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ADVANCES IN NANOSUSPENSION TECHNOLOGY FOR IMPROVED THERAPEUTIC PERFORMANCE

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ABSTRACT

The study of nanotechnology examines processes that take place at the molecular level at nanoscale lengths. The current article highlights the significance of the new and exciting future of nano suspension and new age dosage forms. With regard to the particle size range of 1 to 1000 nm, nano suspension can be given orally, parenterally, or intravenously. It can also be combined with ocular inserts and mucoadhesive hydrogels for targeted drug administration. Pharmaceutical nano suspensions fall under the category of nanotechnology. They are characterised by extremely finely dispersed, biphasic, and colloidal solid drug particles in an aqueous solution. In particular, nanonization is a universal, nanospecific method of increasing the bioavailability of poorly soluble drug vehicles with sizes less than 1 um, stabilised by surfactant and polymers made using appropriate techniques for drug delivery applications. The following papers discuss the unique characteristics of nano suspensions, their preparation methods, and their benefits and drawbacks. description of patents for nano suspensions promoted the product and its use in the hopes of simplifying further study in the field of nano suspension (NS). Their distinct physicochemical characteristics and submicron particle sizes offer a flexible way to improve the delivery of drugs that aren't very soluble in lipids or water. Recants are highlighted in this review. Along with scale-down technologies and bottom-up approaches for NS creation, this article also examines a variety of in vitro and

in vivo characterisation methodologies. There is discussion of a few commercial NS medicine product examples. These systems have shown great promise in the delivery of a wide range of pharmaceuticals, such as antibiotics, antiviral drugs, neuroprotective substances, anticancer agents, anti-inflammatory therapies, and poorly soluble vitamins**.**

KEYWORDS: Nanotechnology, nanosuspension, solubility enhacement techniques, bioavailablity.

INTRODUCTION

About 40% of newly discovered chemical entities employed in drug development have either water insoluble or lipophilic properties. Creating drugs with low water solubility has proven to be a challenging task for pharmaceutical experts. The BCS micronises class II medications, which have strong permeability but poor solubility. Several traditional methods have been employed to improve the solubility of drugs with low solubility, including micronization, solubilisation with cosolvents, salt production, surfactant dispersions, precipitation processes, and oily solutions. The stability and bioavailability of drugs can be improved using the nanosuspension approach. Any drug that is aqueously insoluble can be used using nanosuspension, which is simple to make. Wet milling, melt emulsification, emulsion-solvent evaporation, high-pressure homogenisation, and supercritical fluid processes are used to create nanosuspensions. Oral, parenteral, pulmonary, and ophthalmic methods can all be used to administer nanosuspensions. Nanosuspensions improve safety and efficacy by changing the drug's pharmacokinetics in addition to resolving issues with poor solubility and bioavailability. For medications that fall within BCS class II of the biopharmaceutical categorisation system, such as itraconazole, simvastatin, and carbamazepine, which are poorly soluble in both aqueous and nonaqueous mediums, the issue is considerably more complicated. An appealing and potential substitute for these issues is formulation as nanosuspension. The pure, poorly water-soluble medication, free of any matrix ingredient, is suspended in dispersion as nanosuspension. Nanosuspension is easy to prepare and works with any medication that is insoluble in water. Nano Suspension definition. In an aqueous or non-aqueous media, a nano suspension is a biphasic colloidal dispersion of pure drug particles stabilised with surfactants or polymers. These particles are usually in the nanometre size range of 10–1000 nm. It is intended to improve the therapeutic efficacy, bioavailability, and solubility of medications that are not very soluble in water. By enhancing drug dissolution, absorption, and stability, nano suspensions get around the drawbacks of

traditional drug delivery methods and can be used for a variety of administration routes, such as oral, injectable, ocular, and pulmonary delivery. The average particle size of nanosuspensions is between 200 and 600 nm, and they are often less than one micron. An increase in the rate at which micronised particles dissolve The dissolving velocity is correlated with an increase in surface area (particle size < 10 μm). The vapour pressure effect allows nanoparticles to enhance saturation solubility and dissolution velocity.

Formulation of Nanosuspension

The formulation of nanosuspension involves several key components that play a crucial role in its stability and effectiveness.

Table No. 1: Formulation Components of Nanosuspension.

Component	Function	Examples
Stabilizers	Wet drug particles	Lecithins, Poloxamers, Polysorbates, Cellulosics, Povidone
	Prevent Ostwald's ripening and agglomeration	
	Provide steric or ionic stability	
Cosurfactants	Improve solubility and stability	Transcutol, Glycofurol Ethanol, Isopropanol
	Influence phase behavior in microemulsion-based formulations	
Organic Solvents	Used as pharmaceutically acceptable solvents	Methanol, Ethanol, Chloroform, Isopropanol, Ethyl acetate, Ethyl formate, Butyl lactate,Triacetin, Propylene carbonate, Benzyl alcohol
	Aid in nanosuspension preparation	
Other Additives	Tailored to route of administration and drug properties	Buffers, Salts, Polyols, Osmogens, Cryoprotectants
	Provide stability, tonicity, or protection	

Techniques For Preparation of Nanosuspensions

Technically preparations of nanosuspensions are simpler alternative than liposome's and other conventional colloidal drug carriers but reported to be more cost effective. it is particularly for poorly soluble drugs and to yield a physically more stable product.

The principle techniques used in recent years for preparing nanosuspensions are.

A. High Pressure Homogenization: It is most widely used method for preparing Nanosuspensions of many poorly aqueous soluble drugs It involves three steps. First drug powders are dispersed in stabilizer solution to form presuspension.

Homogenization Process is homogenized in high pressure homogenizer at a low pressure for premilling, and finally homogenized at high pressure for 10 to 25 cycles until the nanosuspensions of desired size are formed. Different methods are developed based on this principle for preparations of nanosuspensions are Disso cubes, Nanopure, Nanoedge and Nanojet Homogenization in Aqueous Media (Disso Cubes)

This technology was developed by R.H.Muller using a piston-gap type high pressure homogenizer in 1999 In this method, the suspension containing a drug and surfactant is forced under pressure through a Nanosized aperture valve of a high pressure homogenizer.

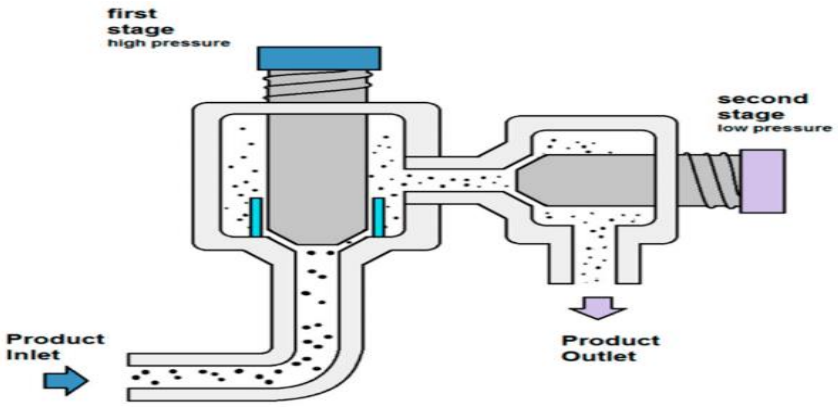

Figure 1. High Pressure Homogenization.

This method is based on cavitation principle. The dispersion present in 3cm diameter cylinder is suddenly passed through a very narrow gap of 25µm.According to Bernoulli's law the flow volume of liquid in a closed system per cross section is constant.

a) Nanoedge

Nanoedge technology is the combination of both precipitation and homogenization. The basic principle is same as that of precipitation and homogenization. The major disadvantage of precipitation technique such as crystal growth and long-term stability can be overcome by using the Nanoedge technology.

b) Nano jet Nanojet technology is also called as opposite stream technology. In this technique a stream of suspension in two or more divided parts were passed with high pressure were made.

B] Dry-Co-grinding

Recently, many nanosuspensions are prepared by dry milling technique. Dry-co-grinding can be carried out easily and economically and can be conducted without organic solvents.

Physicochemical properties and dissolution of poorly water-soluble drugs are improved by Co-grinding because of an improvement in the surface polarity and transformation from a crystalline to an amorphous drug.

C] Precipitation

Within the last decade, precipitation has been applied to prepare submicron particles, especially for the poorly soluble drugs The drug is first dissolved in a solvent, then this solution is mixed with a miscible antisolvent in the presence of surfactants. Rapid addition of a drug solution to the antisolvent leads to sudden super saturation of drug and formation of ultrafine crystalline or amorphous drug solids.

D] Supercritical Fluid Process

The particle size reduction was achieved more by the solubilization and nanosizing technologies through the super critical fluid process. Super critical fluids (SCF) are noncondensable dense fluids whose temperature and pressure are greater than its critical temperature (Tc) and critical pressure (Tp). This process allows the micronization of drug particles to submicron level. Recent advances in SCF process are to create nanoparticulate suspension of particle size of 5 to 2000nm in diameter. The low solubility of poorly water-soluble drugs and surfactants in supercritical CO2 and the high pressure required for these processes restrict the utility of this technology in the pharmaceutical industry.

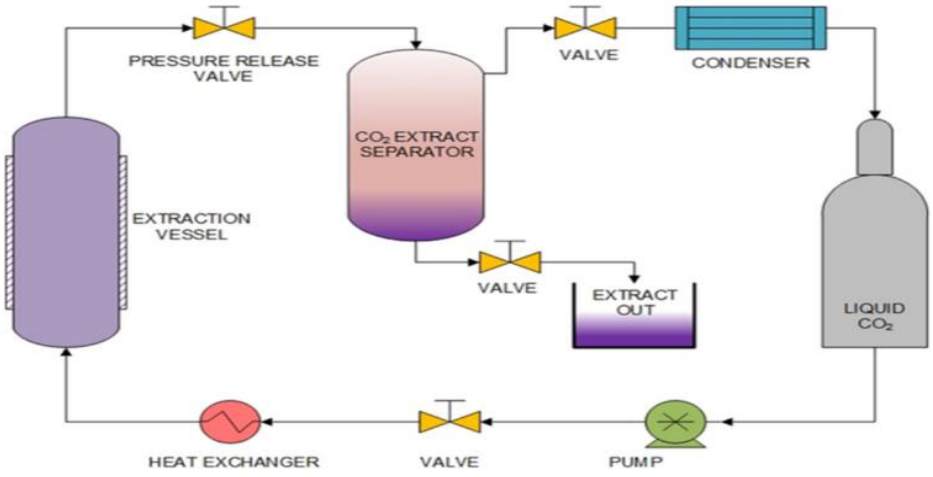

Figure 2. Supercritical Fluid Process.

E] Melt Emulsification Method

In this method drug is dispersed in the aqueous solution of stabilizer and heated above the melting point of the drug and homogenized to give an emulsion. During this process, the

sample holder was enwrapped with a heating tape fitted with temperature controller and the temperature of emulsion was maintained above the melting point of the drug. The emulsion was then cooled down either slowly to room temperature or on an ice bath.50,51

F] Lipid Emulsion/Microemulsion Template

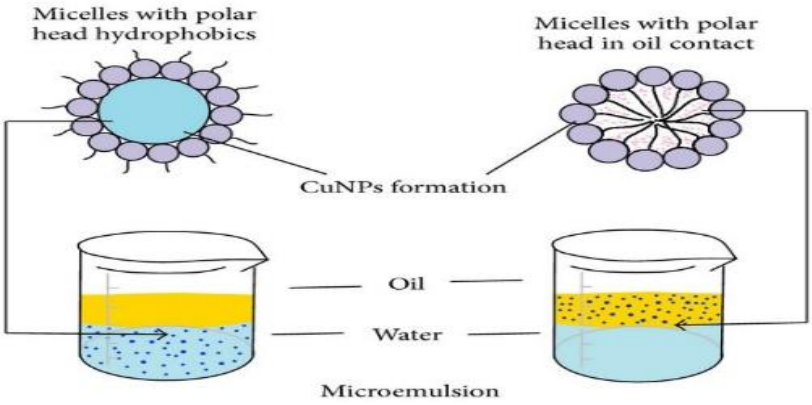

Figure 3: Lipid Emulsion/Microemulsion Template.

This method is mostly applicable for drugs that are soluble in either volatile organic solvents or partially water miscible solvents. In this method, the drug was dissolved in suitable organic solvent and then it is emulsified in aqueous phase using suitable surfactants. Then the organic solvent was slowly evaporated under reduced pressure to form drug particles precipitating in the aqueous phase forming the aqueous suspension of the drug in the required particle size. Then the suspension formed can be suitably diluted to get nanosuspensions. Moreover, microemulsions as templates can produce nanosuspensions. Microemulsions are thermodynamically stable and isotropically clear dispersions of immiscible liquids such as oil and water stabilized by an interfacial film of surfactant and co-surfactant. The drug can be either loaded into the internal phase or the pre-formed microemulsion can be saturated with the drug by intimate mixing. Suitable dilution of the microemulsion yields the drug nanosuspension. The advantages of lipid emulsions as templates for nanosuspension formation are that they are easy to produce by controlling the emulsion droplet and easy for scale up. However, the use of organic solvents affects the environment and large amounts of surfactant or stabilizer are required.

G] Solvent Evaporation

Polymer solutions are made in volatile solvents and emulsions using the solvent evaporation method. However, ethyl acetate, which has a better toxicological profile, has replaced the

dichloromethane and chloroform that were utilised in previous years. When the solvent for the polymer evaporates and the polymer is let to diffuse into the continuous phase of the emulsion, the emulsion transforms into a suspension of nanoparticles. Two primary techniques are employed in conventional procedures to create emulsions: single-emulsion preparation (such as oil-in-water (o/w) or double-emulsion preparation, e.g., (water-in-oil)-in-water, (w/o)/w. These methods require high-speed homogenization or ultrasonication, followed by evaporation of the solvent, either by continuous magnetic stirring at room temperature or under reduced pressure. By ultracentrifugation the solidified nanoparticles are collected which was washed with distilled water to remove the additives like surfactants, and then it lyophilized.

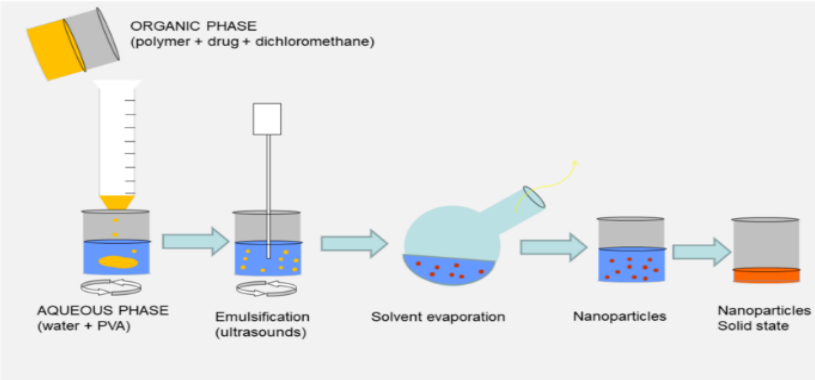

Figure 4: Solvent Evaporation.

Methods for Preparing Microspheres/Nano-emulsions

1. Solvent Evaporation Method

- Organic solvent under vacuum or heating or at atmospheric conditions to obtain microspheres loaded with drug followed by centrifugation or filtration.

2. Hydrogel Method

- This method shares similarity with solvent evaporation method. High shear forces are used to form nano-emulsion of drug-solvent which is miscible with the drug anti-solvent.

3. Parameters for Emulsion Formation

- Emulsion1-5: Microemulsion6-15 emulsion is in ultrasonic field and external pressure is increased, cavitations threshold also increases to limit where fine nano size particles are formed.

4. Phase Inversion Method

- This method uses the principle of phase inversion temperature which is the temperature at which phase transition occurs. Low temperature favours O/W emulsions and high

temperature favours W/O emulsion. Rapid cooling and heating cycles produce fine particles. Non-ionic surfactant like polyoxyethylene becomes lipophilic at high temperature and hydrophilic at low temperature due to dehydration of the polymer chain.

This method is simple and uses volatile organic solvent composition of oil, water, lipophilic and hydrophilic surfactant. This composition is allowed to mix homogeneously by Solvent Evaporation Technique: In this technique, initially mix drug with suitable organic solvent using suitable surfactant and prepare O/W emulsion by mixing continuous phase. Then evaporate organic solvent under vacuum or heating or at atmospheric conditions to obtain microspheres loaded with drug followed by centrifugation or filtration.

Adhesion properties of nanosuspension

In-Vivo Bioadhesive Studies

1. Animal Selection: Male Wistar rats are used for the study.
2. Dosage: Each rat receives a single dose containing 10 mg of nanoparticles combined with the drug (approximately 45 mg particles/kg body weight).
3. Animal Preparation: The stomach, small intestine, and cecum are removed and rinsed with phosphate saline buffer.
4. Tissue Analysis: The stomach, small intestine, and cecum are cut into 2 cm lengths and digested in alkali for 24 hours.
5. Centrifugation and Spectrofluorimetry: 2 ml of methanol is added, and the mixture is centrifuged. 1 ml of the supernatant is assayed for the drug using spectrofluorimetry to estimate the number of nanoparticles adhered to the mucosa.

In-Vitro Evaluation

Interaction with Body Proteins

1. Incubation: Nanoparticles and mucin are incubated in a 4:1 weight ratio in either neutral or acidic medium.

2. Centrifugation: The dispersion is centrifuged, and the supernatant is analyzed for mucin absorption.

Interaction with Body Proteins and In-Vitro Evaluation.

The dispersion is then centrifuged, and 150 µl of each supernatant is placed in a test plate. The plate is incubated for 2 hours at 37°C after the addition of the BCA Protein Assay Reagent Kit to the supernatants. By following this procedure, the absorbance of mucin is

measured at λmax of the drug. The total amount of mucin absorbed to nanoparticles is determined by taking the difference between its initial concentration and the concentration in the dispersion after centrifugation.

3. Mean Particle Size and Particle Size Distribution

The mean particle size and distribution are the two main factors that affect the physical stability, dissolution rate, saturation solubility, and even in-vivo behavior of nanosuspensions. Due to the changing particle size of the drug, there is considerable variation in the saturation solubility and dissolution velocity. Particle size plays a crucial role in determining these properties.

Properties of Nanosuspensions

1. Particle Size Distribution

Distribution can be determined by photon correlation spectroscopy (PCS), laser diffraction (LD), and Coulter counter multiliser.

PI (Polydispersity Index) is an important parameter that determines the physical stability of nanosuspension. It should be as low as possible as it determines the stability of nanosuspension.

The Coulter counter gives the absolute number of particles per volume unit for different size classes and is a more efficient and appropriate technique than LD for quantifying the contamination of nanosuspensions by microparticulate drugs.

2. Surface Charge (Zeta Potential)

Zeta potential provides information about the surface charge and further long-term physical stability of the nanosuspensions.

A minimum zeta potential of ±30 mV is essential. In the case of a combined electrostatic and steric stabilizer, a zeta potential of ±20 mV would be sufficient to stabilize the suspension.

3. Crystalline state and particle morphology

"Due to high pressure homogenization nanosuspension undergo a change in their crystalline structure, which may be to a polymorphic form or to amorphous forms. The determination of the crystalline state and particle morphology helps in understanding the polymorphic or morphological changes that a drug may undergo when subjects to nanosizing. The changes in crystalline structure can be identified by X-ray diffraction analysis and supplemented by DSC. to get an actual idea of particle morphology scanning electron microscopy can be used

Saturation Solubility and dissolution velocity :- The assessment of saturation solubility and dissolution velocity helps in determining the in vitro behavior of the formulation Nanosuspensions have an important advantage that it can increase the dissolution velocity as well as the saturation solubility.

4. pH Value

The ph of aqueous formulation should be taken at given temperature or when the equilibrium attained so as toTo enhance the stability of nanosuspensions, it is crucial to:

Minimize the "pH drift" and electrode surface coating with suspended particles. The addition of electrolyte must be avoided in the external phase of the formulation to stabilize the pH.

5. Stability

The stability of nanosuspensions is directly proportional to particle size. A decrease in particle size leads to an increase in surface area and thus an increase in surface energy, leading to an increase in the tendency of particles to agglomerate. Hence, stabilizers are used to prevent Ostwald ripening, improving the stability of nanosuspensions. Nanosuspensions can be stored at different stress conditions like different temperatures (15, 25, 35, 45°C), thermal cycling, and mechanical shaking, and changes in their mean particle size can be followed for three months.

6. Velocity of drug

Dissolution of drug is increased due to increase in the surface area of the drug particles from micrometers to the nanometer size.

According to Noyes-Whitney equation, dissolution velocity increases due to increase in the surface area from micron size to particles of nanometer size.

$dx/dt = [(D \times A)/ h] [Cs-X/V]$

Where,

D is diffusion coefficient

A is surface area of particle

dx/dt is the dissolution velocity

V is volume of dissolution medium and

h is the thickness of the diffusion layer

X is the concentration in surrounding liquid.

7. Drug Content

The drug content of nanosuspension formulation is achieved by extracting nanosuspension using an appropriate solvent - "mixture like Methanol:THF(1:1) mixture, shake well & centrifuge. The supernatants are separated and diluted with the same solvent mixture and absorbance is measured at suitable λmax. The drug content is calculated using the calibration curve."

"In Vivo Evaluation: The monitoring of in-vivo performance of the drugs is an important part of the study, regardless of the route and the delivery system employed. Formulations are generally administered by the required route and plasma drug concentration is determined by HPLC-UV visible spectrophotometry. In-vivo parameters are generally used to evaluate surface hydrophobicity/hydrophilicity, interaction with body proteins, and adhesion properties. Dissolution rate influences in-vivo biological performance of the oral nanosuspensions. Surface properties and the size of nanosuspension determine the" The monitoring of in-vivo performance of the drugs is an important part of the study, regardless of the route and the delivery system employed. Formulations are generally administered by the required route, and plasma drug concentration is determined by HPLC-UV visible spectrophotometry.

In-vivo parameters are generally used to evaluate surface hydrophobicity/hydrophilicity, interaction with body proteins, and adhesion properties. The dissolution rate influences the in-vivo biological performance of oral nanosuspensions. Surface properties and the size of nanosuspension determine the organ distribution of intravenously injected nanosuspensions.

Surface hydrophobicity is determined by hydrophobic interaction chromatography, and absorption of protein is determined by 2-D PAGE quantitatively and qualitatively after intravenous injection of nanosuspensions of the drug in animals.

8. Solubility of Drugs

A large proportion of new chemical entities coming from drug discovery are water insoluble, and therefore poorly bioavailable, leading to hurdles in formulation development efforts. There are a number of formulation approaches like micronisation, solubilization using cosolvents, precipitation techniques etc., to resolve the problems of low solubility and low bioavailability. Each of them has its own limitations. Other techniques like microemulsions, solid dispersions, and inclusion complexes using cyclodextrins, even though they showed

increased solubility, are not applicable for drugs which are insoluble in both aqueous and organic media. The next development step is the transformation of the micronized drug to drug nanoparticles and nanosuspensions. Nanoparticulate drug delivery systems may offer plenty of advantages over conventional dosage forms, which include improved efficacy and reduced [side effects/dosage]."toxicity, enhanced biodistribution and improved patient compliance. Nanosuspension technology offers novel solution for these poorly soluble drugs. Nanosuspension consists of pure poorly water soluble drugs with or without any matrix material suspended in dispersion. They can be surfactant free; can also comprise surfactants or stabilizers or both. Nanosuspensions differ from nanoparticles, which are polymeric colloidal carriers of drugs (Nanospheres and nanocapsules), and from solid-lipid nanoparticles (SLN), which are lipidic carriers of drug. Nanosuspensions are distinctive and commercially feasible approach to solve the problems of hydrophobic drug such as poor solubility and poor bioavailable.

Nanosuspensions Advantages

1. In nanosuspensions, the drug is in contact with the gastrointestinal mucosa for a longer period, stimulating better absorption.
2. Nanosuspensions offer versatility in drug delivery and various routes can be used to administer them, including parenteral, oral, dermal, pulmonary, and ocular routes, providing treatment options that are flexible.
3. Nanosuspensions have improved physical stability and decreased particle settling due to their increased resistance to oxidation and hydrolysis.
4. Possibility of surface-modification of nanosuspension for site-specific delivery.
5. Possibility of large-scale production, the pre-requisite for the introduction of a delivery system to the market.
6. Long-term physical stability (Due to the absence of Ostwald ripening).
7. Improved solubility nano suspension enhances the solubility of poorly water-soluble drugs enabling better bioavailability.
8. Enhanced stability of nanosuspensions can help stabilize drugs that are prone to degradation in aqueous solutions by preventing crystallization.
9. Versatility: Nanosuspensions can be used for a wide range of drugs, including peptides, proteins, and poorly soluble synthetic compounds, broadening their application in the pharmaceutical industry.

10. Controlled Drug Release*: Nanosuspensions can be engineered for controlled drug release over extended periods, improving therapeutic efficacy and reducing side effects.

Nanosuspensions Disadvantages

1. Less Stable: Nanosuspensions are less stable compared to other dosage forms.
2. Short Shelf-Life: Nanosuspensions possess a short shelf-life.
3. Physical Instability: Creaming, cracking (breaking), flocculation, and phase inversion are common problems observed during storage of emulsions.
4. Partical characteristics; Preserving particle characteristics particularly size and amorphous fraction can be challenging maintaining particle integrity often requires subsequent processes like lyophilization or spray drying
5. Physical stability issues; over time, nanosuspenions can experience particle aggregation or Ostwald ripening ,leading to instabilit
6. Complex Manufacturing Process: Producing nanosuspensions involves sophisticated techniques such as high-pressure homogenization, wet milling, or precipitation, requiring specialized equipment and expertise, which can increase production costs
7. Narrow Practical Size Distributions Challenge: Achieving a uniform particle size distribution can be difficult, potentially resulting in variations in drug release rates and pharmacokinetics profile.
8. Specialized Storage and Handling Requirements*: Nanosuspensions may require specific storage conditions to maintain stability, as factors like temperature, light exposure, and pH can affect their integrity.
9. Compatibility and Safety Concerns*: Interaction with excipients or other formulation components can impact the stability, efficacy, or safety of nanosuspensions, necessitating thorough compatibility testing.
10. High Production Costs: The need for specialized equipment and raw materials, along with stringent quality control measures, can make the manufacturing of nanosuspensions more expensive compared to conventional formulation.

Application Of Nano-Suspensions

1. Oral Drug Delivery Oral course is the most advantageous and favored course particularly on account of orally controlled drugs like anti-microbials, atovaquone and bupravaquone.

Nanosizing method can prompt a sensational expansion in their oral retention and upgrade bioavailability because of the expanded immersion solvency prompting an expanded focus slope between gastrointestinal lot lumen and blood and the expanded disintegration speed of the medication. Oral organization of Amphotherin B Nano-suspensions, which is created by high strain homogenization, effectively reduces parasite numbers by keeping up with consistent blood levels in plasma.

2. Parental drug delivery Medication Conveyance Nimodipine is given to the patients with subarachnoid drain related vasospasm. Oral organization of nimodipine has low bioavailability because of the great first pass digestion in the liver. Intravenous organization is an option in contrast to oral organization and can give better bioavailability. Intravenously managed Nimodipine Nano-suspensions lessens neighborhood disturbance and phlebitis over the orally regulated Nimodipine Nano suspensions
3. Pulmonary Drug Delivery Nano-suspensions are a method for administering medications that are poorly soluble in pulmonary secretions. These medications can be administered via dry powder inhalers or suspension aerosols. Nebulization is accomplished with the assistance of ultrasonics or mechanical nebulizer.
4. Ocular Drug Delivery Nano-suspensions assumes a vital part for drugs that shows unfortunate dissolvability in lachrymal liquids. The nano-measuring innovation represent higher solvency, higher disintegration rate, higher bio grip, corneal entrance and expands the home time in a cul-de-sac and evasion of high tonicity created by water-dissolvable medications. Decrease in the molecule width to under 10 μm will lessen molecule bothering to the eye, reduce tearing and in this way increment the viability of a visual treatment. E.g.: The nano suspensions of hydrocortisone, prednisolone and dexamethasone was showed that it upgrades the disintegration rate and degree of ophthalmic medication ingestion as well as the power of medication activity.
5. Target Medication Conveyance Nano-suspensions can be utilized for designated drug conveyance as their surface properties and in vivo conduct can be adjusted by changing the stabilizers and surfactants. The planning of sheath nano-suspensions finished by using different surface covering procedures for dynamic or aloof focusing for ideal site.
6. Bioavailability improvement A nano-suspension beats the issue of unfortunate bioavailability by utilizing surfactants, stabilizers. Nano suspension plan of oleanic corrosive beats the unfortunate solvency of oleanic corrosive. The helpful impact was altogether upgraded because of the quicker disintegration (90% in 20 min) of the

lyophilized nano-suspensions powder when contrasted and the disintegration of regular measurement form.

7. Novartis' topical formulations The incorporation of the drug's nanocrystalline form into water-free ointments and creams increases the drug's saturation solubility in the topical dosage form, enhancing its diffusion into the skin and thereby its bioavailability and permeability.
8. Mucoadhesion of the Nanoparticles which are orally organization as a suspension diffuse into the liquid media and immediately penetrate the mucosal surface. Bioadhesion causes the particles to become immobile at the intestinal surface. After this, concentrated suspension goes about as a supply of particles and an adsorption interaction happens quickly. Bio-cement stage is the initial step before molecule gets assimilated. The nano-suspensions' adhesiveness aids in the bioavailability and targeting of parasites that are still present in the GIT.

Limitations

1. Physical Stability: Nanosuspensions can be prone to aggregation, sedimentation, or Ostwald ripening, which can affect their stability and performance.
2. Scalability: Scaling up the production of nanosuspensions while maintaining their physical and chemical stability can be challenging.
3. Sterilization: Sterilization of nanosuspensions can be difficult without compromising their stability or altering their particle size distribution.
4. Toxicity: The potential toxicity of the surfactants or polymers used to stabilize nanosuspensions needs to be carefully evaluated.

CONCLUSION

Nanosuspensions represent a groundbreaking advancement in pharmaceutical nanotechnology, offering a promising solution for the effective delivery of poorly soluble drugs. By reducing particle size to the nanometer range (1–1000 nm), nanosuspensions enhance drug solubility, stability, and bioavailability, making them suitable for multiple routes of administration, including oral, parenteral, ocular, and mucoadhesive systems.

Their unique physicochemical properties allow for targeted and controlled drug release, thereby improving therapeutic efficacy and patient compliance. Various preparation methods and characterization techniques have been developed to optimize their formulation, and

several nanosuspension-based products have already been commercialized, demonstrating their practical utility.

In conclusion, nanosuspensions hold significant potential to revolutionize modern drug delivery systems, especially for compounds with poor water or lipid solubility. Continued research and development in this field are essential to unlock further therapeutic applications and ensure the widespread adoption of this versatile drug delivery platform.

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