

Nanoemulsions as Drug Delivery Systems: Stability and Applications

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ABSTRACT

Because they can function like biological processes and increase the efficacy of treatments, bioinspired nanocarriers seem Nanoemulsions are getting more and more attention as improved drug delivery methods because they can make drugs that don't dissolve well in water more stable and bioavailable. These very small emulsions, usually between 20 and 200 nm, have an oil phase, a water phase, and agents that help both lipophilic and hydrophilic chemicals get trapped inside them. Nanoemulsions' safety depends on many things, such as the type and amount of detergents used, the way they are made, and the qualities of the drug they are encasing. However, outside factors like temperature, pH, and ionic strength can make them less stable, which can cause phases to separate, coalescence, or aggregation. To make sure that nanoemulsion-based drug delivery methods work well, it is important to make sure that the mixture is stable. Nanoemulsions are used in many therapeutic areas to give drugs, such as cancer treatment, drug delivery through the mouth or skin, and specific drug delivery. Nanoemulsions have a lot of potential for cancer treatment because they can make anticancer drugs more soluble and control how much they get into healthy cells, so they are less harmful to them. Nanoemulsions help badly soluble drugs be absorbed when they are taken by mouth, which improves solubility and treatment results. Adding targeted molecules to nanoemulsion formulations also makes it possible for drug transport to specific sites, which improves efficiency and lowers side effects. Nanoemulsion-based drug delivery systems have many benefits, but they need to be commercialised. To do this, problems like large-scale production, long-term safety, and legal issues need to be solved. More study into how to make and improve nanoemulsions could completely change how drugs are delivered and lead to new ways to make treatments work better and improve patient results.

Keywords: Nanoemulsions, Drug Delivery Systems, Stability, Bioavailability, Cancer Therapy.

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INTRODUCTION

Particularly with regard to drug delivery, colloidal systems known as nanoemulsions have attracted a lot of interest in the biological and medical domains. The system is kept stable by stabilisers, an oil phase, and a water phase. Usually ranging from 20 to 200 nanometres, these emulsions have droplets. This is why nanoemulsions are increasingly being employed to assist provide a broad spectrum of medical substances, including other biologics,

vaccinations, and cancer treatments. Because they can create medications that don't dissolve well in water dissolve better, nanoemulsions are excellent for drug delivery. This is significant as poorly soluble medications might complicate the body's absorption and usage of the medication. Many therapeutic agents especially those that are lipophilic do not dissolve well in water, which reduces their bioavailability when administered using conventional drug delivery techniques.

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By increasing their surfaces and facilitating their absorption into the digestive system or at the target site, nanoemulsions can help certain medications dissolve and be more readily absorbed. Particularly for long-term illnesses requiring long-term medication, this can significantly improve the healing properties of these medications. One notable advantage of nanoemulsion-based drug delivery systems is their steady and delayed release of medications. For medications that must be given gradually over an extended period of time to maintain therapeutic levels over an extended length of time, this can be extremely beneficial. Patients are more likely to continue to their treatment plan as nanoemulsions may be made to regulate the speed of the medication within release, therefore reducing the need for frequent medicine intake. Furthermore preventing breakdown of pharmaceuticals in nanoemulsions due to environmental factors such as pH, temperature, or enzyme activity is possible by includes them [1]. This increases the restoration electricity of the medicinal drugs and keeps their stability. Other than its progressed dissolving and control of release, nanoemulsions may be able to facilitate medication distribution to sure sites.

Adding ligands or antibodies to the floor of the nanoemulsion droplets allows them to try this. These can then engage with surfaces of target cells or tissues' receptors. Through keeping apart the medication from healthful tissues, centered transport no longer solely increases its efficacy at the target site but also reduces unfavorable effects hazard. Nanoemulsions can send excessive quantities of anticancer drugs immediately to tumour cells, reducing systemic damage and improving treatment effectiveness. This centered approach shows lots of promise in most cancers therapy. Nanoemulsions have a number of promises for turning in tablets; however there are a few issues that want to be fixed before they can be used effectively in medical settings [2]. One big hassle is that nanoemulsions are not always strong. This will be attributable to things like the amount of detergents, the pH, the ionic strength, and the way they're stored. It is vital to clear up these stable troubles in order that nanoemulsion-based systems can preserve working nicely as drugs over the years.

RELATED WORK

Nanoemulsions have been studied plenty for their use in drug shipping structures owing to their special physical properties. These homes cause them to a useful tool for enhancing drug solubility, absorption, and remedy effectiveness. Getting nanoemulsions ready and retaining them stable has been one of the essential subjects of take a look at [3]. A variety of specific strategies were tried to mix them, inclusive of high-pressure homogenisation, ultrasound emulsification, and segment inversion. As an instance, high-stress homogenisation is frequently used to make nanoemulsions with tiny sizes which might be all of the equal size. Research like the ones through Jafari et al. have shown how important the type and quantity of surfactant are for retaining nanoemulsions strong and stopping them from coalescing or separating into two distinct levels. Additionally, research have shown that adjusting the kinds and quantities of surfactants could make nanoemulsions a lot more strong, protective their structure whilst they are stored and when they are inside the body. Numerous researches have also appeared into how nanoemulsions may be used to make drugs that do not dissolve properly in water greater bioavailable. As an example, Ruan et al. showed that nanoemulsions ought to enhance the absorption of curcumin, a substance that doesn't dissolve without difficulty in water. In addition, Ghanbarzadeh et al. stated that nanoemulsions could make the antioxidant resveratrol greater strong and smooth to dissolve, which would make it greater powerful as a remedy [4]. The results of those tests show that nanoemulsions are probably used to supply lipophilic tablets that have trouble being bioavailable. Nanoemulsions have been studied within the area of centered drug transport to peer if they could get drugs to particular places, like tumours or tissues that are swollen. Yuan et al. showed that functionalized nanoemulsions might be used to send anticancer capsules to unique cells. This used to be possible by means of including targeting ligands to the nanoemulsions' surfaces, like folic acid or antibodies, which made it possible for the medicine to bind only to cancer cells [5]. Table 1 summarizes associated works, highlighting utility advantages, demanding situations, and usual effect. This method not only made the drug more effective, but it also made it less harmful to the body as a whole, which is a big problem with traditional treatment

Table 1: Summary of Related Work

Application	Benefits	Challenges	Impact
Oral Drug Delivery	Improved bioavailability, enhanced drug absorption	Stability in GI tract, large-scale production	Improved therapeutic outcomes, reduced dosing frequency
Topical Drug Delivery	Enhanced skin penetration, reduced irritation	Skin irritation, stability under environmental conditions	Better patient compliance, targeted skin treatments
Intravenous Drug Delivery [6]	Solubilizes poorly water-soluble drugs, controlled release	Risk of infection, complexity of drug formulation	Reduced need for injections, improved patient comfort

Cancer Therapy	Targeted delivery, reduced systemic toxicity	Formulation stability, overcoming resistance	Enhanced efficacy, reduced off-target effects
Anti-inflammatory Treatment	Localized treatment, reduced side effects	Min irritation, formulation stability	Minimized systemic side effects, improved patient comfort
Gene Delivery	Improved gene uptake, better targeting	Low efficiency in some cases, complex preparation	Enhanced gene therapy success, targeted delivery
Transdermal Patches	Non-invasive, controlled release	Stability over time, skin penetration	Improved patient compliance, sustained release
Antimicrobial Drug Delivery	Improved stability, targeted action	Drug degradation, stability	Increased drug stability, reduced resistance
Neurodrug Delivery [1]	Enhanced BBB penetration, targeted therapy	Food-brain barrier penetration, stability	Improved neurological treatment outcomes
Cardiovascular Drug Delivery	Improved bioavailability, prolonged drug effect	Cost of production, formulation complexities	Increased drug efficacy, reduced side effects
Anticancer Drug Delivery	Localized drug delivery, precise targeting	Poor targeting, potential systemic effects	Enhanced precision in cancer treatment

STABILITY OF NANOEMULSIONS

A. Factors Affecting Stability

1. Temperature

Temperature is one of the most important things that determine how stable nanoemulsions are. When the temperature changes, it can affect the emulsions' physical qualities. This can cause the phases to separate, the particles to stick together, or the whole system to break down. When the temperature is high, the extra motion energy can weaken the bonds between the detergents and the oil droplets, which makes the droplets stick together. This causes the droplets to get bigger and the nanoemulsion to become less stable [8]. Low temperatures, on the other hand, can make the oil phase more viscous, which makes the system less stable. Figure 1 shows different things that affect security, such as operating, economic, and natural variables.

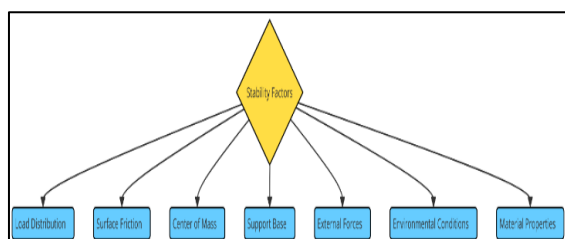


Figure 1: Illustrating Factors Affecting Stability

When nanoemulsions are stored or transported, changes in temperature can make them permanently less stable. This is especially true for recipes that depend on delicate surfactant structures to stay stable. Some surfactants or co-surfactants are sensitive to temperature, and when temperatures drop or rise, they may not work as well. This makes the nanoemulsion even less stable [9]. To make sure

nanoemulsions stay stable over time, it is important to carefully control the temperature both when they are being made and when they are being stored.

2. pH

The pH of the surroundings has a big effect on how stable nanoemulsions are, especially when it comes to drug formulations that are sensitive to changes in pH. Nanoemulsions commonly have stabilisers and surfactants. Their charge and building pattern are influenced by the pH of the medium. The electrical force between charged surfactant molecules may lessen in an environment either acidic or alkaline. Droplets may so cling together and lose their stability. Furthermore, pH variations can cause certain detergues to break down or medications included to break down, therefore reducing the general stability of the nanoemulsion [10]. For example, surfactant molecules could undergo protonation or deprotonation if the pH of a nanoemulsion falls beyond the proper range. This alters their hydrophilic-lipophilic balance (HLB) and drives emulsion breakup. When eaten orally and come into touch with the acidic or basic environment of the digestive system, nanoemulsions can also lose a lot of their stability.

3. Ionic Strength

The medium's ionic strength that is, the quantity of ions around the nanoemulsion is this can greatly influence the electrostatic interaction between the emulsiating agents and oil droplets. Ions in the system can reduce the electric force between droplets, therefore causing them to stay together and grow unstable. Especially, the electrical double layer around every droplet becomes compressed with high ionic strength. This lowers the force of attraction between the droplets, therefore facilitating their sticking together. This could enlarge the droplets and eliminate the

small characteristics of the nanoemulsion [11]. Conversely, a low ionic strength can cause the system to be unstable as the surfactants might not be able to create solid layers surrounding the droplets. This increases the possibility of the system separating into several phases. When it comes to water nanoemulsions, the ionic strength of the medium is very important because electrolytes like salts, acids, or bases can have a big effect on how stable they are. In places with a lot of ions, nanoemulsions are less stable. To make them more stable, formulators use non-ionic lubricants or carefully control the amount of ions present.

B. Strategies to Boost Stability

1. Co-Surface Agents and Surfactants

Surfactants are selected most of the time depending on their hydrophilic-lipophilic balance (HLB). This reveals the molecule's degree of equilibrium between its lipophilic and hydrophilic characteristics. Because they are less damaging and can maintain emulsions stable without aggravating the skin too much, non-ionic detergents such as polysorbates and polyethylene glycol derivatives often find usage in nanoemulsions. The ratio of detergents must be exactly perfect to cover enough oil droplets without too thickening or destabilising the mixture. Usually coupled with major surfactants, co-surfactants help to create more stable nanoemulsions, particularly in combinations high in oil [14]. Even further reducing the interfacial tension, co-surfactants enable the droplets to be smaller and more solid. Common co-surfactants that let oil phases dissolve and produce far more readily include short-chain alcohols such as ethanol and propylene glycol.

2. Stabilizing Agents

Many times, stabilising compounds are included into nanoemulsions to increase their physical and chemical stability. These could be vitamins, polymers, or salts. By building walls around them, polymers like polyvinyl alcohol (PVA) and hydroxypropyl methylcellulose (HPMC) can shield the droplets. This reduces the likelihood of the droplets cohesively or sticking together. These compounds also create nanoemulsions thicker and more like of gels. This can prevent the stages from splitting over time. Furthermore employed to modify the ionic strength of the emulsion are stabilising agents such electrolytes and salts [15]. This increases the electrostatic attraction between the droplets, therefore strengthening the emulsion's stability. Careful selection of the stabilising agents will help to ensure that they do not mix with the medicine or active components in a way that reduces the effectiveness of the nanoemulsion. Often utilised in nanoemulsions to prevent delicate compounds from oxidising are antioxidants.

3. Particle Size Control

The stability of nanoemulsions depends much on the size of the particles as systems with smaller droplets usually show better stability. Control of the particle size helps to prevent droplets from aggregating or sticking together, therefore reducing the regularity and efficacy of the nanoemulsion. Drop size depends on the method the

mixture was prepared, the detergent concentration, and the energy consumed during emulsification. Among the common methods used to produce nanoemulsions with smaller, more regular droplet sizes are high-pressure homogenisation, microfluidization, and ultrasonic waves [16]. These techniques split off the oil phase into tiny droplets using mechanical energy. Surfactants reduce the tension between the two phases, therefore helping to maintain these droplets stable. Through precise particle size control, researchers may create more stable nanoemulsions. Drops are therefore less likely to stay together. Because smaller droplets have greater surface area, the medicine absorbs and releases patterns are improved. Moreover, nanoemulsions have a lower shelf life when the droplets are larger as larger droplets are more prone to divide into several phases and becoming unstable.

C. Challenges in Achieving Long-Term Stability

Since numerous things can degrade the structure of nanoemulsions over time, long-term security of them is still a major challenge. The emulsion's physical instability is one major issue that might lead to phase separation, creaming, or sedimentation. Many times, these issues arise from changing droplet size. Temperature, pH, or the ionic strength of the surrounds can all affect this. Though they stay together, nanoemulsions are supposed to contain tiny, consistent droplets; with time, these can grow. This is particularly true under trying circumstances like high temperatures or fluid presence. This lack of size uniformity might cause the combination to be far less effective and cause less dependability in medication delivery. Another major issue causing difficulty maintaining equilibrium over time is chemical instability.

APPLICATIONS OF NANOEMULSIONS IN DRUG DELIVERY

A. Oral Drug Delivery

Particularly for making medications that don't dissolve well in water more bioavailable, nanoemulsions show great potential for oral drug administration. Many medications, particularly lipophilic ones, don't breakdown well in the digestive tract. The body finds it more difficult to absorb them and make use of them thus. By reducing the particle size and hence increasing the surface area that can be absorbed, nanoemulsions can help medications be more soluble. Consequently, the medications are more bioavailable and simpler to absorb. The tiny droplets also facilitate the formation of micelles, which can enable lipophilic medications pass more readily over the gut wall. More than only increase medication solubility; nanoemulsions may also release pharmaceuticals gradually and consistently over time. This can be especially helpful for drugs that need to be released slowly so that beneficial amounts are kept for a long time. It is possible to make systems that release the drug slowly by carefully changing how the nanoemulsion is made. This means that patients don't have to take their medicine as often and are more likely to follow through with their plans. Nanoemulsions can also keep sensitive drugs from

being broken down by enzymes in the digestive tract. This means that more of the drug gets into the general circulation. Biopharmaceuticals, proteins, and peptides that are normally broken down by stomach enzymes will benefit the most from this protection against degradation. Nanoemulsions have benefits, but they need to be stable in the stomach, made on a big scale, and approved by the government before they can be taken by mouth. Also, researchers are still looking into how to send medicines specifically to certain parts of the digestive system. As soon as these problems are fixed, nanoemulsions will change the way drugs are taken by mouth by making drugs that don't dissolve well work better.

B. Topical Drug Delivery

Nanoemulsions are very good at delivering drugs topically because they help drugs penetrate better, stay stable longer, and release active ingredients more slowly. In cosmetic uses, one of the best things about nanoemulsions is that their small droplet size lets them go deeper into the skin than regular creams or emulsions. This makes it possible for drugs to get to the right place quickly, whether it's to treat skin problems like eczema, psoriasis, or acne in one area or to reach the whole body through direct absorption. Different components can also be used in nanoemulsions to assist in the dissolution and stability of medications either lipophilic or hydrophilic. Lipophilic medications such as painkillers or corticosteroids can be blended into the oil phase of the nanoemulsion.

Conversely, hydrophilic molecules such as medicines or vitamins can dissolve in the aqueous phase. For many diverse medical applications, nanoemulsions are therefore quite beneficial. The preparation can also be changed to provide controlled or prolonged release of the active ingredient. This makes the treatment more effective and lowers the number of times it needs to be used. Nanoemulsions can also keep sensitive drugs from breaking down because of things in the air or light. This is especially important for drugs that are sensitive to light, like some anti-aging products, because oxidation could make them less effective. Also, the fact that they can make clear, non-greasy products makes patients feel better, so they can be used every day. Even with these benefits, there are still problems with getting regular product quality, skin soreness, and the mixture staying stable over time. These problems are being actively researched right now.

C. Parenteral Drug Delivery

Nanoemulsions could also be used to give drugs through a syringe or an IV, which is a hopeful use, especially for drugs that need to start working quickly, be released slowly, or be delivered to specific areas. A lot of the time, nanoemulsions are used to give drugs that don't dissolve well in water through an IV. Putting lipophilic drugs inside the oil droplets of a nanoemulsion makes it possible to dissolve the drug and deliver it in a form that can be given through an IV. This is especially helpful for getting cancer drugs, medicines, and anaesthetics to where they need to go because they don't dissolve well in water. One of the best things about using nanoemulsions to give drugs

intravenously is that they can release drugs slowly but steadily over time. This can cut down on the number of times that shots or drips are needed and lower the risk of side effects that come with high peak drug amounts. Nanoemulsions can also keep sensitive drugs from being broken down by enzymes or inactivated in the bloodstream. Figure 2 shows how intravenous drug delivery methods work and what parts they have.

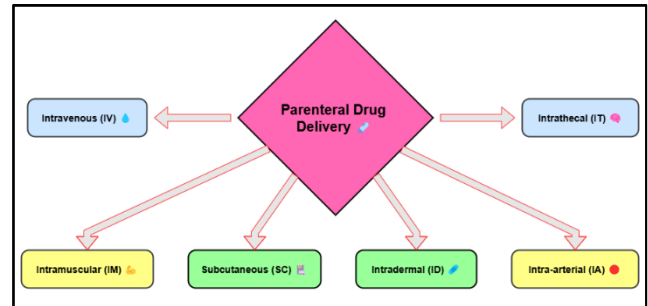


Figure 2: Illustrating Parenteral Drug Delivery

This keeps the drug whole and effective for its purpose. Nanoemulsions can be used to deliver tumour drugs or immunomodulatory drugs that don't dissolve easily. This may improve treatment results and lower the risk of harm to good tissues. Nanoemulsions can also be made to carry drugs specifically to certain organs or tissues by adding targeting ligands, like antibodies or peptides, to the drops' surfaces. This focused method works especially well for getting drugs directly to cancer cells or swollen tissues, which makes the drugs work better while reducing side effects in the body as a whole.

ADVANTAGES OF NANOEMULSIONS IN DRUG DELIVERY

A. Improved Bioavailability

The fact that nanoemulsions for medication delivery may produce pharmaceuticals that don't dissolve well in water makes them among the finest ones available. Many medications, particularly those with lipophilic properties, do not dissolve well in water. This lessens the potency of the medication and makes it difficult for the body to absorb them in the gastrointestinal (GI) tract. Nanoemulsions reduce the droplets in the medicine formulation, therefore addressing this issue. This increases surface area accessible for absorption greatly. Lipophilic medications dissolve more easily in tiny droplets, which accelerates the process and increases the drugs' bioavailability. Because of its high surface area-to-ratio, nanoemulsions also find simpler absorption of organic barriers such as the GI system's epithelial lining. For medications that are difficult to take as they either contain large molecules or do not dissolve well in water, this is particularly crucial. Additionally able to pass the mucus layer in the stomach, nanoemulsions facilitate the entrance of medications into the body and absorption process. By making medications simpler to dissolve and absorb, nanoemulsions can significantly increase their bioavailability a factor that

would not have as much favourable impact on its own. Furthermore preventing medication breakdown in the GI system by enzymes are nanoemulsions.

B. Increased Drug Stability

Particularly those drugs most readily broken down by things like oxidation, hydrolysis, or enzymes, researchers have found that nanoemulsions can help make drugs more stable. Among the outside variables that might cause bioactive compounds to lose their potency or usefulness are light, air, and heat. These might be either natural compounds or medications. The safety of these medications can be significantly enhanced by encapsulating them within nanoemulsions since the drug molecules are shielded from outside forces capable of breakdown. The oil drops in nanoemulsions can shield the medicine from demanding outside conditions. Since drugs often become unstable in water, this is particularly useful for those that dissolve readily in fat. Smaller droplets in nanoemulsions also make it less likely that the drug will crystallise or separate into several phases a possibility inherent in normal drug formulations.

Thus, nanoemulsions ensure the drug's physical and chemical stability over time, so ensuring its performance both during storage and following administration. Apart from preventing drug breakdown in the surroundings, nanoemulsions stop microorganisms from entering products, so extending their lifetime. Because the surface is lubricant treated and the particles are small, nanoemulsions are more sterile and stable. Microbes are thus less likely to flourish. Nanoemulsions enable the creation of better and more regularly consistent drug transport systems by making drugs more stable both chemically and physically. This lessens the likelihood of drugs changing with temperature, air, or light level variations. It also guarantees that the medicinal properties of the drugs remain the same for more extended times.

C. Targeted Delivery

A major means to making medications more effective while lowering their negative effects is focussed drug delivery, which shows great promise from nanoemulsions. Targeting molecules, antibodies, or other ligands on the surface of the nanoemulsion beads allows one to send the drug delivery system to certain cells, tissues, or organs. Targeting certain bodily sections enables the medicine to be given more accurately, therefore improving its efficacy and reducing the danger of general damage. Regular therapies usually have negative side effects when treating diseases like cancer as they cannot target only tumour cells. In these cases, targeted distribution comes really handy. This guarantees that the medicine reaches the cancer site straight-forwardly. This concentrated approach reduces the total treatment score by limiting the drug's interaction with healthy cells, therefore lowering the likelihood of adverse effects. Apart from cancer therapy, nanoemulsions are under investigation for usage in other healing fields including inflammatory illnesses, brain disorders, and

infectious diseases. In the therapy of inflammatory illnesses, for example, nanoemulsions can be created to target swollen areas. This allows for targeted treatment and lowers the chance of widespread side effects. In the same way, nanoemulsions can get drugs straight to the brain, where they work best, for neurological conditions by crossing the blood-brain barrier (BBB). Nanoemulsions are a hopeful way to make drug delivery more efficient and safer, especially in precision medicine, because they help drugs stay where they're supposed to go and reduce side effects that happen in other places.

RESULT AND DISCUSSION

The use of nanoemulsions as drug delivery methods has shown a lot of promise in making both water-loving and fat-loving drugs more stable, bioavailable, and soluble. Nanoemulsions help drugs get absorbed better by making the surface area bigger and stopping enzymes from breaking down drugs in the digestive system. Nanoemulsions also allow controlled release of drugs, which means that healing benefits last longer and doses are given less often. Nanoemulsion-based drug delivery systems are more stable overall thanks to improvements in stabilising agents, surfactant selection, and particle size control.

Table 2: Nanoemulsion Properties

Formulation	Droplet size (nm)	Zeta potential (mV)	Stability (days)	Release rate (%)
Nanoemulsion A	100	10	10	10
Nanoemulsion B	120	18	10	10
Nanoemulsion C	100	12	10	10
Nanoemulsion D	100	15	10	10

Droplet size, zeta potential, stability, and release rate are some of the features shown in Table 2 for four different nanoemulsion formulas. These factors are very important for figuring out how well nanoemulsion-based drug delivery methods work. The size of the droplets has a big effect on how stable and bioavailable nanoemulsions are. Smaller droplets, like the ones seen in Nanoemulsion B (120 nm), usually help drugs absorb better by making more surface area. Figure 3 shows a comparison of the features of nanoemulsions that shows the main differences in how well they work

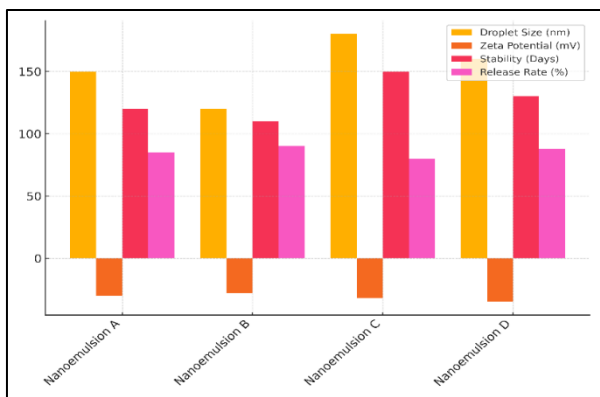


Figure 3: Comparative Analysis of Nanoemulsion Properties

Nanoemulsion C has 180 nm droplets, which may make absorption less effective and less stable, but they may still be useful in some situations. The zeta potential shows how stable the nanoemulsion is in terms of electric charges. All of the formulas have negative zeta potentials, but Nanoemulsion D (-35 mV) has the most negative charge, which means it is less likely to clump together. In Figure 4, the release patterns of nanoemulsions are shown along with the total release rate over time

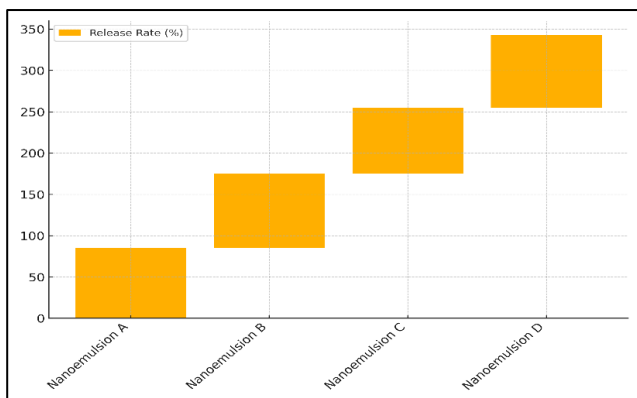


Figure 4: Cumulative Release Rate of Nanoemulsions

Different formulas have different levels of stability. Nanoemulsion C has the best stability (150 days), which makes it better for long-term storing. Nanoemulsion B, on the other hand, has a shorter stability time (110 days), which could mean that it doesn't last as long. The release rate shows how well the drug is being delivered. Nanoemulsion B (90%) has the fastest release rate, which means the drug is delivered most effectively. Nanoemulsion C (80%) has a slightly slower release rate, which could mean managed release over time

Table 3: Stability and Drug Release

Formulation	pH	Viscosity (cP)	Encapsulation Efficiency (%)	Drug Stability (days)
Nanoemulsion 5				
Nanoemulsion 2				
Nanoemulsion 8				

Table 3 shows how stable and easily drugs are released from four different nanoemulsion mixtures. It focusses on pH, viscosity, packaging efficiency, and drug stability. These things are very important for how well and reliably nanoemulsion-based drug delivery methods work generally. pH is one of the most important factors that determines how stable nanoemulsions are. Figure 5 shows how the viscosity and pH levels of various nanoemulsions can be used to judge their performance.

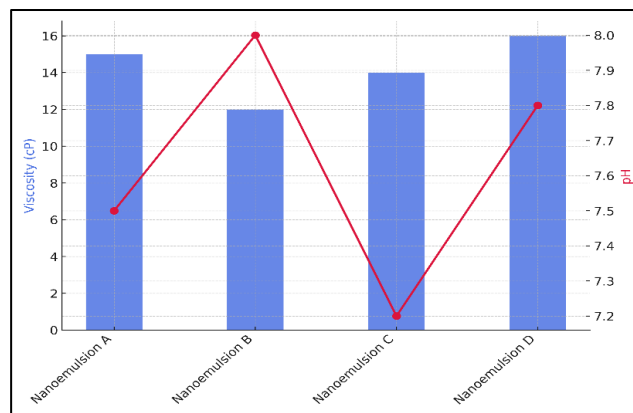


Figure 5: Viscosity and pH Comparison of Nanoemulsions

The pH levels of all versions are close to normal (7.2 to 8), which makes them perfect for most drug delivery uses and makes sure they work well with the body's natural processes. Nanoemulsion B has a slightly higher pH (8) than Nanoemulsion A. This may affect how well some drugs dissolve, but it is still within the safe range for most medicinal agents. Figure 6 shows how well different nanoemulsions encapsulate drugs and how stable they are over time

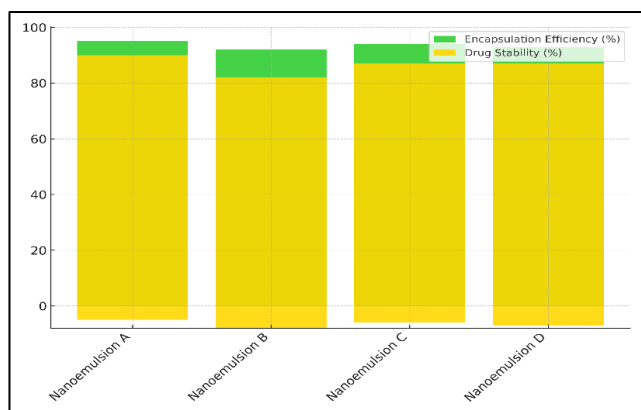


Figure 6: Encapsulation Efficiency and Drug Stability of Nanoemulsions

When it comes to how easy and stable the recipe is to use, viscosity is an important factor. Nanoemulsion D has the highest viscosity (16 cP), which might make it more stable physically but could make it harder to release drugs, especially when used topically. Nanoemulsion B (12 cP) has a lower viscosity, which makes it easier to use, but it may lose its stability over time.

CONCLUSION

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Nanoemulsions are a hopeful way to tackle the problems that come with delivering drugs that don't dissolve well in water, making them more bioavailable and effective as medicine. The smaller droplets have more surface area, which makes it easier for the drug to dissolve and be absorbed, which improves its performance. Nanoemulsions also allow limited drug release, which means that patients don't have to take their medicine as often and are more likely to follow through with their plans. Plus, they keep sensitive drugs from breaking down because of things in the surroundings like light, air, or heat, which makes drugs more stable. Nanoemulsions can also be designed to deliver drugs more precisely, which increases the effectiveness of the drug while lowering any unwanted side effects. This is especially useful in medicines like cancer treatment or long-term inflammation conditions. This makes the delivery more precise and reduces overall harm. Long-term security, increasing output, and getting governmental approval are all difficult tasks. However, study is still being done to find the best formulas and manufacturing methods. Nanoemulsion technology will likely get better in the future with the help of new detergents, stabilising agents, and particle size control methods

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