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ADVANCES IN ORAL NANOSUSPENSION TECHNOLOGY: FORMULATION APPROACHES, CHARACTERIZATION AND RECENT APPLICATIONS

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ABSTRACT
Nanosuspensions are submicron colloidal dispersions of poorly water-soluble drug particles stabilized by suitable surfactants or polymers. They have emerged as an effective drug delivery approach to overcome the challenges associated with poor aqueous solubility, low dissolution rate, and limited bioavailability of many pharmaceutical compounds. By reducing drug particle size to the nanometre range, nanosuspensions significantly increase surface area, resulting in enhanced saturation solubility, faster dissolution, and improved therapeutic efficacy. Various preparation methods, including media milling, high-pressure homogenization, precipitation, emulsion–solvent evaporation, solvent diffusion, and microemulsion techniques, have been successfully employed for laboratory-scale and industrial-scale production. The stability of nanosuspensions depends on appropriate formulation components such as stabilizers, surfactants, polymers, and cryoprotectants, which prevent particle aggregation and crystal growth. Nanosuspensions have demonstrated considerable potential in oral, parenteral, ocular, pulmonary, topical, buccal, nasal, transdermal, and brain-targeted drug delivery systems by improving drug absorption, bioavailability, and site-specific targeting while minimizing adverse effects. Furthermore, their adaptability for surface modification and incorporation into solid dosage forms broadens their pharmaceutical applications. Despite significant advancements, challenges related to long-term stability, redispersibility, large-scale manufacturing, and regulatory acceptance remain. Overall, nanosuspensions technology represents a promising strategy for enhancing the delivery and therapeutic performance of poorly soluble drugs and continues to be an important area of pharmaceutical research and development.

KEYWORDS: Nanosuspensions, enhanced dissolution, bioavailability.

1. INTRODUCTION

1.1 Definition

A nanosuspension is a submicron colloidal dispersion of pure drug particles, usually smaller than 1000 nm, stabilized by polymers and/or surfactants.[1] A pharmaceutical nanosuspension is a biphasic colloidal dispersion consisting of clean, poorly water-soluble drug particles dispersed in an aqueous vehicle, stabilized by surfactants or polymers, without the usage of matrix ingredients.[2] Colloidal dispersions of nanosized drug particles, known as nanosuspensions, increase the solubility, rate of dissolution, and bioavailability of medications that are poorly soluble in water.[3] Nanosuspensions are two-phase pharmaceutical systems in which solid drug particles, usually smaller than 1 µm, are dispersed in an aqueous medium with the aid of stabilizers.[4]

1.2 Need for nanosuspension

Over 40% of medications have low water solubility, making it difficult to formulate them into traditional dosage forms. Class II medicines with low solubility in aqueous and organic environments provide a more challenging issue. Preparing nanosuspension is ideal for chemicals that are insoluble in water but soluble in oil and have a high log. P value. To address poor solubility and bioavailability, several strategies can be used, including micronization, co-solvency, oily solutions, salt creation, liposomes, emulsions, microemulsions, solid dispersion, and ß-cyclodextrin inclusion complexes. However, many of these strategies are not relevant to all medications. In these instances, nanosuspensions are preferable. Nanosuspensions are used to produce medications that are insoluble in both water and inorganic environments, replacing lipidic systems. It is best suited for substances with high log P value, melting point, and dosage. Nanosuspensions can improve medication solubility in both aqueous and lipid environments. By administering the nanosuspension orally or intravenously (IV), the active substance floods more quickly and reaches its maximal plasma level. This is one of its distinct benefits over other methods for improving solubility. Formulators have substantial challenges when working with compounds having low solubility, permeability, or both.[5]

1.3 Structure of nanosuspension

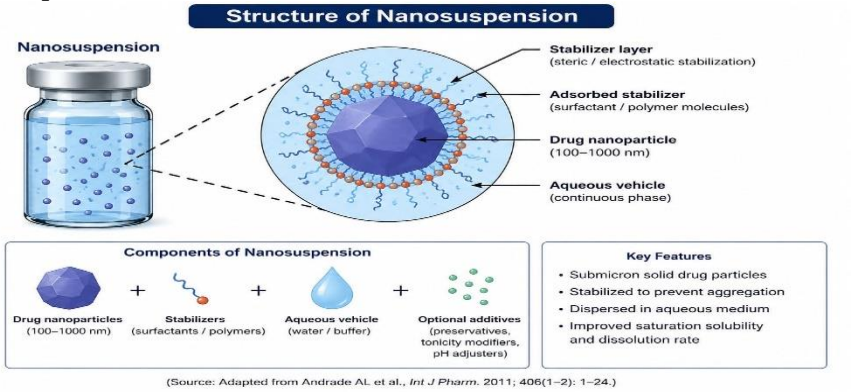

Figure 1: Structure of Nanosuspension.

The medication, the dispersion medium, and stabilizers make up the three primary components of nanosuspensions. The medication forms the core of the system, while the liquid medium is usually water or another suitable solvent. Surfactants and polymers are examples of stabilizers that are added to keep particles from aggregating and to preserve their physical stability while being stored.[6]

These methods are especially beneficial for medicines with limited water solubility and poor oral absorption. They have been created for topical, ophthalmic, pulmonary, parenteral, and oral administration. To enhance handling and storage stability, nanosuspensions can frequently be transformed into tablets, capsules, pellets, or dry powders.[7]

Nanosuspensions can be prepared using bottom-up techniques like precipitation or top-down techniques like media milling and high-pressure homogenization. The drug's characteristics, the intended particle size, and the final dose form all influence the technique selection. Particle size, zeta potential, drug content, saturation solubility, dissolution rate, and physical stability are all assessed after preparation.[8]

Due to their ease of use, affordability, and versatility in terms of dose formulations, nanosuspensions are seen as a promising strategy. They are also helpful in enhancing the efficacy of hydrophobic medications without altering the drug molecule's chemical structure.[9]

1.4 Stabilization of nanosuspension.

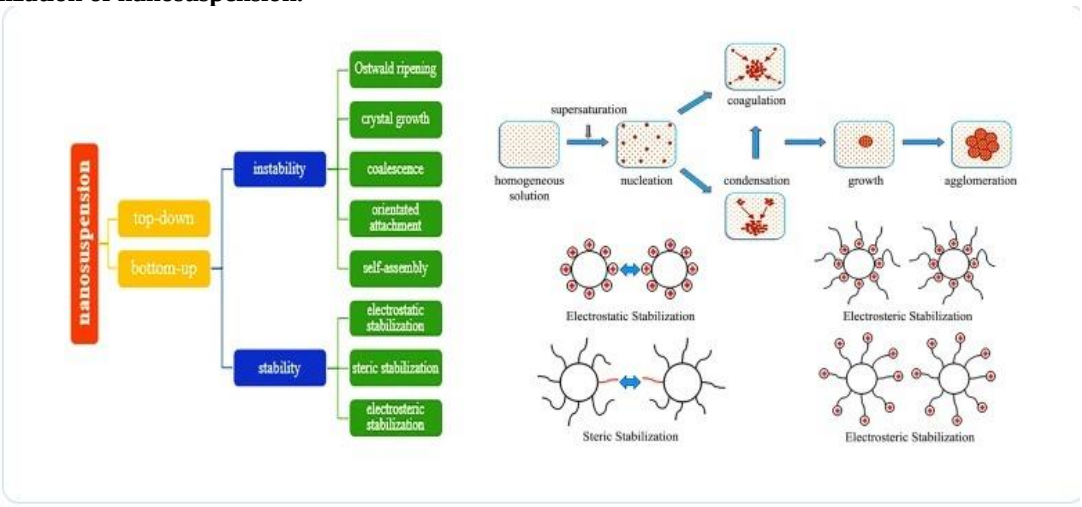

Figure 2 Stabilization of nanosuspension.

1.5 Factor affecting nano suspension.

1.5.1Stabilizers

In order to prevent Ostwald's ripening and the agglomeration of nanosuspensions, a stabilizer's main function is to guarantee the complete wetting of drug particles, hence enhancing the formulation's physical stability. This is accomplished by acting as an ionic or steric barrier.[12]

The physical stability and in vivo behavior of the nanosuspension are significantly influenced by the kind and amount of stabilizer used. Thus far, a variety of stabilizers have been employed in the production of nanosuspensions, such as lecithins, povidones, cellulosics, polysorbates, and poloxamers. Lecithin has been the favored stabilizer in the search for a nanosuspension that can withstand autoclaving and be administered parenterally.[13]

1.5.2 Organic solvent

Organic solvents are required in the nanosuspension formulation when emulsions or microemulsions are used as templates. Methanol, ethanol, chloroform, and isopropanol are examples of water-miscible solvents that are safe for use in medicinal settings. In the formulation process, partially water-miscible solvents such ethyl acetate, ethyl formate, butyl lactate, triacetin, propylene carbonate, and benzyl alcohol are also favored over traditional toxic solvents like dichloromethane.[14]

1.5.3 Co-surfactant

The choice of an appropriate co-surfactant becomes crucial when creating nanosuspensions using microemulsions. This is due to the fact that the selection of co-surfactants can have a substantial impact on the drug loading and internal phase uptake within a particular microemulsion composition, which in turn affects the phase behavior. While bile salts and dipotassium glycyrrhizinate are frequently mentioned in literature references as possible co-surfactants, alternative solubilizers including transcutol, glycofurol, ethanol, and isopropanol can be used in the formulation of microemulsions without posing any significant concerns.[15]

1.5.4 Other additives

Additives such as buffers, salts, polyols, osmotic agents, and cryoprotectants can be added to nanosuspensions. These previously mentioned additions serve a variety of purposes intended to improve the stability and effectiveness of the nanosuspension.

While salts contribute to system stability by providing ionic strength, buffers play a critical role in maintaining accurate pH levels. Conversely, polyols prevent particle aggregation by acting as stabilizers. In order to maintain compatibility with cellular structures, osmotic agents are responsible for controlling the osmolarity of the solution. Lastly, throughout the freezing and thawing processes, cryoprotectants are used to protect the nanosuspension.[16]

1.5.5 Post-product processing

When a therapeutic candidate is very vulnerable to hydrolytic cleavage or chemical degradation, post-production processing becomes crucial for nanosuspensions. Furthermore, processing can be necessary if even the best stabilizer is unable to keep the nanosuspension stable for a long time or if specific administration routes present challenges.[17]

In light of these factors, methods like lyophilization or spray drying can be used to produce a dry powder that contains medication particles at the nanoscale. Choosing amongst these unit procedures requires careful consideration of the drug's properties and cost-effectiveness. Generally speaking, spray drying is a more practical and economical option than lyophilisation.[18]

2. MATERIALS AND METHODS

2.1 Materials

Table 1: shows list of excipients used in NLCs preparation.[19]

Excipient	Function	Examples
Stabilizers	Wet the drug thoroughly, prevent Ostwald's ripening and agglomeration of nanosuspension, providing steric or ionic barrier.	Lecithins, poloxamers polysorbates, cellulosics, povidones.
Co-surfactant	Influence phase behavior when micro emulsions are used to formulate nanosuspension.	Bile salts, dipotassium glycerrhizinate, trancutol, glycofurol, ethanol, isopropanol
Organic solvent	Pharmaceutically acceptable less hazardous solvent for preparation of formulation.	Methanol, ethanol chloroform, isopropanol ethyl acetate, ethyl formate, butyl lactate benzyl alcohol.
Other additives	According to the requirement of the route of administration or the properties of the drug moiety	Buffers, salts, polyols, osmogens, cryoprotectant etc.

2.2 Methods

2.2.1 Bottom-up Technology

List and Sucker employed the bottom-up technique, also known as "nanoprecipitation," for the first time in 1987.[20] The idea behind this bottom-up method is to precipitate dissolved molecules with the addition of another insoluble material to produce nanosized particles. The active ingredient must be soluble in at least one solvent for this technique to work, and appropriate stabilizers must be used to stop particle development following precipitation.[21] The fishbone diagram in Figure 4 illustrates the characteristics that influence particle size and particle size distribution in NS formulations produced by the bottom-up method. Table 2 summarizes the benefits and drawbacks of the bottom-up approach.

Table 2: comparison of advantage and disadvantage of nanosuspension preparation methods.

Preparation Method	Advantages	Limitations
Bottom-up technology	Simple in principle and operation No device requirement Rapid preparation	Poor reproducibility Non-homogeneous particle size Risk of toxic effects of the solvent Difficult to scale up
Top-down technologies		
High-pressure homogenization method	Easy to scale up Easy to reproduce Obtaining homogeneous particle size Obtaining the desired particle size with process modifications Decreasing for recrystallization	Expensive equipment Risk of heating in the device because of high pressure Risk of clogging the chamber
Wet media milling method	Easy to scale up Easy to reproduce Obtaining homogeneous particle size Obtaining the desired particle size with process modifications	Expensive equipment Risk of corrosion of beads and milling chamber

The literature also includes recently discovered bottom-up techniques including emulsion polymerization, high-gravity-controlled precipitation (HGCP), liquid antisolvent precipitation (LAS), precipitation assisted by the acid-base method, and supercritical fluid method (SCF).[22]

2.2.2 Top-down technology

The reduction of big particles to the nanoscale is the foundation of top-down technology. The two primary techniques are media milling, a low-energy procedure, and high-pressure homogenization, a high-energy process.[23] These techniques are used for commercially sold items and are better suited for industrial manufacturing than bottom-up technologies.[24]

2.2.3 Combination technology

In addition to these two technologies (top-down and bottom-up), a number of ways can be combined to prepare NSs, and by making certain adjustments, NSs with desired properties can be obtained. Studies on the use of multiple approaches in combination are included in and these studies also offer an assessment of the benefits of the aforementioned methods. NSs of the discovered formulation can be created using a combination of top-down and bottom-up technologies, or vice versa.[25]

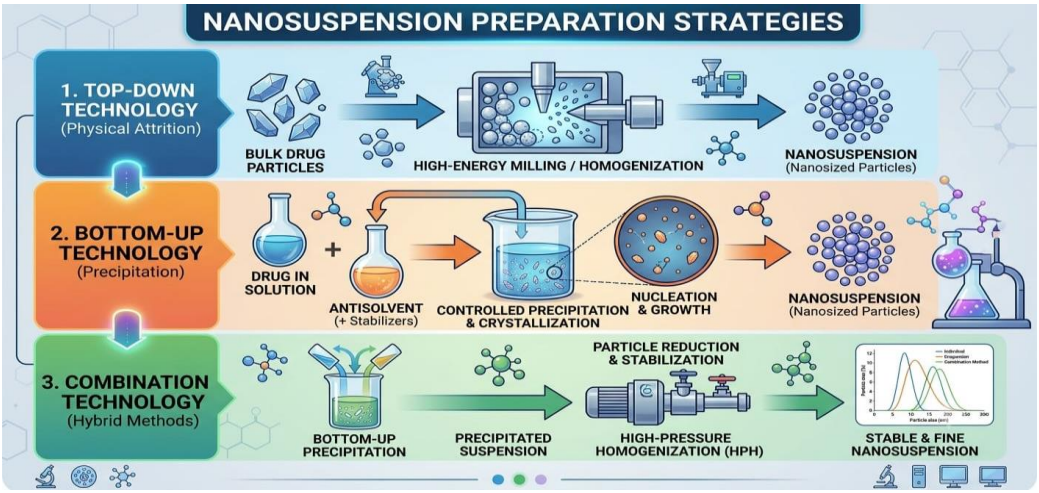

Figure 3: Nanosuspension preparation strategies.

2.2.4 High pressure homogenization

It is the most popular technique for creating nanosuspensions of numerous medications that are poorly soluble in water. It involves three steps. To create a presuspension, drug powders are first dispersed in stabilizer solution. The presuspension is then homogenized at low pressure for premilling in a high

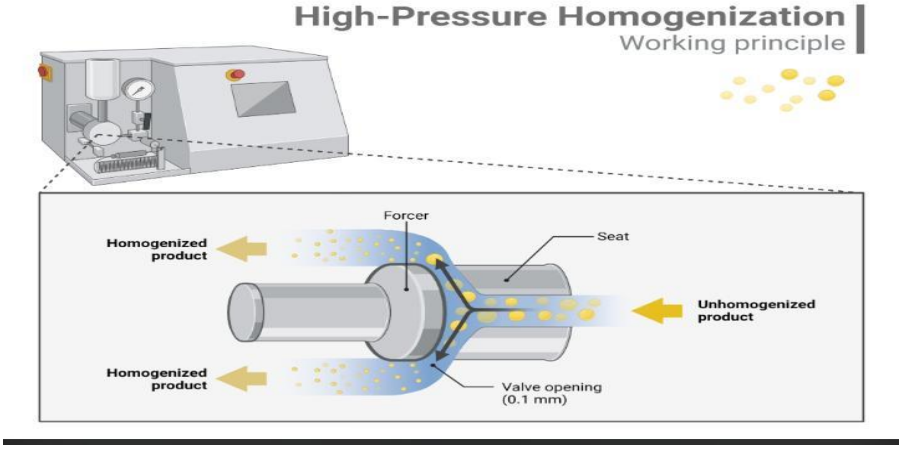

Figure 4 High Pressure Homogenization.

pressure homogenizer, and finally homogenized at high pressure for 10 to 25 cycles until the desired-sized nanosuspensions are formed. Different technologies are developed based on this idea for preparations of nanosuspensions are Disso cubes, Nanopure, Nanoedge and Nanojet.[26]

2.2.5 Media milling (nanosystem or nanocrystal)

The technique was initially created by Liversidge et al. High-shear media mills or pearl mills are used in this process to create the nanosuspensions. A milling chamber, a milling shaft, and a recirculation chamber make up the media mill. Glass, zirconium oxide, or strongly cross-linked polystyrene resin are used to frame the milling medium. The milling media or pearls are rotated at a very high shear rate once the milling chamber is filled with the milling media, water, medication, and stabilizer.

The energy input needed to break the microparticulate drug into nanoparticles is provided by the high energy and shear forces produced when the drug and milling media are impacted. A time profile of 30 to 60 minutes is necessary for the unimodal distribution profile and mean diameter of less than 200. Both micronized and non-micronized drug crystals can be successfully processed using the media milling technique.

The quality of the dispersion shows very little fluctuation from batch to batch after the formulation and technique are perfected. Using the pearl milling process, a nanosuspension of naproxen with a mean particle size of 300–600 nm was created.[27]

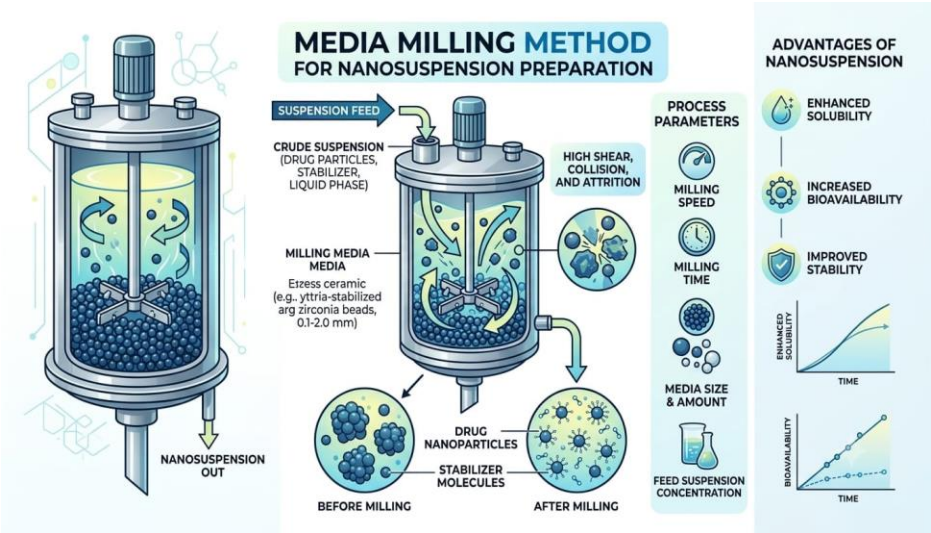

Figure 5: Media Milling Method.

2.2.6 Nano edge technology

The nanoedge process requires homogenization and precipitation Homogenization decreases crystal development and improveslong-term stability, addressing the primary shortcomings of precipitation. This process involves dissolving API in an organic solvent and then adding it to an anti-solvent that renders it insoluble. This causes drug particles to precipitate. Precipitation and homogenization are simultaneous processes. Concurrent precipitation and homogenization create nanosuspensions without crystal formation. Additionally, the stability of the created nanosuspension improves fast.[28]

Figure 6: Nano-edge Technology.

2.2.7 Super critical fluid extraction

The SCF approach is a sophisticated method used to manufacture NS that takes use of its special qualities to create particles with improved solubility, especially for medications that are poorly soluble in water. A supercritical antisolvent, the fast expansion of supercritical solutions, SCF extraction of emulsion, and the gas antisolvent method are some of the ways that the SCF methodology may be applied. There are clear benefits and drawbacks of using SCF methods to prepare NS. The solubility of chemicals in supercritical CO2 limits the use of the supercritical antisolvent approach, which permits control over particle size and is appropriate for thermolabile compounds. Although it is limited to chemicals that are extremely soluble in CO2 and may result in particle agglomeration, the rapid

expansion of supercritical solutions yields tiny, homogenous particles with little leftover solvent. Although it requires intricate and expensive multistep procedures, the SCF extraction of emulsion is an efficient method for creating nanosized particles with high drug loading. The SCF extraction of an emulsion in a microfluidic system using supercritical CO2 has been developed to improve the mass transfer of organic solvents. Finally, the gas antisolvent approach produces high-surface-area particles and is appropriate for large-scale manufacturing; however, it is not compatible with all solutes and solvents and may produce non-uniform particles.

Precise control over particle size and distribution, little to no solvent residues, relatively moderate temperatures that are appropriate for treating thermolabile chemicals, and simplicity of industrial scale-up are just a few of the benefits that the SCF approach offers in NS production. Surface-modified NPs were washed and dried using supercritical CO2. schematic illustration of NS preparation utilizing supercritical CO2.[29]

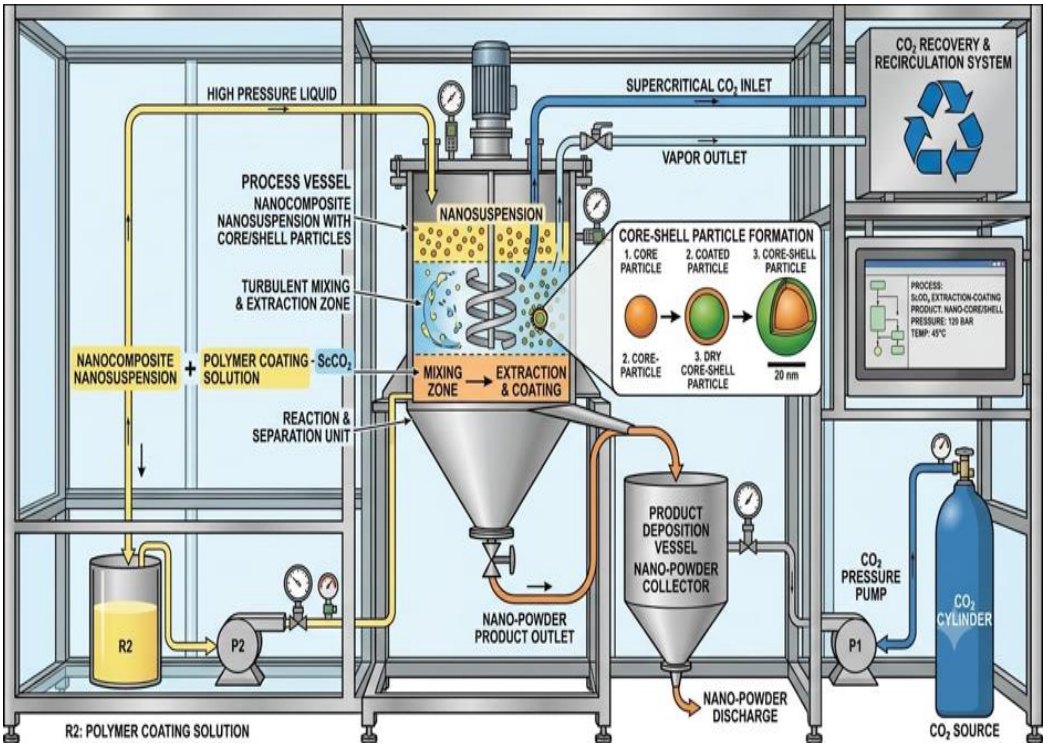

Figure 7: Supercritical Fluid Extraction.

2.3 PRE-FORMULATION STUDIES

To ascertain the properties of the medicine and excipients, pre-formulation studies were conducted, with a focus on the physicochemical, physicomechanical, and biopharmaceutical aspects.[30]

The basic method in the development of dosage forms of a medicinal agent is preformulation testing. The process of optimizing medication delivery and identifying the physicochemical characteristics of the novel compound that impact drug performance and the creation of an appropriate, stable, and safe dosage form is known as preformulation testing or study.[31]

2.4 FORMULATION OF NANOSUSPENSIONS

Basically, stabilizer or surfactant, an appropriate solvent solution, and additional ingredientsare needed for the manufacture of nanosuspension formulation.

2.4.1 Stabilizers

In order to provide a physically stable formulation, a stabilizer's primary purpose is to completely wet the drug particles and prevent Ostwald's ripening and agglomeration of nanosuspension by offering a steric or ionic barrier. The type and amount of stabilization has a considerable effect on the physical stability and in vivo behaviour of nanosuspension. Poloxomers, polysorbate, cellulosics, povidones, and lecithins are the stabilizers that have been employed thus far. If one wants to create a nanosuspension that is both autoclavable and acceptable to parents, lecithin is the preferred stabilizer.[32]

2.4.2 Organic solvent

When creating a nanosuspension using emulsions or microemulsions as a template, organic solvents are utilized. In the formulation, pharmaceutically acceptable less hazardous water miscible solvents like methanol, ethanol, chloroform, ispropanol, and partially water miscible solvents like ethyl acetate, ethyl formate, butyl lactate, triacetin, propylene carbonate, and benzyl alcohol are preferred over traditional hazardous solvents like dichloromethane.[33]

2.4.3 Other Additives
Uses of other compounds relies on either the method of administration or physicochemical qualities of candidate drug although some additives such as buffers, salts, polyols, osmogent and cryoprotectant are routinely utilized.[34]

3. EVALUATION OF NANOSUSPENSION

3.1 Particle size and polydispersity index (PDI)
Determines the mean particle diameter and homogeneity; a low PDI (<0.3) indicates a narrow distribution, while a smaller size enhances dissolution and bioavailability. determined using laser diffraction or dynamic light scattering (DLS).[35]

3.2 Zeta potential
Indicates surface charge and electrostatic stability (high absolute values help prevent aggregation); evaluated by electrophoretic light scattering. Typical objectives depend on stabilizer system (e.g., ±20–30 mV often considered stable.[36]

3.3 Drug content / assay
Verifies the precise amount of medication in the formulation and the percentage of medication recovered after processing using approved HPLC/UV techniques.[37]

3.4 Saturation solubility and apparent solubility
Shows how much solubility enhancement the nanosuspension delivers versus bulk drug; assessed by equilibrium solubility experiments (shake-flask) followed by testing.[38]

3.5 Viscosity and rheology
Impacts physical stability (sedimentation rate), pourability, and redispersibility. Use a rheometer or Brookfield viscometer to measure at the appropriate temperatures and shear rates.[39]

3.6 Ph
Important for drug stability and compatibility with route of administration; measured with pH meter and monitored during stability.[40]

3.7 Morphology (SEM/TEM)
SEM/TEM imaging supports DLS by providing visual confirmation of particle size, shape, and aggregate presence.[41]

3.8 Crystallinity / solid state (XRD, DSC)
detects amorphization or polymorphic changes brought on by precipitation or milling that have an impact on stability and dissolution.[42]

3.9 In vitro dissolution / release profile
fits release data to kinetic models and compares the release rate from nanosuspension versus raw drug (using USP equipment where necessary).[43]

3.10 Stability studies
To evaluate physical and chemical stability, short-term accelerated and long-term storage tests (particle size, PDI, zeta potential, drug content, appearance, pH, viscosity at predetermined intervals, and temperatures/humidity).[44]

3.11 Sedimentation volume / redispersibility
For suspensions, measure sedimentation behavior and capacity to redisperse with gentle shaking; note re-suspension time and any cake development.[45]

3.12 Microbial quality (if aqueous and for intended clinical use)
When necessary, follow pharmacopeial guidelines for sterility or microbiological limits testing.[46]

3.13 Tissue Distribution (Biodistribution)
Determines whether nano-sized crystals aggregate or target certain organs (for example, the mononuclear phagocyte system in the liver and spleen). Tissues are collected, processed, and evaluated using proven bioanalytical procedures that adhere to ICH S3A guidelines.[47]

3.14 Safety, Toxicity, and Biocompatibility
Preclinical safety profile tests confirm the absence of systemic and local irritation at the site of administration. These assessments adhere to the worldwide OECD Guidelines for Chemical Testing (e.g., OECD 423 for acute oral toxicity) as well as safety pharmacology concerns from ICH S7A and S7B.[48]

4. ADVANTAGE OF NANOSUSPENSION

* Improves the solubility and bioavailability of chemicals
* Ideal for hydrophilic substances.
* Increased drug loading is conceivable.
* Dose decrease is feasible.
* Increase the physical and chemical stability of medications
* Can be supplied by any route.
* Reduced tissue irritation with subcutaneous or intramuscular injection. Rapid disintegration and tissue targeting with IV injection.
* Increasing the amorphous proportion of particles can alter the crystalline structure and increase solubility.
* Large-scale manufacturing is conceivable.[49]

5. DISADVANTAGE OF NANOSUSPENSION

5.1 Physical instability
Particles may agglomerate, expand, or undergo Ostwald ripening during storage, reducing performance.[50]

5.2 Chemical instability
The large surface area can increase degradation such as oxidation or hydrolysis.

5.3 Stabilizers
Stabilizers are frequently necessary to avoid aggregation, and selecting the appropriate mix can be tricky.[51]

5.4 Costly production
Specialist equipment and process control are frequently required, making scale-up and manufacturing more costly.[52]

5.5 Limited applicability for some medications
Highly soluble pharmaceuticals or drugs with inadequate physicochemical qualities may not benefit much from this technique.[53]

5.6 Sterility and handling issues
Nanosuspensions may necessitate meticulous processing and packaging, particularly for injectable products.

5.7 Possible redispersion problems
Dried nanosuspensions can be hard to redisperse uniformly after lyophilization or spray drying.[54]

6. PHARMACEUTICAL APPLICATION OF NANOSUSPENSION

Through the preparation of postproduction, Because of its higher surface area and smaller particle size, nanosuspension speeds up medication absorption and dissolution.[55]

6.1 Oral administration Drug nanosizing increases oral absorption and, thus, bioavailability. Improved bioavailability is attributed to the adhesiveness of drug nanoparticles to the mucosa and the increased saturation solubility resulting to an increased concentration gradient between gastrointestinal tract lumen and blood. Both liquid and dry dosage forms, such as tablets or hard gelatin capsules containing pellets, can beemployeddirectlywithaqueous nanosuspensions. Nanosuspensions can also be spray-dried to create granulates.[56]

6.2 Pulmonary Drug Delivery
For pulmonary distribution, nanosuspensions can be nebulized by mechanical or ultrasonic nebulizers. Due to the existence of many tiny particles, all aerosol droplets include drug nanoparticles. For pulmonary administration, budesonide corticosteroid has been effectively produced as a nanosuspension.[57]

Due to the extremely small particle size, aqueous solutions of the medication are easily nebulized and administered by pulmonary route. Different types of nebulizers are available for the administration of liquid formulations. Budesonide, ketotifen, ibuprofen, indomethacin, nifedipine, itraconazole, interleukin-2, p53 gene, leuprolide, doxorubicin, and other medications have been effectively tested via the pulmonary route.[58]

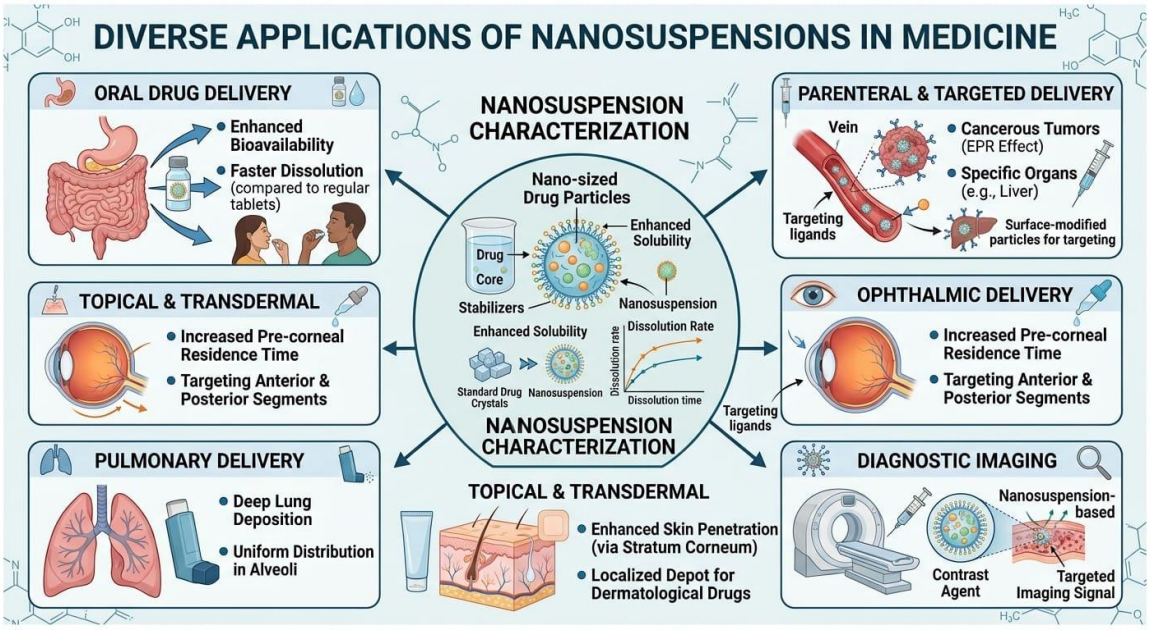

Figure 8 Applications of nanosuspension.

6.3 Parenteral Drug Delivery
The creation of intravenously given goods is one of the key uses of nanosuspension technology. Injectable nanosuspensions of the poorly soluble drug tarazepide have been prepared to overcome the limited success achieved using conventional solubilization techniques, such as the use of surfactants and cyclodextrins to improve bioavailability. These advantages include the ability to administer poorly soluble drugs without using a higher concentration of toxic co-solvents, improving the therapeutic effect of the drug available as conventional oral formulations, and targeting the drug to pathogenic microorganisms residing in macrophages.[59]

6.4 Drug Targeting
Because of their surface characteristics and the ease with which the stabilizer can change the in vivo behavior, nanosuspensions can also be employed for targeting. The

mononuclear phagocytic system will absorb the medication to enable administration that is targeted to a given area. If the infectious disease is intracellular, this can be utilized to direct anti-mycobacterial, fungal, or leishmanial medications to the macrophages.[60]

6.5 Ocular Drug Delivery

For conditions affecting the eyes, such as infections, inflammation, dry eye syndrome, glaucoma, and retinopathies, ocular medication delivery is the recommended method of administration. Because of the extremely low ocular medication bioavailability (often less than 5%), formulation scientists face difficulties due to the intricate structure and biology of the eye. Due to nanocrystals' quicker clinical development and commercialization than other nanotherapeutics like liposomes and dendrimers, the use of nanocrystals as an ocular formulation strategy for poorly water-soluble medications has become more popular recently.[61]

Improved ocular safety, better formulation retention in cul-de-sac, improved corneal permeability across the corneal and conjunctival epithelium, improved ocular bioavailability, dual drug release profile in the eye, and increased tolerability are all benefits of using nanocrystals for drug delivery to the eye.[62]

Produced Eudic nanosuspension. They noticed that the medication was more readily available in rabbit aqueous humor, and the formulation seemed to provide a viable way to increase the medication's bioavailability and shelf life following ocular administration.[63]

CONCLUSION

A useful and adaptable method for enhancing the administration of medications that are poorly soluble in water is nanosuspension technology. Nanosuspensions dramatically improve the dissolving rate, saturation solubility, and oral bioavailability of medications without changing their chemical structure by bringing the particle size down to the nanometer range. They are stabilized with appropriate surfactants and polymers to preserve physical stability and can be made utilizing a variety of top-down, bottom-up, or mixed methods.

Improved therapeutic efficacy, lower dose needs, quicker start of action, and flexibility for oral, parenteral, ophthalmic, pulmonary, and topical drug delivery are only a few benefits of nanosuspensions. Nanosuspensions are a viable platform for contemporary pharmaceutical development despite obstacles such physical instability, particle aggregation, and scale-up difficulty. This is due to ongoing improvements in formulation technologies and manufacturing methods.

All things considered, nanosuspensions are a significant tactic for improving the efficacy of poorly soluble medications and are becoming more and more popular in both commercial pharmaceutical products and research. Future advancements in large-scale manufacturing, quality-by-design (QbD), and nanotechnology are anticipated to broaden their applications, resulting in drug delivery systems that are safer, more efficient, and patient-friendly.

REFERENCES

1. Jacob S, Nair AB, Shah J. Emerging role of nanosuspensions in drug delivery systems. *Biomaterials Research*, 2020; 24: 3.
2. Sutradhar KB, Amin ML. Increasing Possibilities of Nanosuspension. *Journal of Nanotechnology*, 2013; 2013: 346581.
3. Patel VR, Agrawal YK. Nanosuspension: An approach to enhance solubility of drugs. *Journal of Advanced Pharmaceutical Technology & Research*, 2011; 2(2): 81–87.
4. Jadhav SP, Singh SK, Chawra HS. Review on Nanosuspension as a Novel Method for Solubility and Bioavailability Enhancement of Poorly Soluble Drugs. *Advances in Pharmacology and Pharmacy*, 2023; 11(2): 117–130.
5. Quadri N, Abdullah MM. Review on polyherbal nanosuspension and approaches to enhance solubility of drugs. World J. Pharm. Res., 2023 Apr 27; 10: 313-35.
6. Babu, V.R., Aleem, M.A., Nikhat, S.R., Aslam, S., & Khan, M. Nanosuspension Technology for Poorly Water Soluble Drugs: An Overview. Research Journal of Pharmacy and Technology, 2011; 4(4): 515–520.
7. Yadollahi R, Vasilev K, Simovic S. Nanosuspension technologies for delivery of poorly soluble drugs. Journal of Nanomaterials, 2015; 2015(1): 216375.
8. Saddam H, Abdul Baquee A, Jiban D. Nanosuspension: A promising drug delivery system for poorly water soluble drug and enhanced bioavailability. Int. J. Pharm. Sci. Res., 2020; 10: 4822-32.
9. Patravale VB, Date AA, Kulkarni RM. Nanosuspensions: a promising drug delivery strategy. Journal of pharmacy and pharmacology, 2004 Jul; 56(7): 827-40.
10. Ahmadi Tehrani A, Omranpoor MM, Vatanara A, Seyedabadi M, Ramezani V. Formation of nanosuspensions in bottom-up approach: theories and optimization. DARU Journal of Pharmaceutical Sciences, 2019 Jun 1; 27(1): 451-73.
11. Patravale, V. B., Date, A. A., & Kulkarni, R. M. (2011). Nanosuspension: An approach to enhance solubility of drugs. Journal of Advanced Pharmaceutical Technology & Research, 2(2): 81–87.
12. Guan W, Ma Y, Ding S, et al. The technology for improving stability of nanosuspensions in drug delivery. J Nanopart Res., 2022; 24(1): 14. doi:10.1007/s11051-022-05403-9.
13. Bilgili E, Guner G. Mechanistic modeling of wet stirred media milling for production of drug nanosuspensions. AAPS Pharm Sci Tech., 2021; 22(1): 1–23. doi:10.1208/s12249-020-01876-w.

14. Lynnerup JT, Eriksen JB, Bauer-Brandl A, Holsæter AM, Brandl M. Insight into the mechanism behind oral bioavailability-enhancement by nanosuspensions through combined dissolution/permeation studies. Eur J Pharm Sci., 2023; 184: 106417. doi:10.1016/j.ejps.2023.106417.
15. Perrin L, Pajor-Swierzy A, Magdassi S, Kamyshny A, Ortega F, Rubio RG. Evaporation of nanosuspensions on substrates with different hydrophobicity. ACS Appl Mater Interfaces, 2018; 10(3): 3082–3093. doi:10.1021/acsami.7b15743. Zuo W, Qu W, Li N, et al. Fabrication of multicomponent amorphous bufadienolides nanosuspension with wet milling improves dissolution and stability. Cells Nanomed Biotechnol, 2018; 46(7): 1513–1522.
16. Dos Santos AM, Meneguin AB, Fonseca-Santos B, et al. The role of stabilizers and mechanical processes on physico-chemical and anti-inflammatory properties of methotrexate nanosuspensions. J Drug Deliv Sci Technol., 2020; 57: 101638. doi:10.1016/j.jddst.2020.101638
17. Khandbahale SV. A review-Nanosuspension technology in drug delivery system. Asian J Pharm Res., 2019; 9(2): 130–138.
18. Xiang Y, Liang G, Alvaro P, et al. Resonant optical nonlinearity and fluorescence enhancement in electrically tuned plasmonic nanosuspensions. Adv Photonics Res., 2021.
19. Stahr PL, Keck CM. Preservation of rutin nanosuspensions without the use of preservatives. Beilstein J Nanotechnol, 2019; 10(1): 1902–1913. Arora D, Khurana B, Rath G, Nanda S, Goyal AK. Recent advances in nanosuspension technology for drug delivery. Curr Pharm Des., 2018; 24(21): 2403–2415.
20. Azimullah S, Sudhakar CK, Kumar P, et al. Nanosuspensions as a promising approach to enhance bioavailability of poorly soluble drugs: an update. J Drug Delivery Ther., 2019; 9(2): 574–582. Jin SM, Lee SN, Kim JE, et al. Overcoming Chemoimmunotherapy-Induced Immunosuppression by Assemblable and Depot Forming Immune Modulating Nanosuspension. Adv Sci., 2021; 8(19): 2102043.
21. Kovalchuk NM, Johnson D, Sobolev V, Hilal N, Starov V. Interactions between nanoparticles in nanosuspension. Adv Colloid Interface Sci., 2019; 272: 102020.
22. Galinovskiy AL, Htet KM, Provatorov AS. Ultra-Jet as a Tool for Dispersing Nanosuspensions. Polym Sci Ser D., 2020; 13(2): 209–213.
23. List, M.; Sucker, H. Pharmaceutical Colloidal Hydrosols for Injection. UK Patent GB2200048B, 6 February 1991. [Google Scholar].
24. Junyaprasert, V.B.; Morakul, B. Nanocrystals for enhancement of oral bioavailability of poorly water-soluble drugs. Asian J. Pharm., 2015; 10; 13–23.
25. Ran, Q.; Wang, M.; Kuang, W.; Ouyang, J.; Han, D.; Gao, Z.; Gong, J. Advances of combinative nanocrystal preparation technology for improving the insoluble drug solubility and bioavailability. Crystals, 2022; 12: 1200.
26. Zhang, J.; Xie, Z.; Zhang, N.; Zhong, J. Nanosuspension Drug Delivery System: Preparation, Characterization, Postproduction Processing, Dosage Form, and Application; Elsevier Inc.: Amsterdam, The Netherlands, 2017; 413–443.
27. Keck, C.M.; Müller, R.H. Drug nanocrystals of poorly soluble drugs produced by high pressure homogenisation. Eur. J. Pharm. Biopharm, 2006; 62: 3–16.
28. Pınar SG, Oktay AN, Karaküçük AE, Çelebi N. Formulation strategies of nanosuspensions for various administration routes. Pharmaceutics, 2023 May 17; 15(5): 1520.
29. Geetha G, Poojitha U, Khan KA. Various techniques for preparation of nanosuspension-a review. International Journal of Pharma Research & Review, 2014 Sep; 3(9): 30-7.
30. Lakshmi P, Kumar GA. Nanosuspension technology: A review. Int J Pharm Pharm Sci., 2010 Aug; 2(4): 35-40.
31. Jadhav SP, Singh SK, Chawra HS. Review on Nanosuspension as a Novel Method for solubility and bioavailability enhancement of poorly soluble drugs. Adv Pharmacol Pharm., 2023; 11(2): 117-30.
32. Byrappa K, Ohara S, Adschiri T. Nanoparticles synthesis using supercritical fluid technology - towards biomedical applications. Adv Drug Deliv Rev., 2008; 299-327.
33. Bachhav, A.A.; Ahire, S.A.; Jadhav, A.G. Preformulation Study of Piroxicam. Int. J. Pharm. Sci. Res., 2019; 10: 811–818.
34. Mastiholimath VS, Rajendra BA, Mannur VS, Dandagi PM, Gadad AP, Khanal P. Formulation and evaluation of cefixime nanosuspension for the enhancement of oral bioavailability by solvent-antisolvent method and its suitable method development. Indian Journal of Pharmaceutical Education and Research, 2020 Jan 1; 54(1): 55-67.
35. Lakshmi P, Kumar GA. Nanosuspension technology: A review. Int J Pharm Pharm Sci., 2010 Aug; 2(4): 35-40.
36. Muller RH. Zetapotential und Partikelladung–Kurze Theorie, praktische MeBdurchfuhrung, Dateninterpretation. Wissenschaftliche Verlagsgesellschaft, Stuttgart, 1996.
37. N Arunkumar, M Deecaraman and C Rani, Nanosuspension technology andits applications in drug delivery, Asianjournal of pharmaceutics, 2009; 168-173.
38. Keck CM, Müller RH. Drug nanocrystals of poorly soluble drugs produced by high-pressure homogenization. European Journal of Pharmaceutics and Biopharmaceutics, 2006; 62(1): 3–16.
39. Bhattacharjee S. DLS and Zeta Potential – What They Are and What They Are Not? Journal of Controlled Release, 2016; 235: 337–351.

40. Thongrakard V, et al. Development of a Resveratrol Nanosuspension Using the Antisolvent Precipitation Method. Pharmaceutics. 2020. USP General Chapter <621> Chromatography.
41. Higuchi T, Connors KA. Phase-Solubility Techniques. Advances in Analytical Chemistry and Instrumentation. 1965. OECD Guideline No. 105. Water Solubility.
42. Peltonen L, et al. Study of Rheology and Polymer Adsorption onto Drug Nanoparticles in Pharmaceutical Suspensions Produced by Nanomilling. Journal of Pharmaceutical Sciences, 2017; 106(11): 3395–3401.
43. Aulton ME, Taylor KMG. Aulton's Pharmaceutics: The Design and Manufacture of Medicines. 6th ed. Elsevier, 2021.
44. Van Eerdenbrugh B, et al. Downscaling Drug Nanosuspension Production: Processing Aspects and Physicochemical Characterization. AAPS PharmSciTech., 2009; 10(1): 44–53.
45. Chogale MM, Ghodake VN, Patravale VB. Performance Parameters and Characterizations of Nanocrystals: A Brief Review. Pharmaceutics, 2016; 8(3): 26.
46. Müller RH, Peters K. Nanosuspensions for the Formulation of Poorly Soluble Drugs. International Journal of Pharmaceutics, 1998; 160(2): 229–237.
47. Wang Y, Zheng Y, Zhang L, Wang Q, Zhang D. Stability of nanosuspensions in drug delivery. Journal of Controlled Release, 2013; 172(3): 1126–1141. (Comprehensive review on nanosuspension stability.)
48. Lachman L, Lieberman HA, Kanig JL. The Theory and Practice of Industrial Pharmacy. 3rd ed. Lea & Febiger, 1986.
49. European Pharmacopoeia (Ph. Eur.) Chapters 2.6.1 (Sterility) and 2.6.12 (Microbiological Examination).
50. Patil, A. S., Hegde, R., Gadad, P. M., Dandagi, P. M., Masareddy, R., & Bolmal, U. (2021). Exploring the Solvent-Anti-solvent Method of Nanosuspension for Enhanced Oral Bioavailability of Lovastatin. Turkish Journal of Pharmaceutical Sciences, 18(5): 514–549.
51. Pirincci Tok, Y., Mesut, B., Güngör, S., Sarıkaya, A. O., Aldeniz, E. E., Dude, U., & Özsoy, Y. (2023). Systematic Screening Study for the Selection of Proper Stabilizers to Produce Physically Stable Canagliflozin Nanosuspension by Wet Milling Method. Bioengineering, 10(8): 927.
52. Pawar SS, Dahifale BR, Nagargoje SP, Shendge RS. Nanosuspension technologies for delivery of drugs. Nanosci Nanotech Res., 2017; 4(2): 59-66.
53. Shahidulla SM, Miskan R, Sultana S. Nanosuspensions in pharmaceutical sciences: A comprehensive review. Situations, 2023 Jul; 8: 9.
54. Goel S, Sachdeva M, Agarwal V. Nanosuspension technology: recent patents on drug delivery and their characterizations. Recent patents on drug delivery & formulation, 2019 Jun 1; 13(2): 91-104.
55. REVIEW ON NANOSUSPENSION DRUGDELIVERY SYSTEMUmaRani.G, Lavanya.K, March 2024; 11(3).
56. Singh AK, Verma A, Jaiswal S, Mishra A, Khan I, Shukla H. Nanosuspension as Novel Drug Delivery Approach: A Review. Safety, 6: 8.
57. Verma AK, Bindal MC. Nanosuspensions: advantages and disadvantages. Indian Journal of Novel Drug Delivery, 2012; 4(3): 179-88.
58. Pu X, Sun J, Li M, He Z. Formulation of nanosuspensions as a new approach for the delivery of poorly soluble drugs Curr Nanosci, 2009; 5: 417–27.
59. Mathew M, Krishnakumar K, Dineshkumar B, Nair SK. Antibiotics nanosuspension: A review. J Drug Deliv Ther, 2017; 7: 128-31.
60. Hernandez-Trejo N, Kayser O, Steckel H, Muller RH. Characterization of nebulized bupravaquone nanosuspensions-Effect of nebulization technology J Drug Target, 2005; 13: 499–507.
61. Heidi MM, Yun-Seok R, Xiao W. Nanomedicine in pulmonary delivery Int J Nanomed, 2009; 4: 299–319.
62. Mishra S. Nanosuspension in advanced drug delivery. Int J AdvPharm Sci., 2017; 1: 56-65.
63. Narkhede K. A brief review on nano-pharmaceuticaltechnology. J Pharm Sci., 2015; 5: 520-8.
64. Reimondez-Troitin˜o S et al. Nanotherapies for the treatment ofocular diseases. Eur J Pharm Biopharm, 2015; 95: 279-293.
65. Malamatari M, Taylor KM, Malamataris S, Douroumis D, Kachrimanis K. Pharmaceutical nanocrystals: Productionby wet milling and applications. Drug Discov Today, 2018; 23: 534-47.
66. Mirza RM. A nanocrystal technology: To enhance solubility of poorly water soluble drugs. J Appl Pharm Res., 2017; 5: 1-13.