

The background of the image is a dense field of colorful, translucent microcapsules. These capsules are in various sizes and colors, including green, blue, red, purple, and yellow. Some capsules have a white, star-like or snowflake-like pattern on their surface. The overall effect is a vibrant, textured surface that represents the concept of microencapsulation.

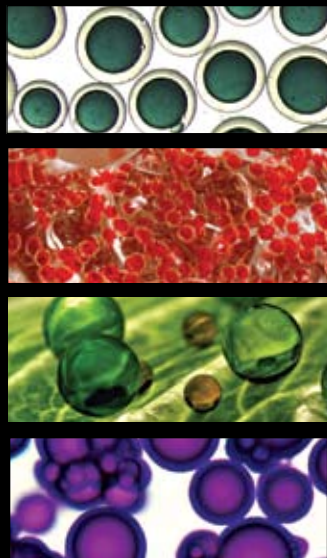
MICRO encapsulation NANO

Southwest Research Institute®
San Antonio, Texas

encapsulation

For more than 60 years, Southwest Research Institute (SwRI®) has been a leader in encapsulation research and development. Using their extensive expertise in diverse technical fields such as pharmaceuticals, food and nutrition, polymer and materials science, and process engineering, Institute encapsulation specialists solve product stability, release and application problems in a wide range of industries. The Institute has conducted more than 1,000 encapsulation research programs for commercial and government clients.

SwRI employs diverse encapsulation methods to solve product performance requirements for its clients. Encapsulation methods are broadly categorized as either physical or chemical.



Southwest Research Institute

Founded in 1947 as an independent, nonprofit research and development organization, Southwest Research Institute provides a significant research, engineering and testing resource for industry, business and government. The Institute uses a multidisciplinary, integrated approach to solving complex problems in science and applied technology. As part of a long-held tradition, patent rights arising from sponsored research at the Institute are often assigned to the client. SwRI generally retains the rights to Institute-funded advancements.

SwRI® maintains Controlled Substance Registrations with the Drug Enforcement Administration permitting the Institute to handle controlled substances for the business activity of research and manufacturing.

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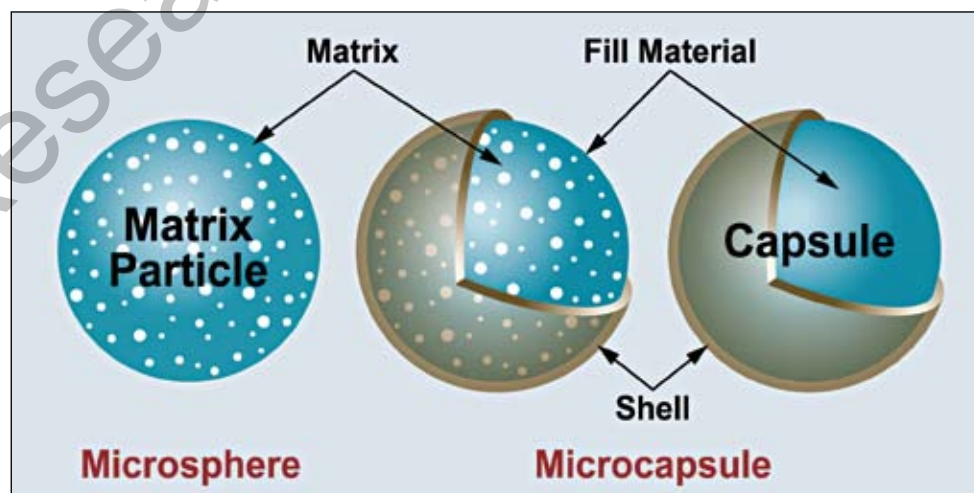
Physical Methods

- Extrusion
- Fluidized bed
- Pan coating
- Atomization
 - Spinning disk
 - Spray drying
 - Spray chilling/congealing

Chemical Methods

- Solvent loss
- Phase separation
- Coacervation
- Polymerization
- Precipitation
- Nanoencapsulation
- Liposomes
- Sol-gel

SwRI's Chemistry and Chemical Engineering Division, which houses the comprehensive encapsulation program, has achieved certification to ISO 9001:2008, ensuring compliance with stringent quality control procedures in development, production and testing. The encapsulation program maintains numerous facilities, including current Good Manufacturing Practices (cGMP) suites.



Particle size and morphology can be tailored to achieve the desired product performance.

Atomization

SwRI practices several atomization processes, including spinning disk, spray drying and spray congealing.

Spinning disk is a highly versatile encapsulation process used to prepare matrix morphology and overcoated particles. SwRI personnel have innovated the disk process to yield narrow particle size distributions, produce micron-sized particles, and process batch sizes down to a few grams with high recovery efficiency.

Applications

- Hot melts, prilling and congealing
- Solvent evaporation
- Water evaporation
- High-solids and high-viscosity feedstocks

Characteristics

- Particle sizes from 5 μm to 3,000 μm
- Narrow particle size distributions
- Feedstock versatility
- Scalability and high production capacity
- High recovery efficiency
- Continuous production

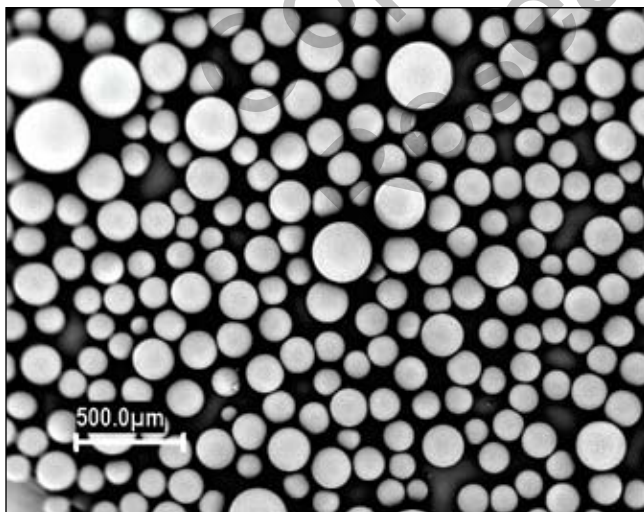
Spray drying is a traditional atomization process suitable for many feedstocks. Atomization is achieved by nozzle or veined wheels, two-fluid spray nozzles, pressure nozzles or sonic energy.

Spray drying can be used for

- Water- or solvent-based materials
- Temperature sensitive materials



cGMP pilot-scale facilities are available for sample preparation. Custom encapsulation equipment is often fabricated to meet unique client demands.



SwRI scientists utilized a spray-chilling process to prepare these microspheres.



An SwRI-developed spinning disk provides spherical particles with uniform coating and narrow particle size distributions.

Extrusion

SwRI has developed and practices several particle and fiber extrusion techniques, including stationary nozzle, centrifugal extrusion, vibrating nozzle, submerged nozzle, electrohydrodynamics, single or twin-screw extrusion and microextrusion.

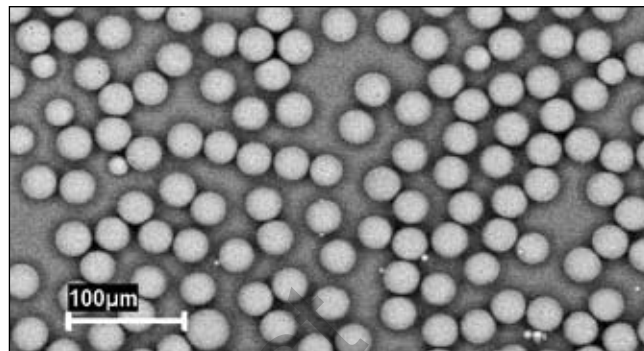
Extrusion processes produce matrix or core-shell morphologies, depending on nozzle configuration. Particle extrusion processes produce narrowly distributed particles. SwRI scientists have innovated particle extrusion processes to produce capsules down to sub-micron sizes with small particle size variances, operate with complex thermal profiles, and support production capacity. Fiber extrusion processes produce single or multiple fibers with diameters down to several hundred nanometers. SwRI personnel have devised fiber extrusion processes to produce matrix fibers, core-shell fibers, and multilayer, fibrous structures.

Applications

- Narrow size distributions
- Core-shell morphologies
- Gas, liquid or solid cores
- Variable shell thickness
- Variable payload composition

Characteristics

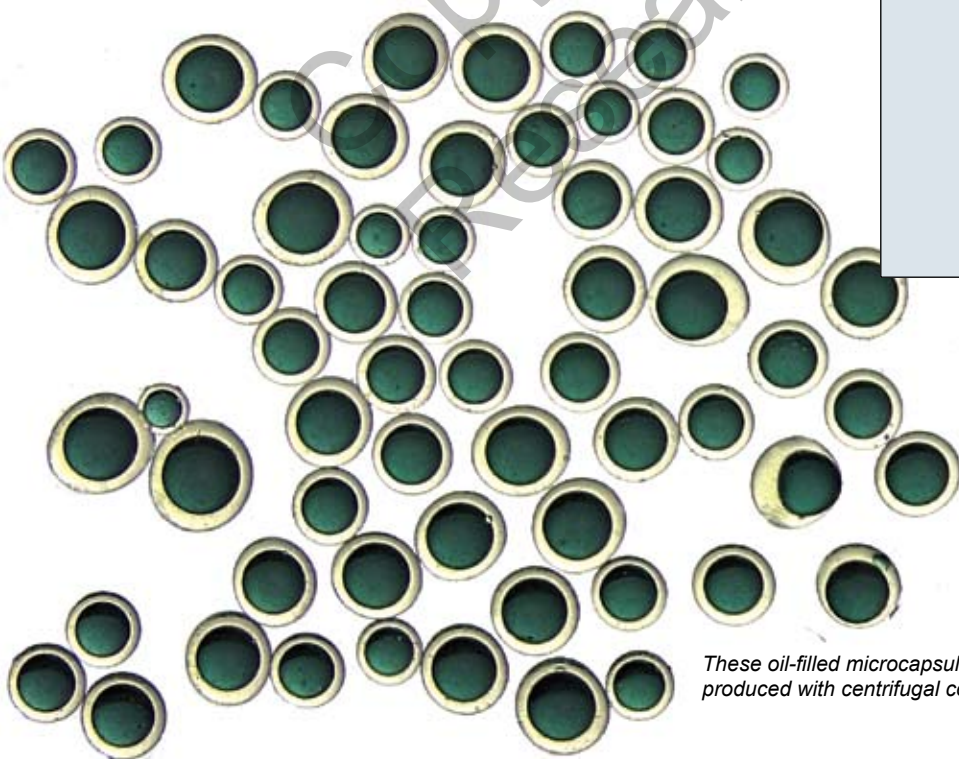
- Sizes from $1\ \mu\text{m}$ to $10,000\ \mu\text{m}$
- Narrow size distribution
- Material versatility
- Scalability and high production capacity
- Continuous production



Vibrating nozzle systems produce microcapsules or microspheres with a very narrow size distribution.



Stationary and submerged nozzles produce capsules of oils or aqueous fill materials using waxes or hydrophilic and lipophilic polymers.



These oil-filled microcapsules were produced with centrifugal coextrusion.

Nanoencapsulation

SwRI works extensively with many nanoencapsulation techniques to produce nanosized particles and capsules to address the high performance needs of many applications. Nanocapsules can be used in combination with other microencapsulation methods to provide new release characteristics.

SwRI personnel routinely use the following nanoencapsulation techniques:

- Micelles
- Liposomes and polymersomes
- Phase inversion/precipitation
- Solvent evaporation
- Polyelectrolyte complexes
- Layer-by-layer deposition
- Controlled precipitation
- Surfactant-free particle formation
- Templating
- Molecular encapsulation

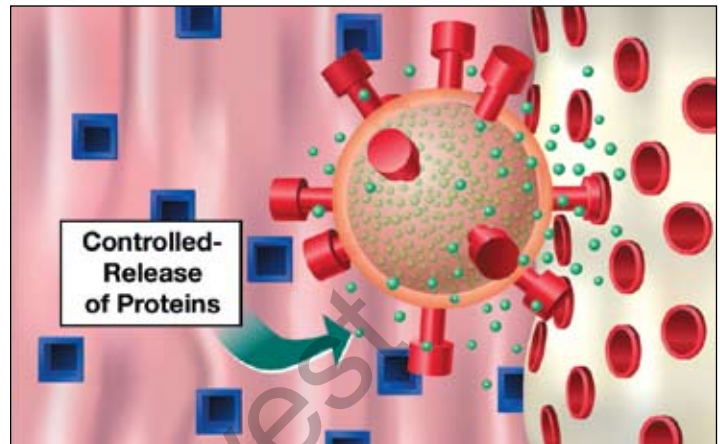
Applications

- Protein, DNA and RNA stabilization
- Small molecule delivery
- Extending circulatory half-life
- Modifying drug transport
- Clear liquid formulations
- Stable colloid dispersions
- Controlled release
- Targeted delivery
- Triggered release

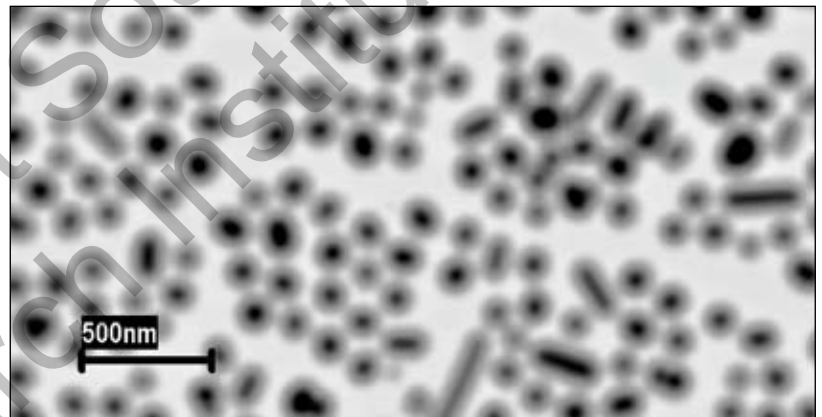
Characteristics

- Particle sizes from 10nm
- Tunable colloid properties
- Chemically functional surfaces
- Hydrophobic or hydrophilic payloads
- Low payloads
- Organic or inorganic compositions
- High surface area particles

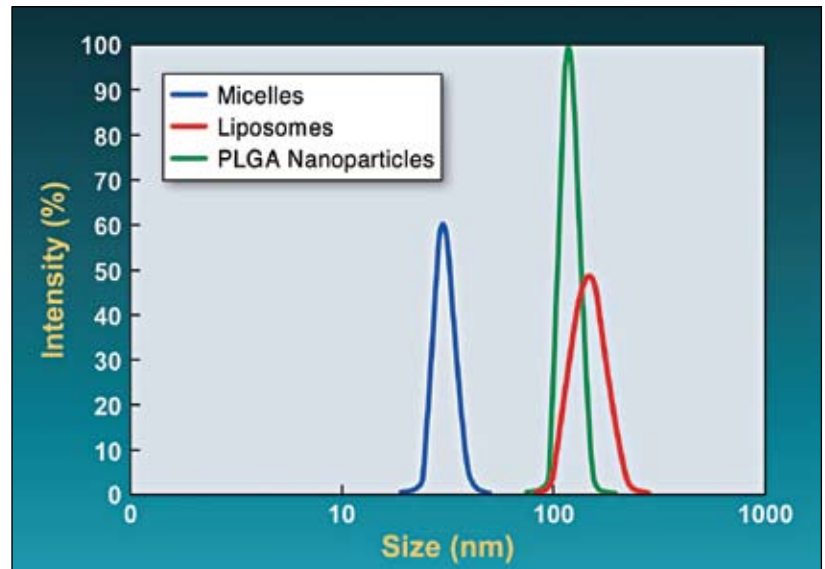
A variety of nanoencapsulation techniques are practiced at SwRI to match the growing demand for these technologies.



SwRI scientists developed bone-targeting nanocarriers that release their payload following attachment to the target site. Payload release may occur by natural nanocarrier degradation, application of external stimuli, administration of a complementary factor in schedule, or in response to local biochemical signals.



This scanning transmission electron micrograph shows silver nanoparticles encapsulated in a silica shell.



Chemical Techniques

Chemical encapsulation techniques typically yield particle dispersions that can be used as is or post-processed by other methods, such as spinning disk, spray drying or fluid bed to produce free-flowing powders.

Applications

- Oil-in-water emulsions
- Water-in-oil emulsions
- Core-shell capsules or matrix particles
- Stable, high-solid dispersions

Characteristics

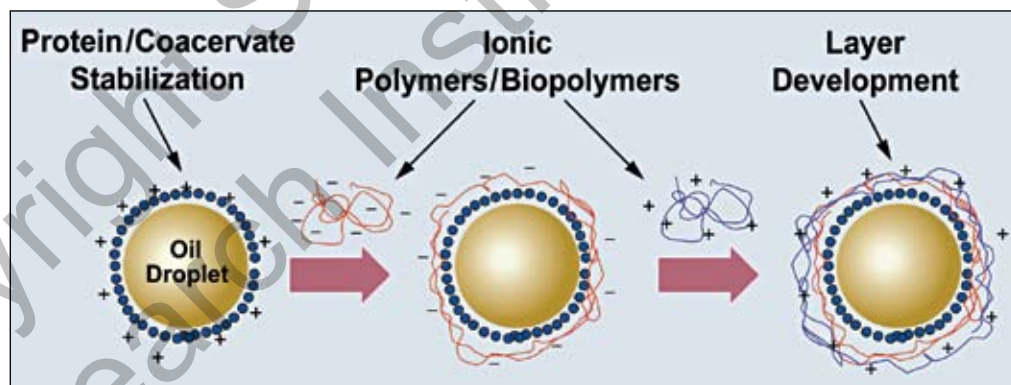
- Particle sizes from about 0.1 μm to 500 μm
- High payloads
- Uniform particle size distribution
- Scalability and high production capacity
- Batch production

SwRI has developed and practices several chemical techniques, including:

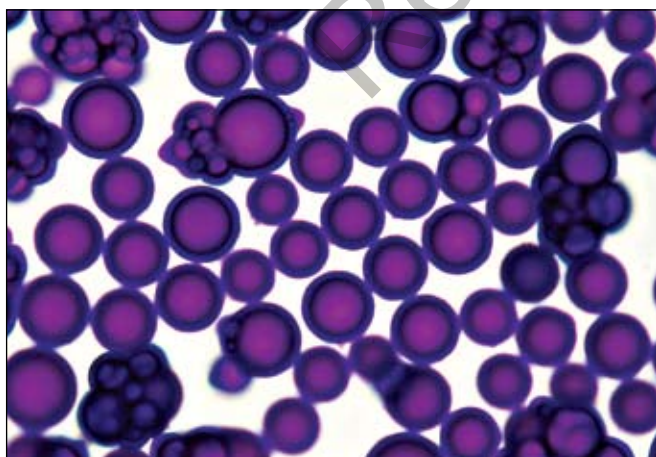
- Solvent evaporation
- *In situ* polymerization
- Interfacial polymerization
- Emulsion polymerization
- Simple and complex coacervation
- Layer-by-layer deposition
- Liposomes



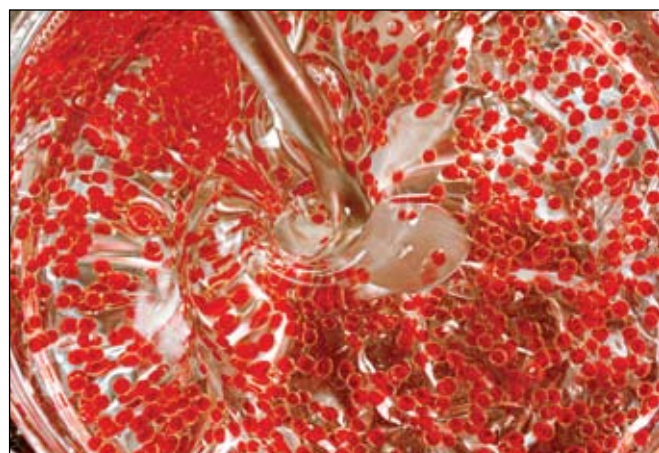
Using the SwRI pilot plant equipment and 200-liter reactors, Institute chemists produce microspheres and synthesize kilogram batches of pharmaceuticals for phase one clinical trials.



Layer-by-layer deposition adds new properties and stability to existing shell systems.



SwRI scientists have developed a novel core material for fluorescent monitoring of microcapsule oxidation.



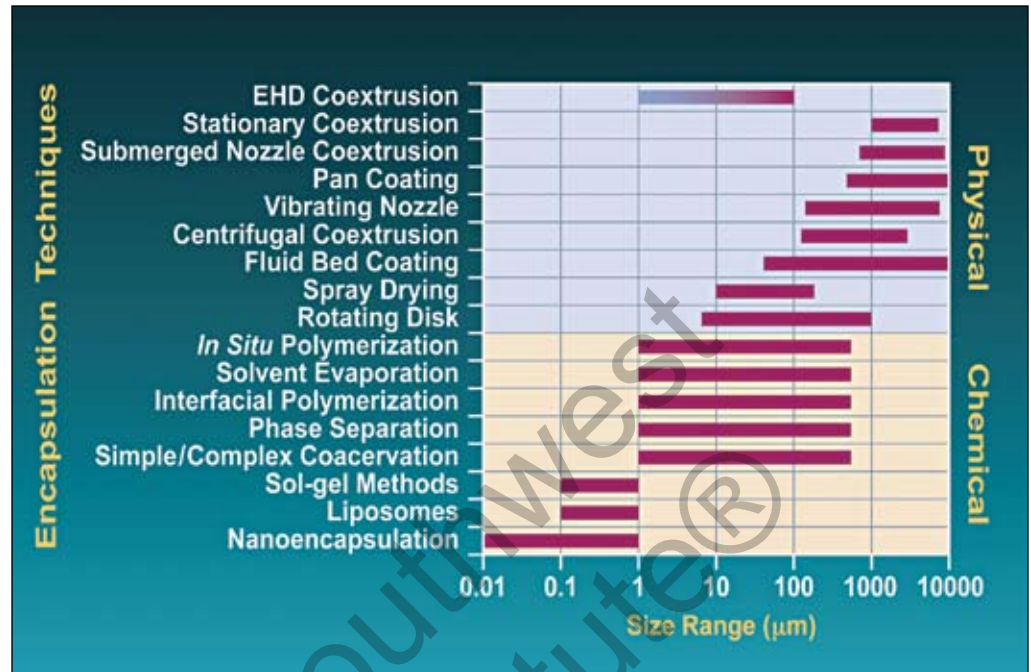
The Institute employs a number of chemical methods to develop highly stable microcapsules as small as 0.1 μm .

Process Comparisons

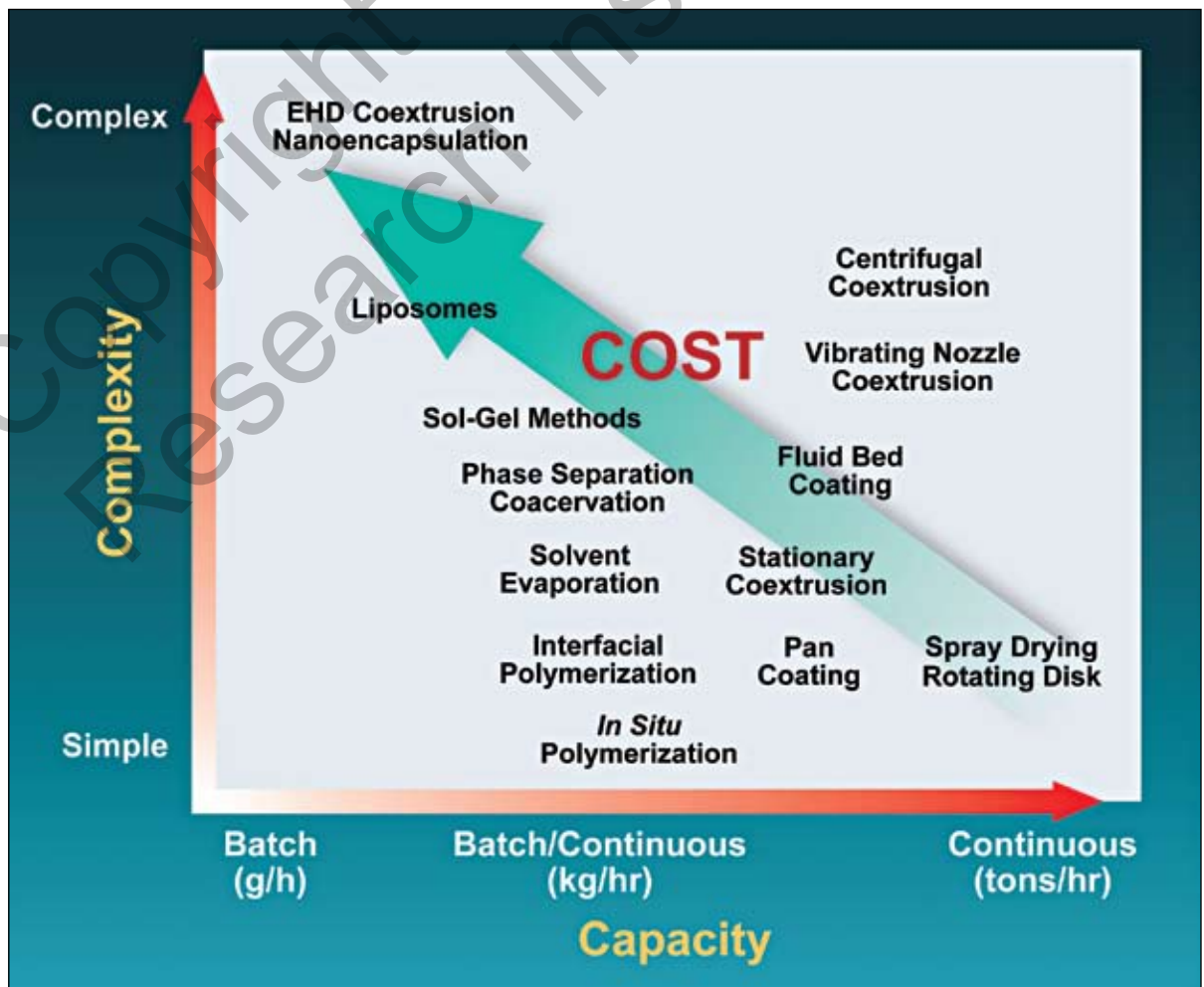
SwRI scientists, with collaborative support from clients, evaluate and balance a variety of performance and formulation criteria when selecting the appropriate encapsulation process to meet customer objectives.

Process Selection Criteria

- Core/shell material properties
 - Gas/liquid/solid
 - Solubility
 - Viscosity/surface tension
 - Density
 - Reactivity
- Capsule size
- Capsule percent payload
- Capsule morphology
- Production capacity
- Release profile/mechanism
- Stability



Microcapsule size is highly dependent on the process. The above graph illustrates general guidelines.



Encapsulation processes offer different levels of complexity, capacity and operating cost with relative comparisons shown in the accompanying graph.

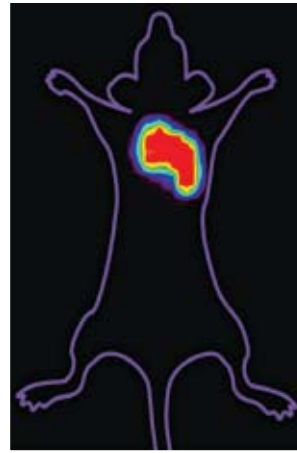
Pharmaceuticals

Applications

- Oral
- Injectibles
- Nasal
- Ocular
- Otic
- Transdermal

Features

- Targeted delivery
- Lower dose requirements
- Fewer systemic side effects
- Improved bioavailability
- Taste masking
- Improve drug stability
- Alternative formulations
- Potent drug
- Controlled substances



Encapsulated



Non-encapsulated

The use of microencapsulation technology provides increased retention of the active ingredient at the site of tumor injection resulting in reduced exposure to healthy tissue.



SwRI offers a broad spectrum of services to the pharmaceutical industries, including drug discovery, drug synthesis, drug delivery, modeling, method development, and analytical and bioanalytical testing. All services are performed under Good Laboratory Practices.

Food and Nutraceuticals

Applications

- Functional foods
- Taste masking
- Color masking
- Flavor stabilization
- Oxidation stability

Features

- Improved shelf life
- Formulation compatibility
- Liquid to solid



Institute facilities include a Good Manufacturing Practices-compliant laboratory for encapsulation studies related to the food and drug industries.



Microencapsulation is crucial for the nutraceutical market in developing health foods that taste good. SwRI encapsulation improves the shelf life and stability of nutritional supplements and can even mask the taste of fish oil, a nutritional supplement.

Consumer and Diversified Products

Applications

- Cosmetics and cosmeceuticals
- Personal care
- Pet care
- Household products
- Toys and novelty items

Features

- Improved shelf life
- Formulation compatibility
- Liquid to solid

With more than 60 years experience, SwRI provides microencapsulation solutions by offering a variety of controlled release mechanisms to the consumer and diversified products industries. Examples include detergents, cosmetics, deodorants and textiles.



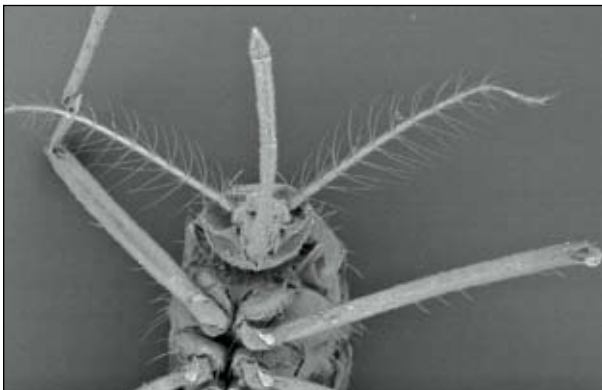
Agricultural and Industrial

Applications

- Pesticides, fungicides and fumigants
- Animal feeds, seeds
- Veterinary formulations
- Paints and coatings
- Catalysts, resins, adhesives
- Pigments, dyes, colorants
- Lubricants and additives
- Scratch and sniff
- Anti-counterfeiting
- Print advertising
- Inks



SwRI scientists develop encapsulated products for agricultural applications such as sustained release of pesticides and fertilizers, stabilization and increased bioavailability of animal feed nutrients and seed protection.



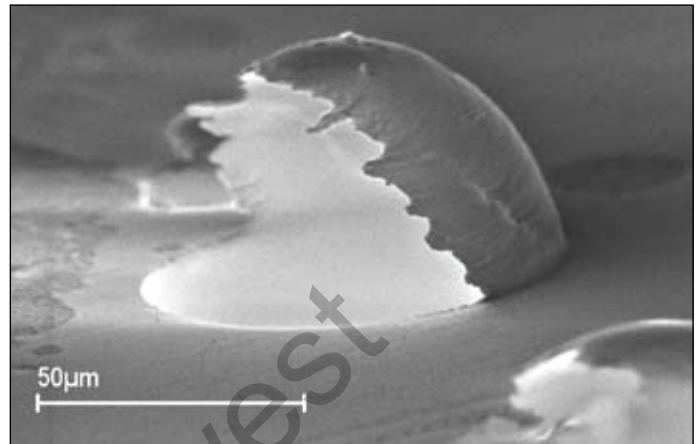
SwRI has completed numerous projects related to the encapsulation of mosquito attractants, repellants and larvicides.

Release Mechanisms

SwRI develops particle and capsule formulations to achieve one or more release mechanisms to meet product performance requirements. SwRI routinely fine-tunes formulations and particle properties to tailor release rate and/or release profile.

Common Controlled Release Profiles

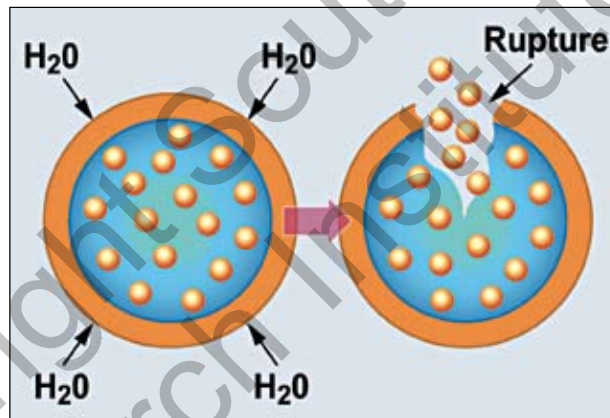
- Triggered release – Release occurs due to a change in environment, such as pH, temperature, moisture, pressure, electromagnetic. This is used to achieve immediate, delayed or pulsatile release profiles.
- Sustained release – Release occurs for an extended period of time. This can be used to achieve constant active ingredient exposure for a fixed period.
- Burst release
- Combination release profiles



Mechanically ruptured microcapsules are used to manufacture paper products such as scratch and sniff items and carbonless copy paper.

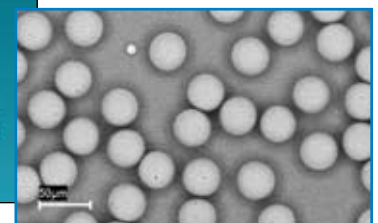
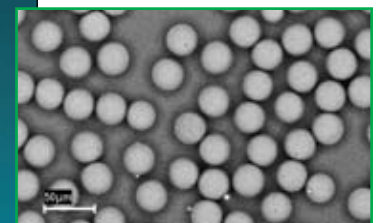
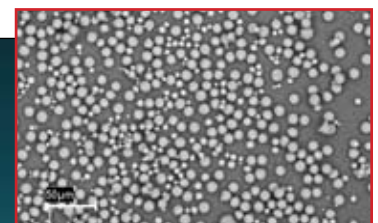
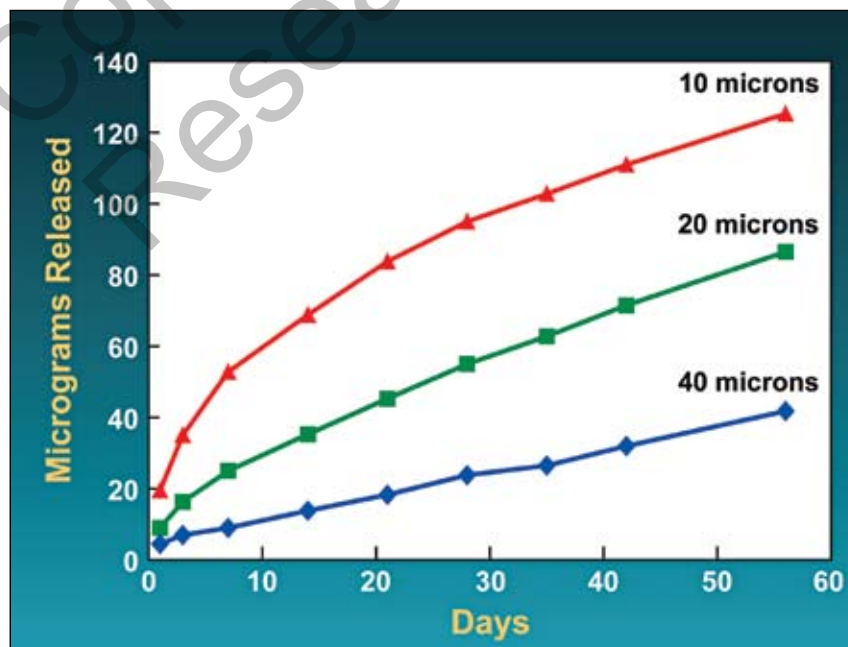
Release Mechanisms

- Diffusion
- Dissolution
- Molecular trigger (such as pH)
- Biodegradation
- Thermal
- Mechanical
- Osmotic



Osmotic release is triggered by the absorption of water into the microcapsule core. Subsequent swelling ruptures the microcapsule shell.

Particle size is one of many parameters that may be adjusted to control release rates of encapsulated ingredients.



Product Characterization

SwRI uses a variety of analytical and physical methods to characterize particles and encapsulated ingredients. SwRI routinely determines particle size, payload, content uniformity and stability, active ingredient release profiles and activity, colloid stability and particle stability.

Particles

- Sizing down to 3 nm
- Powders
- Dispersions (aqueous and organics)
- Zeta potential

Particle Morphology

- Atomic force
- SEM/EDX
- Environmental SEM/STEM
- Optical microscopy

Thermal Analysis

- Differential scanning calorimetry
- Thermal gravimetric analysis
- Dynamic mechanical analysis

Rheology

- Low viscosity fluids, gelation and curing profiles, reinforced solid mechanical properties
- Large dynamic shear range, sub-ambient to >600°C temperature range
- Multiple frequency waveform generation

Payload

- HPLC
- IC, GC, GC/MS
- Fluorescent
- Thermal gravimetric analysis

Release

- Dissolution (pH, solvent)
- Thermal
- Pressure
- Simulated body fluids
- Cell culture
- Tissue culture

Stability

- Controlled environment (such as time, temperature, relative humidity, ultraviolet, acoustic)
- Simulated fluids
- Thermal and pressure
- Byproducts

Specialized

- Biological Safety Laboratory (BSL) 2-4
- Good Laboratory Practices (GLP)



SwRI scientists use top-of-the-line molecular modeling systems for applying computational methods in pharmaceutical development to better understand protein and ligand interactions and new compound designs.



Using an environmental scanning electron microscope, SwRI scientists are able to image nonconductive samples without extensive sample preparation.



ESEM images of the SwRI MEMS logo.





Southwest Research Institute, an independent, nonprofit applied engineering and physical sciences research and development organization with 11 technical divisions, uses multidisciplinary approaches to problem solving. The Institute occupies more than 1,200 acres in San Antonio, Texas, and provides more than 2 million square feet of laboratories, test facilities, workshops and offices for more than 3,000 employees who perform contract work for industry and government clients.

***Benefiting government, industry
and the public through innovative
science and technology***



*We welcome your inquiries.
For additional information, please contact:*

Joseph T. Persyn, Manager
(210) 522-2691 • Fax (210) 522-4565
joseph.persyn@swri.org

James D. Oxley, Senior Research Scientist
(210) 522-2913 • Fax (210) 522-4565
james.oxley@swri.org

Microencapsulation and Nanomaterials Department
Chemistry and Chemical Engineering Division
Southwest Research Institute
6220 Culebra Road • P.O. Drawer 28510
San Antonio, Texas 78228-0510

microencapsulation.swri.org
swri.org



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