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An Extensive Assessment of Liposomes: An Innovative Medication Delivery System

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ABSTRACT:

Liposomes, are microscopic spherical vesicles formed by phospholipid bilayers surrounding an aqueous core. Their architecture mimics natural cell membranes, offering biocompatibility, biodegradability, and low toxicity. Liposomes can encapsulate both hydrophilic and hydrophobic drugs, enhancing solubility, stability, and therapeutic efficacy. They provide sustained release, protection of sensitive compounds, and targeted delivery to specific tissues, though challenges such as short half-life, high production costs, and drug leakage remain. Preparation methods include thin-film hydration, reverse-phase evaporation, extrusion, sonication, micro fluidization, and supercritical fluid techniques, each with distinct advantages for drug encapsulation and size control. Liposomes are classified based on composition, size, lamellarity, and functional properties, ranging from conventional and pH-sensitive types to immune and long-circulating liposomes. Evaluation involves physical, chemical, and biological characterization, including particle size analysis, zeta potential, encapsulation efficiency, and drug release studies. Recent advances include stealth liposomes (PEGylated systems), immunoliposomes for cancer therapy, liposomal vaccines, and gene delivery applications. Their versatility extends to pharmaceuticals, cosmetics, nutraceuticals, diagnostics, and biotechnology. Clinically, liposomal formulations such as Doxil have revolutionized cancer therapy, while liposomal mRNA vaccines have transformed infectious disease prevention. Despite limitations, liposomes remain a promising nanocarrier system with broad applications in medicine, biotechnology, and industry, offering controlled release, site-specific targeting, and improved therapeutic indices.

Keywords: Liposomes, Nanocarriers, Phospholipid bilayers

INTRODUCTION

In 1961, British blood specialist Dr Alec D Bangham FRS first talked about liposomes. He saw them using an electron microscope after putting a dark stain on dry phospholipids. The name liposome comes from two Greek words: "Lipos," which means fat, and "Soma," which means body. When phospholipids are placed in water, they naturally create a closed structure that has an inner space filled with water, and this structure is surrounded by a layer made of phospholipids.[1] This type of structure is known as a liposome. Liposomes are microscopic spherical vesicles that form when phospholipids are hydrated [2]. Liposomes are spherical vesicles composed of one or more phospholipid bilayers surrounding an aqueous core. This architecture closely mimics natural cell membranes and is responsible for their excellent biocompatibility, biodegradability, and low toxicity. [3]

Liposomes consist of long chains of fatty acids, glycols, sphingolipids, cholesterol, and membrane proteins. It is a two-layered concentric vesicle with a diameter of 0.01 to 5.0 m. Different types of carriers like nanoparticles, microparticles, polysaccharides, lectins, and liposomes can be used to deliver drugs to specific areas in the body [4]. Liposomal drug delivery is becoming more popular because it helps in different fields such as delivering drugs, making cosmetics, and understanding how biological membranes are structured. Greater liposome size is quickly taken out of the bloodstream [5]. Liposomes are distinct in their capacity to accept medications, which vary Extensively in physicochemical characteristics like charge and polarity and dimensions. [6]

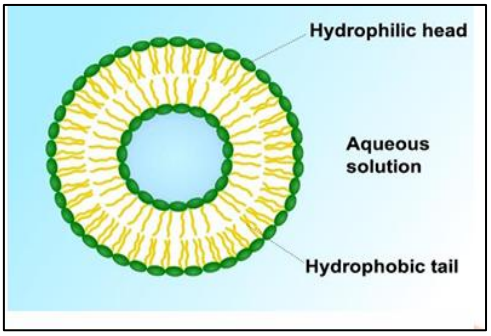


Figure 1: Structure of liposome

ADVANTAGES [1,2,4,5,8,11]

- ❖ Provide sustained release.
- ❖ Biodegradable, non-toxic.
- ❖ Improvement of the efficacy and therapeutic index of drug.
- ❖ Protection of Sensitive Compounds
- ❖ Liposomes can be targeted to specific cells or tissues.
- ❖ They are no antigenic, nonpyrogenic and nontoxic.

DISADVANTAGES [3,6,7]

- ❖ Low solubility.
- ❖ The half-life is short.
- ❖ The expense of production is substantial.
- ❖ Drug or molecule fusion and leakage from encapsulation.
- ❖ Allergic reaction may occur to liposome constituents.

APPLICATION FOR LIPOSOMES

Respiratory disorders: Liposomes are more stable than conventional aerosols, have better stability, and are less side effects than drugs. Liquids and dry forms can be inserted into the form of neonid liposomes.

Tumour therapy carrier: Liposomes are developed as nano-carriers for chemotherapy. Many drugs are already approved for chemotherapy.

Eye diseases: Liposomes have a positive effect on many eye diseases, including dryness, corneal rejection, etc. The drug verteporfin has been approved as a liposomal formulation for visual disorders.

Liposomal application: Liposomes are one of the best tools for drug pulmonary delivery because of their superior solubility characteristics.[5]

Liposomes in cosmetics: Liposomes are also used in cosmetics because they have a release pattern similar to cell membranes.

Specific targeting of the site: Immune liposomes can identify and connect with the targeted cells more sensitivity.

Liposomes as pharmaceutical delivery of proteins: Liposomes are used to increase drug solubility.

Genetic therapy: Liposomes are widely used in genetic therapy[7]

Drug Delivery: Liposomes are commonly used as drug delivery vehicles to encapsulate and deliver both hydrophobic and hydrophilic drugs. They can improve drug solubility, stability, and bioavailability. Liposomal drug formulations can target specific tissues or cells, reducing systemic side effects.

Vaccines: Liposomes are used as adjuvants or carriers for vaccines to enhance immunogenicity. They can improve antigen delivery to immune cells, leading to a stronger immune response.[10]

Cosmetics and Skincare: Liposomes are utilized in cosmetics and skincare products for controlled release of active ingredients, such as vitamins and antioxidants. They can enhance the penetration of ingredients into the skin, improving their efficacy.

Gene Delivery: Liposomes can be used to deliver genetic material, including DNA and RNA, for gene therapy applications. They protect and facilitate the transport of genetic cargo into target cells.

Diagnostics: Liposomes can serve as carriers for contrast agents in medical imaging, such as magnetic resonance imaging (MRI) and ultrasound. They enable targeted imaging of specific tissues or cells.

Cancer Therapy: Liposomal formulations of chemotherapy drugs, like Doxil (liposomal doxorubicin), are used to treat cancer. They can improve drug circulation time and reduce damage to healthy tissues.[9]

Food Technology: Liposomes are applied in the food industry for encapsulating and protecting sensitive ingredients, such as vitamins, Flavors, and antioxidants. They can improve the stability and bioavailability of these additives in food products.

Biotechnology: Liposomes are used in research and biotechnology applications for drug screening and delivery to cells in vitro. They are valuable tools for studying cell membrane interactions and drug transport mechanisms.

Transdermal Drug Delivery: Liposomal formulations can be applied topically to deliver drugs through the skin. They offer controlled release and can avoid the first-pass metabolism in the liver.

Personal Care Products: Liposomes are employed in personal care products such as sunscreens and moisturizers to enhance the delivery of active ingredients. [20]

Veterinary Medicine: Liposomes are used in veterinary medicine for drug delivery to animals, similar to their applications in human medicine.

Environmental Remediation: Liposomes can be utilized for the controlled release of remediation agents in environmental cleanup efforts.

Intracellular Delivery: Liposomes are valuable tools in research for delivering molecules into specific organelles within cells.

Nutraceuticals: Liposomes are used to enhance the bioavailability of nutraceutical compounds in dietary supplements.

Wound Healing: Liposomal formulations can be applied to wound dressings to promote the controlled release of wound-healing agents.[22]

MECHANISM OF ACTION OF LIPOSOMES [1,4,5]

Liposomes are formed open hydration of lipid molecules normally lipids are hydrated from a dry state (thin or thick lipid film, spray dried powder), and stacks of crystalline bilayers become fluid and swell myelin-long, thin cylinders grow and upon agitation detach self-close in to large, multilamellar liposomes because this eliminates unfavorable interactions at the edges. Once the large particles are formed, they can be either broken by mechanical.

Endocytosis: Endocytosis is observed in retinal endothelial cell phagocyte cells, such as neutrophils.

Adsorption: Occurs on the cell surface through non-specific electrostatic forces or interactions with components of the cell surface.

Fusion: occurs when a liposomal bilayer is inserted into the plasma membrane and its contents are continuously released into the cytoplasm.

Lipid exchange: on this transfer of liposomal lipids to the cellular membrane without association of liposomal contents.

CLASSIFICATION OF LIPOSOMES[4]

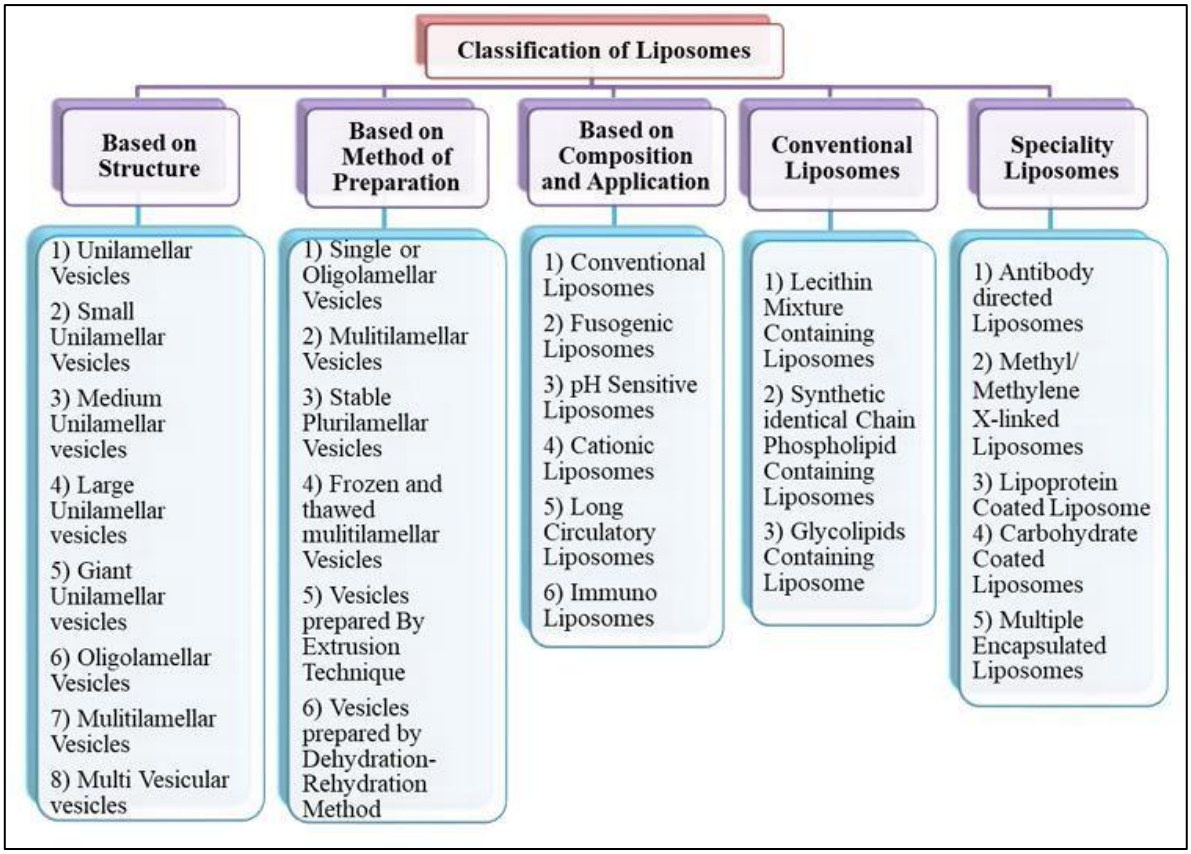


Figure 2: Classification of Liposomes

On The Basis of Composition

Liposomes are composed of natural or synthetic lipids (phospho- and sphingo-lipids,) and may also contain other bilayer constituents such as cholesterol and hydrophilic polymer conjugated lipids.

Liposomes can be divided into five categories based on their intracellular delivery method and composition:

- ❖ Conventional liposomes
- ❖ pH sensitive liposomes
- ❖ Cationic liposomes
- ❖ Immune liposomes

❖ Long circulating liposomes [3]

Based on their functional properties

Liposomes that are specially made to target specific areas of the body by attaching molecules like antibodies, peptides, or sugars to them. Liposomes that release medicine when they encounter certain changes, such as changes in pH, temperature, enzymes, light, or magnetic fields. Liposomes that stay in the bloodstream for a longer time to improve drug delivery. Liposomes that have both treatment and diagnostic functions in one system. [2]

Based on method of preparation

❖ REV: Single or oligolamellar vesicles using the reverse-phase evaporation technique.

❖ MLV-REV- Multilamellar vesicles made by reverse- phase evaporation method

❖ SPLV- Stable plurilamellar vesicles

❖ FATMLV- Frozen and thawed MLV

❖ VET- Vesicles prepared by extrusion technique

❖ DRV- Dehydration –rehydration method [8]

Based on size and the number of phospholipid membrane layers

Multilamellar Vesicles (MLV): They consist of number of concentric phospholipid bilayer membrane separated by aqueous phase. They are large structurally, with observed diameters near 5 m25.

Small Unilamellar Vesicles (SLV): These liposomes are composed of aqueous compartments enclosed by a single lipid bilayerThese liposomes range in size from 20 to 100 nm.

Large Unilamellar Vesicles (LUV): They are also composed of a single lipid bilayer surrounding aqueous compartment but have a larger size in the range of 100-250 nm.[10]

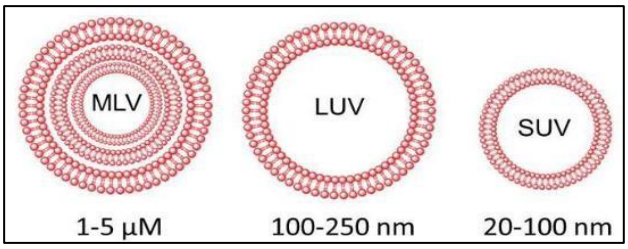


Figure 3: Size of liposomes

Based on production method

A) Passive loading technique

a) Mechanical dispersion method

❖ Lipid hydration by hand shaking or freeze drying

❖ Micro emulsification

❖ Sonication

❖ French pressure cell

b) Solvent dispersion method

❖ Ethanol injection

❖ Ether injection

❖ Double emulsion vesicle

❖ Reverse phase evaporation

c) Detergent removal method

❖ Dialysis

❖ Detergent removal of mixed micellar

❖ Dilution

B) Active loading technique

METHODS OFLIPOSOME PREPARATION

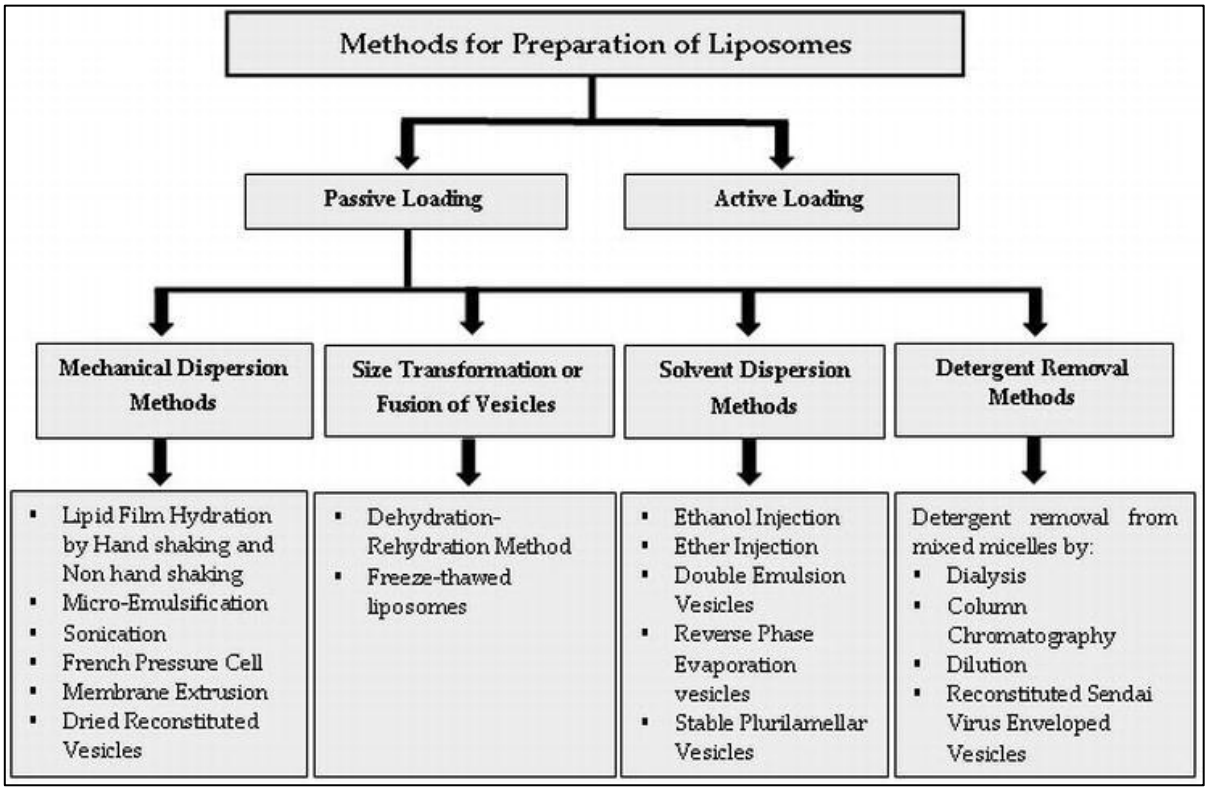


Figure 4: methods of Preparation

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METHODS OF PREPARATION

Basic studies on liposomal vesicles resulted in numerous methods of their preparation and characterization.[3]

I. Thin-Film Hydration (Bangham Method)

This is the most common and simple method of preparing liposomes.

Process:

❖ Dissolve phospholipids in a volatile organic solvent (e.g., chloroform or methanol).

❖ Remove the solvent by rotary evaporation to form a thin lipid film on the walls of a round-bottom flask.

❖ Hydrate the lipid film by adding an aqueous buffer (e.g., PBS) with gentle agitation, which leads to the formation of multilamellar vesicles (MLVs).

❖ Subject the MLVs to further processing (e.g., sonication, extrusion) to obtain smaller[7] [7][7]unilamellar vesicles (SUVs) or large unilamellar vesicles (LUVs).

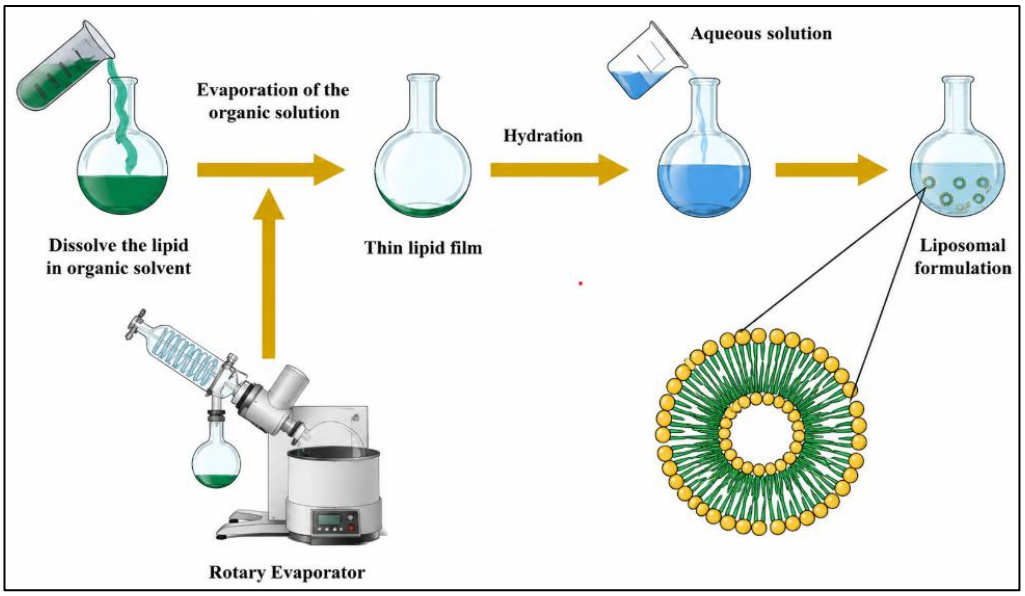


Figure 5: Thin film hydration

Applications

Widely used for basic research, encapsulation of both hydrophilic and hydrophobic drugs.[2]

II. Reverse Phase Evaporation Method

In the reverse phase evaporation method, lipids are dissolved in an organic solvent and mixed with an aqueous phase to form a water-in-oil emulsion using sonication or homogenization. Removal of the organic solvent under reduced pressure leads to the formation of liposomes with a large internal aqueous space, making this method particularly suitable for encapsulating hydrophilic drugs with high efficiency. However, exposure to organic solvents and mechanical stress may limit its applicability for sensitive biomolecules.[4]

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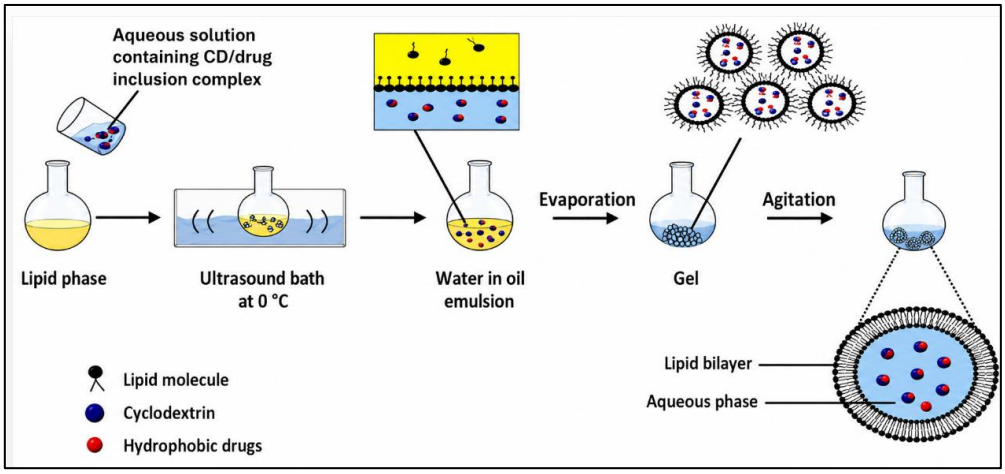


Figure 6: Reverse Phase Evaporation Method

III. Extrusion Method

This method is used to prepare liposomes with uniform size and narrow size distribution.

Steps:

❖ Prepare liposomes using the thin-film hydration method to create MLVs.

❖ Pass the liposome suspension through a series of polycarbonate membrane filters with defined pore sizes using a hand-held extruder or a high-pressure extruder.

❖ This process results in smaller liposomes with a consistent size.[7]

IV: French pressure cell

This method is mainly used in the processing of reduction of liposomes in combination methods. However, this method has many drawbacks such as intense heat is hard to maintain and small capacity are relatively small.129-131 But it has many advantages over the sonication method. This method is attained by extrusion over large MLVs through small orifice. [8]

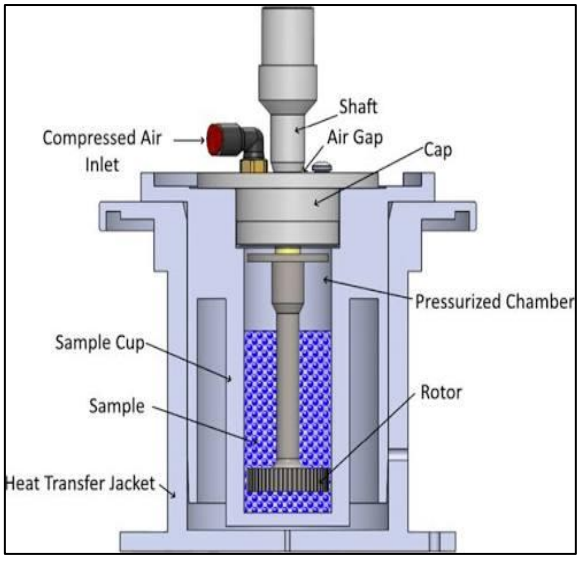


Figure 7: French pressure cell

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V: INJECTION METHOD

❖ **Ether injection method**

This method involves dissolution of lipids in diethyl ether or ether/methanol. This lipid mixture is then injected into an aqueous solution containing material to be encapsulated. This is performed at a temperature of 55-65º C or under reduced pressure. Evaporation of organic solvent is bought about by vacuum application. Finally, liposomes are obtained.[9]

❖ **Ethanol injection method**

The ethanol injection method is ethanolic lipid solution is rapidly injected to a vast excess of preheated distilled water or TRIS-HCl buffer. The incorporation of the drug in liposomal vesicle depends on its hydrophilic/hydrophobic character Nimesulide is lipid soluble component incorporates better in liposomes than 5-fluorouracil which migrates to external aqueous phase. The main advantage of ethanol injection method is including of non-harmful solvent as ethanol method. The possibility formation of azeotrope with water reduces its applicability.[10]

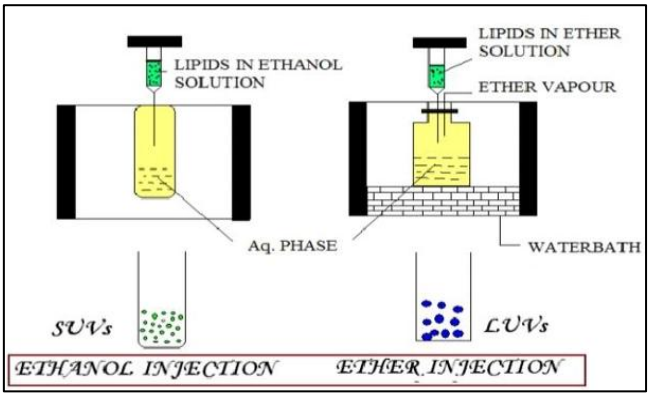


Figure 8: Injection Method

VI: Micro fluidization

A method based on micro fluidization i.e. micro emulsification is used for the large-scale manufacture of liposomes. The preparation of antibiotic liposomes by thin-layer hydration method followed by sonication with a bath-type sonicator and micro fluidization in order to achieve partial homogenization was described by Baltic. The process of micro fluidization is reproducible and yield liposomes with good aqueous phase encapsulation. [11]

VII: Supercritical fluids in the Preparation of Liposomes

Supercritical fluids are used to overcome the existing problems posed by conventional methods such as use of highly toxic solvents and limited laboratory preparation.10 Supercritical carbon dioxide is the most used fluid in the preparation of liposomes. It has several advantages as non-toxicity, non-flammability, recyclable and easy removal from solvent, operation at moderate temperature and avoiding degradation at inert atmosphere.10 This method allows controlling the extraction condition by variation of temperature, pressure or adding modifier solvents as co-solvents.[12]

VIII: Freeze Thaw Extrusion Method

An extension of the traditional DRV method is the freeze-thaw technique. After the entrapped solute has been vortexed with the film-formed liposomes, the entire film is suspended. After that, the resultant MLVs are vortexed again after being frozen in lukewarm water. Following two cycles of freezing, thawing, and vortexing, the sample undergoes three extrusions. Eight extrusions and six freeze-thaw cycles are then included the procedure, SUVs are ruptured and defused, the solute equilibrates between the interior and exterior, and the liposomes fuse and enlarge to create huge Uni lamellar vesicles using the extrusion technique (LUVET).[14]

IX: Lipid Hydration

Lipid hydration is a straightforward method for preparing liposomes by directly hydrating lipid films with an aqueous solution. Lipids dissolved in an organic solvent are evaporated to form a thin lipid film on the surface of a glass vessel, which is then hydrated with an aqueous solution containing the drug. Gentle agitation or sonication may be employed to facilitate lipid hydration and vesicle formation. This method is suitable for preparing MLVs, which can be further downsized using extrusion or sonication techniques.[12]

X: Sonication Method

Sonication is the method most commonly used to prepare SUVs. Here, MLVs are subjected to passive sonication utilizing a probe-style or bath-style sonicator. The main disadvantages of this approach are its incredibly small interior capacity, ineffective encapsulation, phospholipid degradation and removal of large molecules, metal contamination from the probe tip, and the presence of MLV in addition to SUV.]20]

❖ **using Bath sonicator**:

o The probe sonicator is used for suspensions which require high energy in small volume. (e.g.: high concentration of lipids or viscous aqueous phase).

❖ **using Probe sonicator:**

o The bath sonicator is used for a large volume of dilute lipids. The disadvantage of Probe sonicator is contamination of preparation with metal from the tip of the probe. By this method small Unilamellar vesicles are formed and they are purified by ultra centrifugation.[21]

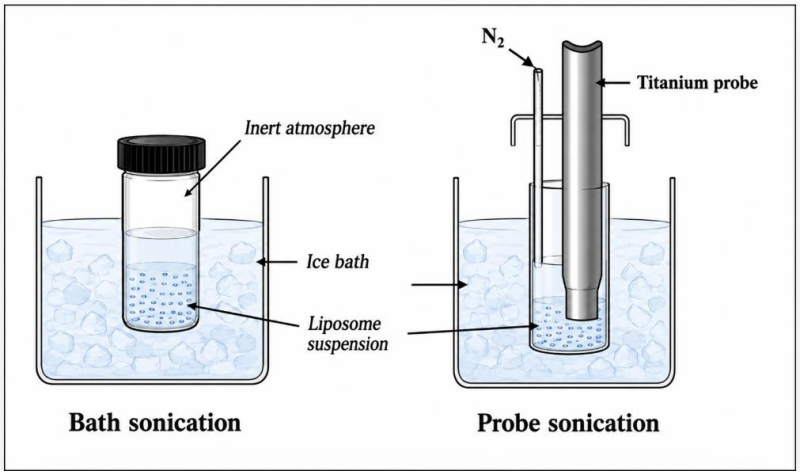


Figure 9: sonication Method

XI: Dilution

Upon dilution of aqueous mixed micellar solution of detergent and phospholipids with buffer, the micellar size and the polydispersity increase fundamentally, and as the system is diluted beyond the mixed micellar phase boundary, a spontaneous transition from polydisperse micelles to vesicles occurs.[16]

XII: Detergent removal method

The detergents at their critical micelle's concentrations have been used to solubilize lipids. As the detergent is removed the micelles become progressively richer in phospholipid and finally combine to form LUVs. The detergents can be removed by dialysis. The advantages of detergent dialysis method are excellent reproducibility and production of liposome populations which are homogenous in size. The main drawback of the method is the retention of traces of detergent within the liposomes. A commercial

device called LIPOPREP (Diachema AG, Switzerland) which is a version of dialysis system is available for the removal of detergents.[15]

XIII: Calcium-Induced Fusion Method:

The calcium-induced method is based on adding of calcium to SUV. The formation of multilamellar vesicles is as result of fusion. The addition of ethylenediaminetetraacetic acid (EDTA) to the preparations results in the formation of LUV liposomes. The preparation of LUV liposomes can be obtained only from acidic phospholipids.[9]

STABILITY OF LIPOSOMES:

The therapeutic effect of pharmaceutical molecules depends on the stability of liposomes. There are two types of stability:

❖ **Physical stability:**

Various physical processes influence the life expectancy of liposomes, such as fusion, aggregate, shape and size. The shape and distribution of sizes are important parameters for stability. Physical stability can be maintained by avoiding excessive phospholipid unsaturation. They should be stored at 4◦C without freezing or exposure to light.

❖ **Chemical stability:**

Phosphate is a water-resistant unsaturated fatty acid that changes the stability of pharmaceuticals. Add antioxidants such as butylated hydroxy nitre to avoid oxidation of liposomes.

EVALUATION OF LIPOSOMES:

Liposomal processing and formulation for specified purpose are characterized to ensure their predictable in vivo and in vitro performance. The characterization parameters for purpose of evaluation could be classified into three categories.

1) Physical characterization.

2) Chemical characterization.

3) Biological characterization. [10]

Physical characterization

Physical characterization evaluates various parameters include size, shape, surface features, release profile and phase behaviours.

Chemical characterization:

It includes study of purity and potency of various lipophilic constituents.

Biological characterization:

They are useful in safety and suitability of formulation for therapeutic application.

In vitro Cell Studies:

Cell viability assays (MTT, Alamar Blue) to assess liposome cytotoxicity. Cellular uptake studies to evaluate liposome internalization and drug delivery efficiency.

In vivo Studies:

Animal models to evaluate the pharmacokinetics, biodistribution, and therapeutic efficacy of liposomal drug formulations. [5]

Physical characterization

CHARACTERIZATION PARAMETERS	INSTRUMENT FOR ANALYSIS
Vesicle shape and surface morphology	TEM and SEM
Vesicle size and size distribution	Dynamic light scattering TEM
Electrical surface potential and surface pH	Zeta potential measurement and pH sensitive probes.
Surface charge	Free flow electrophoresis
Lamellarity	P31 NMR
Phase behaviour	DSC. Freeze fraction electron microscopy
Percent capture	Mini column centrifugation
Drug release	Diffusion cell/ dialysis

Chemical characterization

Characterization parameters	Instrument for analysis
Phospholipids concentration	HPLC/ Barret assay
Cholesterol concentration	HPLC/ Cholesterol oxide assay
Phospholipids per oxidation	U.V Observation
pH	pH meter
Osmolarity	Osmometer

Biological characterization

Characterization parameters	Instrument for analysis
Sterility	Aerobic/ Anaerobic culture
Pyrogenicity	Rabbit fever response
Animal toxicity	Monitoring survival rats.

❖ **Vesicular shape and lamellarity:**

o Vesicular shape is studied with an electron microscope.[2]

❖ **Particle size and distribution**:

o The analysis of laser diffraction analyzers with a minimum power of 5 MW [25]. The amount of drugs trapped in the liposome helps to estimate the behaviour of the drugs in the biological system. [6]

❖ **Hydrodynamic Techniques:**

This technique includes gel Permeation and Ultracentrifuge. Exclusion chromatography on large pure gels was introduced to separate SUVs from radial MLVs.The large vesicles of 1- 3µmdiameter.usually fail to enter the gel and is retained on top of column. A thin layer chromatography system using agarose beads has been introduced as a convent, fast technique for obtaining a rough estimation of size distribution of liposome preparation.[10]

❖ **Differential Scanning Calorimetry (DSC) Study:**

In this method drug loaded multilamellar liposomes are submitted to DSC analyzer. This method is used to determine phase transition temperature of phospholipids sample. The temperature of maximal excess heat capacity is defined as the phase transition temperature6,10. Thermograms are obtained6,21,49,50 at a scanning rate of 10 ºC/min or 20 ºC/min. Each sample is scanned49,50 between 20 ºC to 200 ºC or 25 ºC to 500 ºC [18].

❖ **Zeta potential determination**:

The zeta potential was evaluated by the determination of electro mobility of the 90c angle. The measurement was performed in triplicate using the 3000 HS Zeta-Seizer equipment. The sample is diluted with suitable diluents for the potential determination [7]

❖ **Visual Appearance:**

Liposome suspension can range from translucent to milky, depending on the composition and vesicle size. If the turbidity has a bluish shade this means that vesicles in the sample are homogeneous; a flat, Gray colour indicates that presence of a non-Liposomal dispersion and is most likely a disperse inverse hexagonal phase or dispersed microcrystalline. An optical microscope (phase contrast) can detect liposome> 0.3 µm and contamination with larger vesicles.[19]

❖ **Trapped Volume**:

It is an important parameter related to Liposomes. It is aqueous entrapped volume per quantity of lipids. This can vary from 0.5 to 30 microliters/micromole. [5]

❖ **Encapsulation Efficiency**:

This determines the amount and rate of entrapment of water - soluble agents in the aqueous compartment of the liposome. [13]

❖ **Drug Release:**

The component of medication discharge from liposome can be surveyed by utilizing very much aligned in -vitro dispersion cells.[13]

RECENT APPROCHES:

Interferon- gamma:

Liposome as sustain release system for human interferon-gamma. Interferon gamma (IFNgamma) has proven to be a promising adjuvant in vaccines against cancer and infectious disease. However, due to its rapid bio degradation and clearance, its efficacy is severally reduced. The liposomal association IFNgamma produce prolong residence time. Human IFNgamma can be formulate in large and multilamellar liposomes with high association efficiency (>80%) and preservation of bio bioactivity. A critical parameter is the inclusion of negatively charged phospholipids to obtain a high liposomal efficiency, which is dominated by electrostatic interactions.[11]

Stealth liposome:

Stealth liposome technology is one of the most used liposome-based system for delivery of active molecules. This liposome was developed to overcome most of the challenges encountered by conventional liposome technology. Such as, inability to evade interception by the immune system, toxicity due to charged liposome, low blood circulation half-life, and steric stability. The strategy of stealth liposome was achieved by modifying the surface of the liposome membrane, a process that was achieved by engineering hydrophilic polymer conjugate. The hydrophilic polymer such chitosan, silk fibroin, polyethylene glycol (PEG) and polyvinyl alcohol (PVA). The advantages to polymeric conjugate were considered such as high biocompatibility, low immunogenicity, nanotoxicity, and antigenicity e.g. PEGylated liposomal doxorubicin (DOXIL/Calyx).[18]

Immunoliposomes

Immunoliposomes, which are antibody-conjugated liposomes, are designed for targeted drug delivery to cancer cells or other disease-specific sites. By attaching monoclonal antibodies to the surface, these liposomes can specifically bind to antigens overexpressed in certain diseases, particularly cancers.

Example: Anti-CD19 immunoliposomes for targeted therapy of B-cell malignancies.[15]

Liposomal Vaccines:

Liposomes are now being explored as carriers for vaccines. They offer protection of the antigen, ensure slow release, and enhance immune responses. Some COVID-19 vaccine candidates have utilized liposomal technology to deliver mRNA effectively. Example: The development of liposomal mRNA vaccines for infectious diseases such as COVID-19, which leverage lipid nanoparticles for encapsulating mRNA, as seen with the Pfizer-BioNTech and Moderna vaccines.[16]

Liposomal gene therapy:

Liposomes are being utilized to deliver gene-editing tools like CRISPR-Cas9 to target specific genes in diseases. Cationic liposomes, which carry a positive charge, are especially effective in encapsulating and delivering negatively charged nucleic acids (like DNA or RNA) to cells.[14]

CONCLUSION:

Liposomes, since their discovery by Dr. Alec D. Bangham in 1961, have evolved into one of the most versatile and promising nanocarrier systems in pharmaceutical and biomedical sciences. Their unique structure—phospholipid bilayers enclosing aqueous compartments—closely mimics natural cell membranes, enabling excellent biocompatibility, biodegradability, and low toxicity. Over the decades, diverse preparation methods such as thin-film hydration, reverse-phase evaporation, extrusion, sonication, and micro fluidization have been developed to tailor liposome size, lamellarity, and encapsulation efficiency. Despite challenges like short half-life, drug leakage, and high production costs, liposomes offer significant therapeutic advantages, including sustained release, protection of sensitive compounds, and targeted drug delivery.

Recent innovations, including stealth liposomes, immunoliposomes, and liposomal vaccines, have expanded their clinical relevance, particularly in cancer therapy, infectious disease prevention, and gene delivery. Applications now extend beyond medicine into cosmetics, nutraceuticals, diagnostics, food technology, and environmental remediation, underscoring their multidisciplinary impact. Evaluation techniques such as zeta potential analysis, DSC, encapsulation efficiency, and in vivo studies ensure their stability and efficacy.

Ultimately, liposomes represent a critical advancement in nanotechnology-driven drug delivery, offering controlled release, site-specific targeting, and improved therapeutic indices. Their adaptability to encapsulate both hydrophilic and hydrophobic agents, coupled with their expanding role in biotechnology and industry, positions them as indispensable tools for modern science. With ongoing research addressing limitations, liposomes are poised to remain at the forefront of innovative therapeutic and technological applications.

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