structure (Shahidi and Han, 2009) (Fig. 3)

1. **Single particle structure**: This is simplest structure in which a sphere is surrounded by a wall or membrane of uniform thickness; resemble that of a hen's egg. In this design, the core material is buried to varying depths inside the shell.
2. **Aggregate structure:** Microcapsule that have several distinct cores within the same capsule or numerous core particles embedded in a continuous matrix of wall material.
3. **Multiwalled structure**: Microcapsule having different concentric wall layers can have the same or different compositions of core material.

3.0 Encapsulation matrix

Coating substances may be of natural or synthetic polymer and their properties depend on the material to be coated and the characteristics desired in the final microcapsule. The composition of coating material is the main determining factor for the functional properties of microcapsule. An ideal coating material should have good rheological properties at high concentration, easy workability, ability to disperse or emulsify the active material, stabilize the emulsion produced, non-reactivity with core material, both during processing or prolongs storage, ability to completely release the core material, ability to provide maximum protection to the active material against environmental conditions (e.g. oxygen, heat, light, humidity), solubility in solvent acceptable to the food industry (e.g. water, ethanol) with cheap food grade status (Bakan, 1986).

3.1 Carbohydrate

The ability of carbohydrate to absorb and adsorb volatiles from the environment or to retain them tenaciously during the drying process has important implication and application for encapsulation. Carbohydrates are the most commonly used coating material for encapsulation process. Carbohydrates as the encapsulation matrix are used in the preparation of microcapsule by spray drying and extrusion (Kenyon, 1995). A summary of coating material is given in Table 1 (Shahidi and Han, 1993).

Table 1: Coating material for encapsulation in food sector

Parameter	Coating material
Carbohydrates	Starch, malt dextrin, corn syrup solid, dextran, cyclodextrins, modified starch, sucrose
Cellulose	Carboxymethyl cellulose , methylcellulose ethycellulose , nitrocellulose
Gum	Gum acacia , agar , carrageen , sodium alginate
Lipid	Wax, paraffin, beeswax, tristearic acid, oil, fats, hardened oils
Protein	Gluten , casein , gelatin , albumin , peptides

3.2 Gum

These compounds are long chain polymer that dissolve or disperse in water to give a thickening or viscosity building effect (Godshall, 1997). Gums are generally used as texturizing ingredients, stabilization of emulsion, suspension of particulates and control of crystallization and inhibition of syneresis (Williams and Phillips, 2000). Food gums are obtained from variety of sources. Some are obtained from plant material such as seaweed, seeds, tree exudates, microbial biosynthesis (Reineccius, 1995).

3.3 Lipids

Wax, acylglycerol, lecithin, liposome are used as encapsulating agent (Robert and Woodbridge, 2000). Waxes are ester of long chain saturated and unsaturated fatty acids with long chain monohydroxy alcohols. The fatty acids and alcohol should be in the range between C_{14}-C_{36} and C_{16}-C_{36} respectively. Edible waxes are more resistant to moisture transport than most other lipid and non-lipid coating. Paraffin wax is the most resistant followed by bees wax. Waxes are used for encapsulation of water soluble ingredients. Paraffin wax and bees wax coating are resistant to water diffusion as these are the mixture of long chain saturated hydrocarbons polar group which are absent in paraffin and are present in relatively low level in bees wax.

3.4 Proteins

Due to the presence of divergent chemical groups present in protein, it possesses amphiphilic properties which have ability to self-associate and interact with a variety of diûerent types of substances. Proteins have large molecular weight with chain ûexibility and contribute excellent functional properties such as solubility, viscosity, emulsiûcation, ûlm-forming properties and are capable of being used in encapsulation (Dalgleish, 1997; Dickinson, 2001).

4.0 Encapsulation techniques

Various encapsulation methods have been previously proposed and some of the most popular techniques are coacervation, co -crystallization, molecular inclusion, spray drying, spray cooling, chilling, extrusion and fluidized bed drying (Dziezak, 1988). Various microencapsulation techniques with different particle sizes are given in Table 2 and depicated in Fig. 3.

Table 2. Characteristics of encapsulation process

	Encapsulation technique	Particle size(µm)
Chemical techniques	Simple coacervation	20-200
	Complex coacervation	5-200
	Molecular inclusion	5-50
	Cocrystallization	3-30
	Interfacial polymerization	1-several
Mechanical technique	Spray drying	1-50
	Spray chilling	20-200
	Extrusion	200-2000
	Fluidized bed	>100

4.1 Chemical Technique

Coacervation Technique

It is also known as Phase separation. Coacervation is a phenomenon occurring in colloidal solutions (Risch, 1995). It was developed and patented in the 1950 by the National Cash Register Company in the USA. This was the first encapsulation technique studied to produce pressure-sensitive dye microcapsules for the manufacturing of carbonless copying paper (Green and Schleicher, 1955). Because of the very small particle size attainable with this technique (ranging from a few sub micrometer to 6 mm), coacervation is coined as the original and true microencapsulation technique. Coacervation can be simple or complex. Simple coacervation involves only one type of polymer with the addition of strongly hydrophilic agents to the colloidal solution but for complex coacervation, two or more types of polymers are used. In general, the batch type coacervation process consists of 3 steps: formation of a three immiscible chemical phase, deposition of the coating and solidification of the coating (Flores *et al.*, 1992). The advantages of coacervation technique is very small particle size from sub µm to 6mm that can be developed but the disadvantages of this technology is it has not been commonly used in the food industry because it is complicated and expensive. Others limitations of coacervation technique are: evaporation of volatile,

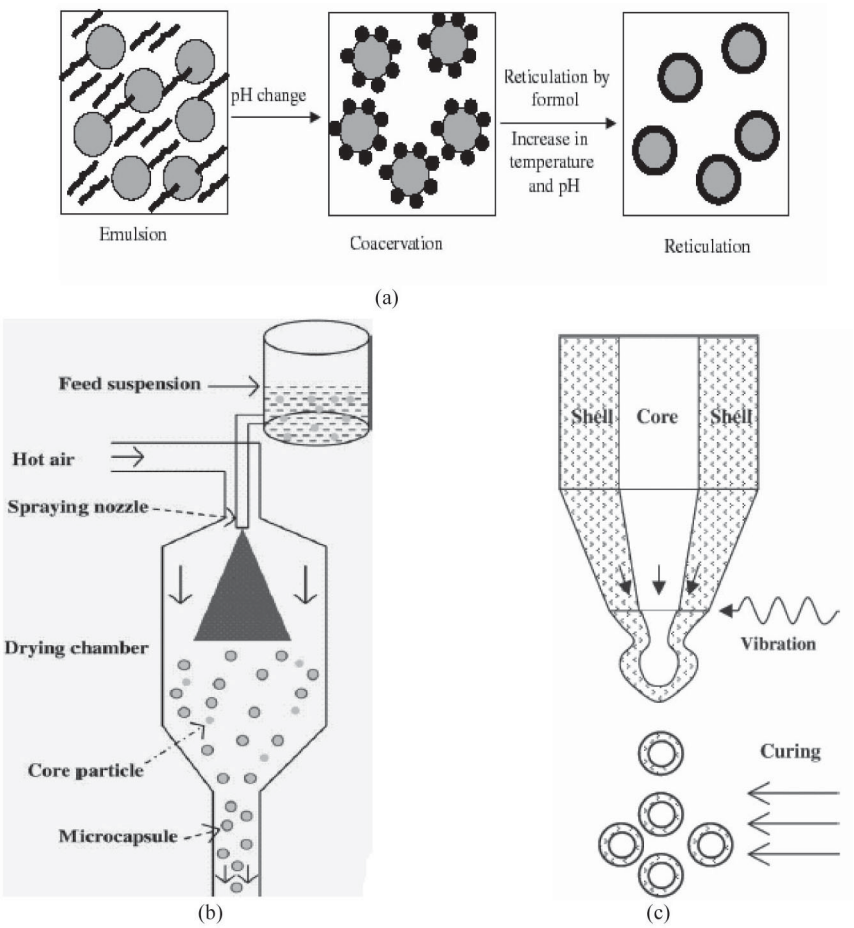

Fig. 3. Microencapsulation Technique (a) Coacervation (b) Spray Drying (c) Extrussion

dissolution of active compound into the processing solvent and oxidation of product (Shahidi and Han, 1993; King, 1995; Gibbs *et al.*,1999) (Fig. 3).

Co-crystallization Technique

In co-crystallization sucrose is used as a matrix for incorporation of core material. Although granulated sugar is composed of solid dense monoclinic spherical crystals with a limited surface area. In order to flavor encapsulation into the matrix, sucrose syrup is concentrated to the supersaturated state and maintained at a temperature high enough to prevent crystallization and predetermined amount of core material is then, added to the concentrated syrup with vigorous mechanical agitation, to provide nucleation for sucrose mixture. Agitation is continued in order to promote and extend transformation until the agglomerates are discharged from the vessel. Later the encapsulated products are dried to the desired moisture and screened to a uniform size. It is very important to properly control the rates of nucleation and crystallization as well as the thermal balance during all steps. The co-crystallization technique is simple, economical and flexible. The product formed are granular product formed have low hygroscopic and good flowability. The main disadvantages of co-crystallization technique lead to loss of heat sensitive compound either by evaporation or degradation (Jackson and Lee, 1991; Chen, 1994).

Molecular inclusion Technique

Cyclodextrins are enzymatically modified starch molecules, which can be made by the action of cyclodextrin glucosyltransferase upon starch containing 1-4 linkage (Hedges and McBride, 1999). Generally, in the food industry, flavors have been encapsulated within cyclodextrins. The β-cyclodextrin, torus shaped molecular

dimensions, containing inner hydrophobic cavity and outer surface hydrophilic character which allow total or partial inclusion of a wide range of complex compounds (Godshall, 1997). The retention of aroma compounds can be influenced to a greater or lesser extent by the molecular weight, shape, steric hindrance, chemical functionality, polarity and volatility of the core material (Goubet *et al* 1998). The presence of water or high temperature is required to liberate guest molecules (Shieh and Hedges, 1996; Steinbock *et al*, 2001). The advantages of molecular inclusion is a simpler and quicker process than drying while disadvantages of this is cyclodextrin are costly and energetically unfavorable situation (Gouin, 2004).

4.2 Mechanical Technique

Spray chilling Technique

The encapsulating material is typically a fractionated or hydrogenated vegetable oil with a melting point in the range of 32–42°C. In the spray chilling technique, the coating material is melted and atomized through a pneumatic nozzle into a vessel generally containing a carbon dioxide ice bath as in a holt-melt fluidized bed. Thus, droplets adhere on particles and solidify forming a coat (Augustin *et al*, 2001).

Spray cooling Technique

This method is similar to spray chilling, the only difference is the temperature of the reactor in which the coating material is sprayed. The coating substance is typically some form of vegetable oil or its derivatives. Besides this, a wide variety of other encapsulating material may also be employed. These include fat with melting point of 45-65°C. The advantage of spray cooling is that it is least expensive encapsulation process and are routinely used for encapsulation of aroma compounds to improve heat stability, delay release in wet environments or convert liquid compound into free flowing powders (Gouin, 2004). Generally, no water is to be evaporated, there is emulsification of the flavor compounds into molten wall materials, followed by atomization into chilled air which causes the wall to solidify around the core (Risch, 1995). After that, the droplets are immediately mixed with a cooling medium and subsequently solidify into powder form. Spray cooled products have applications in bakery products, dry soup mixes and foods containing a high level of fat. It is used in encapsulation of solid food additive such as ferrous sulfate, acidulent vitamin solid flavor heat sensitive products, the process is suitable for protecting many water-soluble materials that may otherwise be volatilized or damaged during thermal processing while disadvantage of technique is that special handling and storage conditions are required as these can affect the polymorphism of fat (Taylor, 1983). The main difference with spray drying is that there is no water to be evaporated, temperature of air and type of coating applied

Spray drying Technique

This is one of the most popular and inexpensive technique. It involves formation of stable emulsion of the substance to be encapsulated in a carrier material, followed by atomization and spraying of the mixture into a hot chamber. The resulting microcapsules are then transported to a cyclone separator for recovery (Reineccius, 1988). Retention of core material during encapsulation by spray drying is achieved by chemical and physical properties of the wall or core materials content, processing temperature, nature or performance of the encapsulating support (i.e. emulsion-stabilizing capabilities, film-forming ability and low viscosity at a high concentration) (Re, and Liu, 1996; Greenwald and King, 1982). The functional property of wall materials that are optimal for spray drying includes a high solubility, a low viscosity at high concentration, effective emulsification and efficient drying properties. When core materials of limited water solubility are encapsulated by spray drying, the resulting capsules are of a matrix-type structure. In such case the core is organized into small droplets coated with wall materials that are embedded in the wall matrix. Microstructures of spray-dried capsules have been shown to be affected by wall composition, core-to-wall ratio, atomization, drying parameters, surface tension-driven viscous flow and storage conditions (Luckham, 1994). The disadvantage of spray drying is that some aromatics can be lost, require agglomeration to make dried material as particle size is in the range of 10–100 mm in diameter. The degree of core material retention is strongly dependent on the moisture content of the final microcapsules and on the humidity of the exhaust air. The advantages of spray drying is low cost, wide choice of carrier solids, good retention of volatiles, good stability of finished product, large scale production technique, technique, useful for heat labile materials (Rosenberg, 1990; Teixeira *et al.,* 2004; Dziezak, 1988; Desobry *et al*., 1997; Adem *et al.,* 2007; Risch, 1995) (Fig. 3).

Fluidized bed Technique

In this technique firstly the core particles are fluidized in

the hot atmosphere afterwards coating material is sprayed through a nozzle and film formation is initiated. The small droplets of the sprayed liquid spread onto the particle surface and coalesce. The hot air then evaporates the mixtures and the coating material adheres on the core particles (Jacquot and Pernetti, 2003). This technology allows specific particle size distribution and low porosity's to be designed into the product (Panda *et al*. 2001). Microencapsulated fish oil prepared with 2 production processes, spray granulation (SG) and film coating using a fluid bed equipment, was investigated. The advantages of fluidized bed technique are high drying rates (because of good gas-particle contact leads to optimal heat and mass transfer rates), smaller flow area, high thermal efficiency, lower capital cost, maintenance costs and ease of control. The disadvantage of fluidized bed technique is 0.2 to 1.5 % of particle remains uncoated.

Freeze drying Technique

The freeze-drying technique or lyophilization, is one of the most useful technique for drying of heat sensitive substances (i.e. unstable in aqueous solutions). In this technique non-frozen solution turns to viscous and the diffusion of core material is retarded due to water crystallization. Initially surface of the solution becomes an amorphous solid in which selective diffusion is possible (Karel and Langer, 1988; Buffo and Reineccius, 2001). The production of dried microencapsulated fish oil by freezing and subsequent freeze drying offered an opportunity to achieve a product with good resistance to oxidation. It was shown that the freeze drying process maintained the shape of the microcapsules because of fixation. However, this drying technique is less attractive than others because the costs is 50 times higher than spray drying and the storage, transport of particles produced is extremely expensive . The advantages of freeze drying is it retains volatile compounds, maintains the shape of microcapsules (because of fixation by freezing), simple process, good for water soluble and heat sensitive product (Nagata, 1996; Desobry *et al*., 1997). The draw back of freeze drying,it is very costly, storage and transport of particles produced is extremely expensive, commercial applicability is also severely restricted by the long processing time (Jacquot and Pernetti, 2003).

Extrusion Technique

Extrusion was first patented in 1957 and further developed by the group that originally patented the technique. Encapsulation via extrusion has been used for volatile and unstable compound in glassy carbohydrate matrices (Swisher, 1957). In this process, low temperature force core material to dispersed in a molten carbohydrate mass through a series of dies into a bath of dehydrating liquid pressure (<100 psi) and temperature (115^0C) (Wampler, 1992). Upon contact with the liquid coating material, matrix hardens and entraps the core material. Isopropyl alcohol is the most common liquid used for dehydration and harding process. It is expensive technique than spray drying. The advantages of extrusion are applicable for heat labile core material and provide protection to flavor from oxidation but could not be used for heat sensitive product (Benczedi and Blake, 1999; Gouin, 2004) (Fig. 3).

Centrifugal extrusions Technique

It is liquid co extrusion process utilizing nozzles consisting of concentric orifice located on the outer circumference of a rotating cylinder. The encapsulating cylinder or head consist of a concentric feed tube through which coating and core material are pumped separately to the many nozzle mounted on the outer surface of the device (Schalmeus, 1995). While the core material passes through the center tube, coating material flows through the outer tube. The entire device is attached to a rotating shaft such that the head rotates around its vertical axis. As the head rotates, the core and coating material are co-extruded through the concentric orifices of the nozzle as a fluid rod of core sheathed in coating material. Centrifugal force implies the rod outward causing it to break into tiny particle. By the action of surface tension, the coating material envelops the core materials, thus accomplishing encapsulation. The capsules are collected on a moving bed of fine-grained starch which cushions their impact and absorbs unwanted coating moisture. The advantages of centrifugal extrusions is high production rate can be achieved i.e. up to 22.5 kg of microcapsules (particles 400-2000µm in diameter) can be produced per nozzle per hour per head. The disadvantage of centrifugal extrusion is the process is only suitable for liquid or slurry (Schalmeus, 1995).

Interfacial polymerization Technique

In this technique, two different polymeric solution are brought together these two reactive polymeric species each solubilized in a different liquid react with one another when one liquid is dispersed in the other. The polymerization reaction takes place at the interface between the two polymeric liquids (Janssen and Nijenhuis,1992). An

interfacial polymerization reaction proceeds at rapid rates that result in the formation of a very thin film having characteristics of a semi -permeable membrane. The ultimate capsule size of interfacial polymerization is determined by the size of first monomer. In general, the capsule size ranges from about 1µm to several millimeters. The advantages of Interfacial polymerization is it can be used to encapsulate solution (or dispersions of hydrophobic materials), aqueous solutions (or dispersions of hydrophilic substances). The disadvantages of interfacial polymerization is that its use is limited since most coatings are not of food grade (Janssen and Nijenhuis, 1992).

Liposome, Microfluidization, Ultrasonication, Reverse phase evaporation microencapsulation Technique:

A liposome can be defined as an artificial lipid vesicle that has a bilayer and phospholipids arrangement with the head groups oriented towards the interior of the bilayer and the acryl group towards the exterior of the membrane facing water (Torchillin and Weissig 2003).

Microencapsulation by microfluidization method is obtained through the dynamic interaction of two pressurized aqueous lipid fluids that create a large momentum and flow turbulence that allows the system to overcome the energy barrier to microcapsule formation. The pressure applied in air driven microfluidizers can be as high as 10,000psi. The ultra-high velocities reached by this technique allow the creation of small liposome (<0.3µm) with high capture efficiency. This system is useful because of its capability to produce very large amount of liposome's with adjusted size in a continuous process (Were *et al.*, 2003; Torchillin and Weissig, 2003).

Casana *et al.*, 2009 patented the technique reverse-phase microencapsulation for water soluble or water dispersible compounds. Mainly agrochemicals like oil soluble or oil dispersible compounds can be encapsulated in the range preferably <5-10 µm in agriculture products.

5.0 Controlled release mechanism

Controlled release may be defined as a method by which one or more active agents or ingredients are made available to a desired site, time and at specific rate (Pothakamury and Barbosa-Canovas, 1995).

Advantages of the mechanism

* The active ingredients are released at controlled rates over prolonged periods of time.
* Loss of ingredients during processing and cooking can be avoided or reduced.
* Reactive or incompatible components can be separated.
* A substance in formulated food may be released upon consumption but prevented from diffusing throughout the product during processing operations(e.g. flavors, nutrients)

5.1 Release Rate

Release rates that are achievable from a single microcapsule are generally zero, half, or first order (Ghulam *et al*. 2009).

* Zero order occurs when the core is a pure material that may be released through the wall of a microcapsule as a pure material.
* Half order release generally occurs with matrix particles.
* First order release occurs when the core material is actually a solution trapped within a solid matrix.

5.2 Parameters affecting the release rate of core materials

* *Coating material properties*-density, crystalline, orientation, solubility, plasticizer level, cross linking pretreatment
* *Capsule properties*-size, wall thickness, configuration, conformity, coating layers, post-treatment.
* *Experimental parameters*-Temperature, pH, moisture, solvent mechanical action, partial pressure differential(inside and outside of coating)

5.3 Various release mechanism

Fracture or pressure activated release

For this, a complete impermeable capsule is needed that release only on rupture. The coating can be fractured or broken open by external forces such as pressure shearing or by internal forces as would occur in a microcapsule having a permeation selective coating. Capsule made from hardened fats or waxes are insoluble in water but can be made to release their contents by mechanical breakage e.g. shear or by increasing the temperature to the melting point of the fat. The acts of chewing and drug release are the most commonly used mechanical release means (Waruwan *and Clyde*, 1989).

Diffusion Controlled Release

Diffusion is controlled by the solubility of a compound in the matrix (this establishes a concentration in the matrix which drives diffusion) and the permeability of the compound through the matrix. The vapor pressure of a volatile substance on each side of the matrix is the major driving force influencing diffusion (Gibbs *et al*, 1999a). Diffusion is strictly governed by the chemical properties of the microcapsule and physical properties of the wall material such as the matrix structure and pore size. Diffusion also depends upon the size, shape, vapors pressure and polarity of the penetrating molecule as well as segmental motion of polymer chains (Fan and Singh, 1989; Reineccius, 1995). It should be obvious that if the food component is not soluble in the matrix then it will not enter the matrix and so diffusion will not take place irrespective of the pore size of the matrix (Crank, 1975; Cussler, 1997).

Melting-Activated Release

In Melting-Activated Release mechanism, by melting of the capsule wall active material release. In food industry there are numerous materials that can be melted and hence approved for food use (lipids, waxes, modified lipids). For this coated particles are stored below the melting point of the coating then heated above this temperature during the process of cooking. In general salts, nutrients, leavening agents and some water soluble flavorings agents have been protected by hydrophobic coating. The hydrophobic coating and core material must be immiscible in order to avoid migration of the active ingredient through the wall material (Sparks *et al*, 1995).

Biodegradation and pH sensitive release

Lipid coating may be degraded by the action of lipase. Enzymes can be released from liposome using pH as a stimulant to initiate release as pH changes destabilized the phospholipids based liposome structure thereby releasing the enzymes from the liposome core (Fereidoon *et al.* 2007).

6.0 Application of microencapsulation

6.1 In Meat Industry

In meat industry, encapsulated acids, such as lactic, citric and glusono-d-lactone are used to assist in the development of color and flavor in meat emulsion, dry sausage products, uncooked processed meats and meat containing products, such as pasta meats (Shripad 2003) .

6.2 In Bakery Industry

Variety of leavening system like baking soda, stable acids as well as vitamin C, acetic acid, lactic acid, potassium sorbate, sorbic acid, calcium propionate and sodium chloride can be encapsulate (Wilson and Shah, 2007). Ascorbic acid used for strengthening, conditioning of bread and roll dough provides many positive effect of finished products like stronger sidewalls, uniform crust color and improve slicing property. Generally, most of ascorbic acid degrades rapidly in the presence of H_2O and oxygen. Generally, most of the acid is destroyed before it is needed.

6.3 In flavoring

Flavor compounds used are a liquid at room temperature and constituents of flavors tend to show sensitivity towards air, light, irradiation and elevated temperature. Moreover, flavor concentrate are oily and lipophillic which can be difficult to work with . Therefore, convert these flavor compounds to a more useable form. One of the purposes behind encapsulation in the food industry is the conversion of liquid to dry powders for easy handling and incorporation into food system. Micro encapsulated product provides the convenience of a solid form over a liquid one, with reduced volatility and less oxidation (Benczedi, 1999). Commonly used encapsulated material are citrus oils, mint oils, onion, garlic oils spice, and oleoresins. Citrus oils are very susceptible to oxidation due to sites of unsaturation in their mono and sesquiterpenoid structure. Encapsulated citrus oil, prepared by spray drying in malt dextrin matrix, has a greater stability than unprotected oils (Reineccius, 1988). Different wall components such as proteins (sodium caseinate and gelatin), hydrocolloids (Arabic gum) and hydrolyzed starches (starch, lactose, and maltodextrin) were utilized for encapsulation of extra-virgin olive oil by spray-drying (Patricia *et al.*, 2010). Ginger oil powder prepared by using acacia gum as wall material by spray drying (Kadam *et al.*, 2011). Curcumin microcapsules were prepared by spray-drying process using porous starch and gelatin as wall material (Wang *et al.*, 2008).

6.4 In sweetner, colourants, vitamins and enzymes

Sweetness is often subjected to effects of moisture and temperature. Encapsulation of sweetener (namely sugars or artificial sweetener) reduces their hygroscopic, improvers their flow ability and prolongs their sweetness perception. Sugar that has been encapsulated with fat and incorporated in a chewing gum requires more shear, high temperature release than uncreated sugar (which dissolves

more rapidly in the mouth) (Schobel and Yang ,1989). At high temperature, aspartame degrades into the amino acid, aspartic acid and phenylalanine, accompanied by a loss of sweetness. Natural colours such as annatto, β-carotene and turmeric present solubility problems during their use and may create dust clouds. Encapsulated colors are easier to handle, offers improved solubility, stability to oxidation, control over stratification from dry blends and synthetic colors can also be encapsulated for improving their stabilities (Bernard and Selim, 1999). Encapsulation of enzymes could enhance their properties in a number of very different ways. The enzyme activity of the immobilized enzyme capsule varied with the thickness of the membrane (0.5-2mm) and size of the capsule (50-200μ). The durability of the capsules was examined by continuous enzyme reaction (Markus *et al.,* 2008). Encapsulation of vitamins and minerals offers many advantages as it reduces per units' time release of the nutrients which enhances stability of vitamins to extreme in temperature, moisture and reduces each nutrients reaction with other ingredient. Both fat and water soluble vitamins may be encapsulated with a variety of coatings to provide many advantage. The coating matrix for this process in chiefly ethyl cellulose together with propylene glycol monoester and acetylated monoglyceol. Vitamins and minerals can also be encapsulated in fat or in starch matrices. Lycopene, microencapsulated in gelatin and pectin by complex coacervation (Silva *et.al.,* 2011). Microencapsulation of sunflower oil, lemon and orange oil flavor was investigate using complex coacervation of whey at pH 3.0-4.5 successfully used for this purpose (Weinbreck *et al.,* 2004). The formation of a smooth biopolymer shell around the oil droplets was achieved at a specific pH and payload of oil was higher than 80%. Small droplets were easier to encapsulate within a coacervate matrix than large ones, which were present in a typical shell structure. The stability of the emulsion made of oil droplets covered with coacervates was strongly pH dependent. At pH 4 the creaming rate of the emulsion was much higher than at other pH values. A proteolytic enzyme, either alpha-Chymotrypsin or a fungal protease from *Aspergilus Oryzea* was encapsulated along with iron oxide nanoparticles within particles yielded via biomimetic silicification of different generations of polyamidoamine (PAMAM) dendrimers (Madadlou *et al.,* 2010). Biosensors with encapsulated enzymes have advantages of high substrate selectivity and sustained enzyme activity (Park *et al.,* 2010).

6.5 In Textile

Uses of microencapsulation technique get increased in Western Europe, Japan and North America to impact durable fragrances to textile as well as skin softness.

6.6 In Microbiology

By the many microencapsulation technique like spray drying exclusion, Emulsion and phase separation none can give satisfactory result of the two problem i.e. survival of bacteria in product and stability of bacteria in gastro intestinal system. The most commonly reported microencapsulation procedure in based on Ca-alginate gel capsule formation (Chai *et al.,* 2004). Kappa-carragenan, gellan gum, gelatin and starch are also used recipients form the micro-cheap of probiotic bacteria (Burgain *et al.,* 2011). Probiotic strain (*Lactobacillus casei*, *L. paracasei*, *L. acidophilus* Ki and *Bifidobacterium animalis* BB-12) microencapsulated to make these strains higher heat tolerance at 55 °C than free cells (Sandra *et al.,* 2012). Freeze-dried commercial *Lactobacillus rhamnosus GG* (LGG) were encapsulated in an emulsion-based formulation stabilized by whey protein and resistant starch and either spray-dried or freeze-dried to produce probiotic microcapsules. Although more water was adsorbed for spray-dried than freeze-dried microcapsules, water mobility was similar for corresponding storage conditions because there was a stronger water-binding energy for spray-dried microcapsule. This possibly accounted for the improved survival of probiotics in spray-dried microcapsules (Dan *et al.* 2010).

6.7 In Pharmaceutical

Previous methods of microencapsulation are unable to process particle smaller than 100um without organic solvents or the use of multistep process. The present study investigate the feasibility of a one step spray drying process to microencapsulate erythromycin, clarithromycin, antibiotics known to have an unpleasant, bitter taste. Mixture of clarithromycin (5%) or erythromycin (30%) with a biodegradable polymer was prepared and spray dried under specific conditions of temperature and turbine speed (Zgoulli, 1999). Encapsulation of lactic acid bacteria was done in calcium alginate beads for bacteriocin production. Felodipine is a poorly water soluble drug. To improve its dissolution rate, the rapid expansion of supercritical solutions technique was used to prepare micronized FLD drug particle, which were encapsulated in polyethylene glycol 4000. The physical properties of the encapsulated

drug particle were characterized by a variety of analytical methods, including optical light microscopy scanning electron microscopy (Andy *et al.*, 2006).

Conclusion

Microencapsulation technique not only protects the volatile component but also provide flavoring components to the right time. Its release mechanism enhances the acceptability of the product, for example flavoring components of chewing gum, aroma producing substances of spices, etc. It is also an important tool of fortification in food industry. Besides all advantages this technique enhance the cost of product up to certain extent so, it is not very feasible for small scale industry.

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