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Review Article

A Detailed Review on Pharmaceutical Applications of Pickering Emulsion

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ABSTRACT

Pickering emulsions, stabilized by solid particles rather than traditional surfactants, have gained significant attention in the pharmaceutical field for their unique physicochemical properties and enhanced stability. These emulsions offer a biocompatible and environmentally friendly platform suitable for various drug delivery applications, including oral, topical, and parenteral routes. Their ability to encapsulate both hydrophilic and hydrophobic drugs, protect sensitive bioactive, and provide controlled and targeted release makes them highly versatile. Recent advancements in the design of biopolymer- and nanoparticle-stabilized Pickering emulsions have further expanded their potential for improving drug solubility, bioavailability, and therapeutic efficacy. This review highlights the current developments, mechanisms, and future prospects of Pickering emulsions in pharmaceutical formulations, underscoring their promise as a next-generation drug delivery system.

INTRODUCTION

A biphasic system is a system consisting of two immiscible phases commonly liquid-liquid or solid-liquid that are stabilized together to form a single dosage form. The different types of biphasic system include: Suspensions (solid in liquid), Emulsions (liquid in liquid), Gels with suspended particles, and Liposome-based systems (aqueous core in lipid bilayer). An emulsion is a biphasic liquid dosage form composed of two immiscible liquids in which an emulsifying agent aids in one liquid (the dispersed phase) dispersed as tiny droplets in another liquid (the continuous phase)[1]. Emulsions are primarily classified based on the nature of the dispersed and continuous phases. In oil in water emulsion, the oil droplets are dispersed in water. Water is the continuous phase. It is common for oral and injectable formulations.

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Common examples are milk, intravenous lipid emulsions. Water droplets are dispersed in oil phase in water in oil emulsion. Here oil is the continuous phase. Common in topical and external application like cold creams, ointments. Multiple Emulsions are complex systems in which one immiscible liquid is dispersed within another liquid, and each droplet of the dispersed phase contain another emulsion within it. They can be either water in oil in water or oil in water in oil systems. Used for controlled drug delivery or masking taste. Microemulsions are thermodynamically stable, transparent and isotropic systems. The Droplet size ranges from 10–100 nm. These microemulsions are stabilized using co-surfactants and surfactants. These systems have better drug solubilization and absorption.[1]

Pickering Emulsion

Pickering emulsion is a type of emulsion which is stabilized by solid particles instead of conventional surfactants or emulsifiers. These solid particles absorb at the oil-water interphase and thus creates a mechanical barrier that eventually prevents coalescence of droplets.[2,3] The concept of pickering emulsion dates back over a century, and found its greatest application in the recent decades because it is sustainable and surfactant-free systems. In 1903, Walter Ramsden first observed the phenomenon of solid particles adsorbing at oil-water interphase, later he published a paper entitled "Separation of solids in the surface-layers of solutions and suspensions". He observed that, certain solid particles can adsorb to liquid interphase and prevent coalescence of droplet, however, his work did not gain popularity at that time. In 1907, S.U. Pickering, a British chemist published a comprehensive study entitled "Emulsions" in the journal of chemical society. He contoured how fumed or precipitated solids stabilized emulsion without the use of any surfactants. This led to the naming of this emulsion as pickering emulsions, even though the concept was first described by Walter Ramsden. Sometimes these emulsions are a referred as Ramsden emulsion. For a long time, Pickering emulsions did not find any practical applications since traditional surfactants ruled food, cosmetics and pharmaceutical industries. Pickering emulsions gained renewed attention in the 21st century with the growing demand for eco-friendly, biocompatible and surfactant-free products as well as nanotechnology and green chemistry. Now it is widely applied in the field of pharmaceuticals, cosmetics, food and material science.[4] In an ordinary emulsion, surfactants stabilize the oil and water phase by lowering the interfacial tension, but in case of pickering emulsion, the traditional surfactants are replaced by solid particles, which adsorb physically at the interface of droplets to stabilize it. Mechanism of stabilization of pickering emulsion can be particle adsorption, interfacial attachment, or barrier formation. In particle adsorption solid particles attach irreversibly to the oil-water interface the particles must have intermediate wettability i.e., it should be neither too hydrophobic nor too hydrophilic. In interfacial attachment, particles once attached, reduce interfacial energy and form a dense layer around the droplets, preventing their fusion or coalescence. In barrier formation, the solid particle layer prevents coalescence by providing steric hindrance and electrostatic repulsion. The emulsion is free from creaming, coalescence or Ostwald ripening due to strong particle network.[3]

Mechanism Of Stabilization by Solid Particles

Pickering emulsions are stabilized not by surfactants, but by solid particles that adsorb at the oil-water interface. The stabilization mechanisms are interfacial energy minimization and physical

barrier formation. Amphiphilic particles adsorb at the oil-water interface, once adsorbed particles anchor irreversibly due to the high energy required for the detachment, which forms a dense protective layer around each droplet. The adsorbed particles form a three-dimensional network, that helps to prevent droplet merging. Solid particles lower the interfacial tension, though less than the traditional surfactants, which reduces the total free energy of the system, making droplet formation more thermodynamically stable. The layer of solid particles also acts as a mechanical barrier to prevent coalescence and Ostwald ripening. Due to the energy barrier, once particle gets adsorbed at the interface, it is not readily desorbed, this enables long term stability even with out the use of surfactants.[3,5]

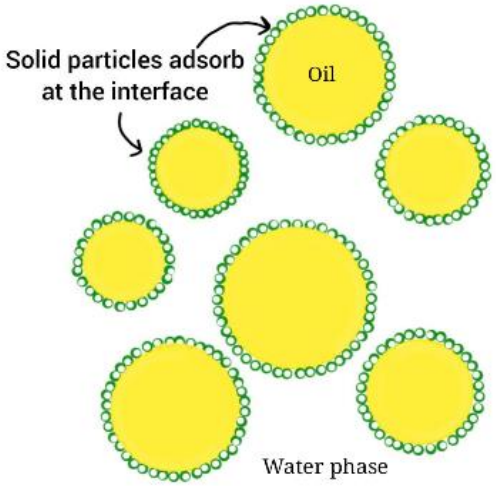

Figure 1: Mechanism Of Stabilization by Solid Particles

Solid Particles Used in Pickering Emulsion

A wide variety of solid particles are employed in pharmaceutical Pickering emulsions, depending upon their desired application and route of administration. Solid particles applied in Pickering emulsions should be partially wetted by both oil and water phases, they have a contact angle between 15°-150°, to ensure better stabilization. These particles are classified broadly based on their origin and functionality. Organic, inorganic, polymeric and biodegradable particles are widely applied in Pickering emulsion. Functionalized particles are created by attaching desired functional groups to improve its stability and wettability properties. Inorganic particles like silica nanoparticles, titanium dioxide, calcium carbonate etc. are used commonly owing to their high surface energy and tunable surface chemistry. For example, hydrophobically modified silica can be used for stabilizing W/O emulsions for topical delivery of drug, which offers both emulsion stability and skin compatibility. Polymeric particles such as PLGA, polycaprolactone etc. are utilized for sustained release formulations. Natural biopolymer-based particles such as chitosan, cellulose nanocrystals, starch-based particles, whey protein, zein etc. are widely utilized for their non-toxicity and biodegradability. These formulations are particularly suitable for oral and topical preparations. Hybrid and functionalized particles like magnetic nanoparticles for targeted drug delivery, pH responsive particles for controlled delivery of drug in specific gastric environments. Generally, the choice of solid particles in Pickering emulsions are controlled by

factors like biocompatibility, wettability, particle size, surface charge, drug compatibility, and intended use.[6]

Table 1: Types Of Particles Used in Pickering Emulsion

Particles			Pickering emulsion		
Composition		Shape	Composition	Shape	Composition
Inorganic particles	Silica (SiO_2) nanoparticles	Spherical	O/W or W/O	60µm	Rotor-stator homogenizer
	Calcium carbonate ($CaCO_3$)	Irregular/ spherical	O/W or W/O	1-10 µm	High-shear mixing, vortexing, sonication
	Titanium dioxide (TiO_2)	Spherical/ rod shaped	O/W	100nm-2µm	Sonication, high-shear homogenization
	Hydroxyapatite	Spherical	O/W	-	-
	Laponite	Spherical	O/W	1-30nm	Vertexing/ shear mixing
Organic and polymeric particles	Polylactic co-glycolic acid	Spherical	O/W or W/O	125 µm	Solvent evaporation or nanoprecipitation
	Poly methyl methacrylate (PMMA)	Spherical	O/W or W/O	100nm-5µm	Emulsion polymerization
Biopolymer based particles	Chitosan nanoparticles	Irregular/ spherical	O/W	6.9 µm	Sonication
	Whey protein nanoparticles	Irregular/ spherical	O/W	200nm-2µm	Homogenization / sonication
	Cellulose nanocrystals	Spherical	O/W	32.17-32.83µm	Ultrasonic pulverization (30%, 3 min)
	Bacterial cellulose nanocrystals	Needle-like	O/W	4µm	Ultrasonic device
	Starch nanocrystals	Rod-like/ platelet shaped	O/W	>49.8µm	High- speed stirring/ homogenization
	Zein	Spherical/ irregular	O/W	200nm-2µm	Homogenization / sonication
Hybrid and functionalized particles	Magnetic nanoparticles	Spherical	O/W or W/O	<200nm	Ultrasonication
	Janus nanoparticles	Spherical	O/W or W/O or multiple	100nm-5µm	-
	Carbon nanotubes	Tubular	W/O	100nm-10µm	Sonication

Parameters Influencing Stability of Pickering Emulsions

There are several factors that can affect the formation, type and stability of emulsion. Understanding and controlling these factors is very essential for designing pickering emulsions for

specific applications. Particle wettability (Contact angle): It is a key determinant of emulsion type. A contact angle < 90° (more hydrophilic) stabilizes oil-in-water emulsions, whereas contact angle >90° (more hydrophobic) stabilizes water-in-oil emulsions. Particles with 90° contact angle can stabilize both types of emulsions as well as multiple emulsions. Particle size and shape: smaller particles with nano to micrometer size range pack more densely at the interphase of the emulsion. Rod-like or plate-like particles offer stronger stabilization due to interlocking effects. Uniform particle size enhances emulsion stability. Particle concentration: higher particle concentration increases droplet coverage, reduce droplet size and may increase the viscosity. A minimum particle concentration is required for stable droplet coverage. Oil/water phase ratio determines whether the system favors oil-in-water or water-in-oil emulsions, additionally it influences droplet size and emulsion viscosity. pH of aqueous phase affects surface charge and stability of biopolymer particles.

Ionic strength (salt concentration): salt can screen electrostatic repulsions, promoting droplet flocculation or coalescence. Some particles become less effective at high ionic strength. Temperature affects viscosity of oil and water, particle solubility or aggregation, and phase transitions in thermoresponsive particles.

Mixing and emulsification method: shear force effect droplet size of particles. High speed homogenisation helps to disperse droplets and particles uniformly.

Surface modification of particles:

functionalization tailors, e.g., silanisation of silica, coating with polymers helps to increase wettability, surface charge and interaction with oil or water.[5]

Preparation Of Pickering Emulsion

General Protocol for Preparing Pickering Emulsion

Materials required:

- Oil phase (e.g., sunflower oil, medium chain triglycerides, or any oil suitable for application)
- Aqueous phase (e.g., distilled water or buffer)
- Solid stabilising particles (e.g., whey protein–cress seed nanoparticles, cellulose nanocrystals)

Prepare the stabilizer suspension: disperse the solid particles (e.g., nanoparticles) in the aqueous phase using sonication to ensure homogeneity. 0.1-2% w/v particles are used.

Dissolve Drug: if using a hydrophobic drug, dissolve it in the oil phase. For hydrophilic drugs, dissolve it in the aqueous phase. The pH is adjusted to improve the solubility or to stabilize the drug.

Pre-emulsification: add the oil phase slowly into the aqueous suspension under stirring (e.g., magnetic stirrer at 500–800 rpm). Oil-to-water ratios usually range from 10:90 to 50:50 depending on the formulation needs.

High-Energy Emulsification: use a high-shear homogenizer at 10,000–20,000 rpm for 1–5 minutes, or ultrasonication for 2–5 minutes (pulse mode to prevent overheating). This reduces droplet size and helps particles adsorb to the interface.

Stabilization: keep the emulsion at room temperature or refrigerate it (depending on stability) to allow the particles to stabilize at the interface.[7,8]

Table 2: Types of homogenization techniques used

Method	Tuning process on droplet size	advantages	limitations	Reference
High-pressure homogenization	Pressure, homogenization cycle	Rapid process, large volume of samples can be processed, tunable droplet size in nanometer range,	Higher cost, increased temperature, risk of particle disruption, lack of monodispersity regulation	9
Ultrasonic emulsification	Ultrasonic frequency, amplitude and time	Rapid process, easy to set up, small volumes of samples can be processed, tunable droplet size	increased temperature, risk of particle disruption, lack of monodispersity regulation	10
Membrane emulsification	Membrane pore size, pressure	Energy consumption is low, reduced risk of particle disruption, reduced risk of temperature rise, low polydispersity	More time consuming, low viscosity systems are only suited	11
Microfluidic emulsification	Flow rate, microchannel geometry	Low polydispersity, reduced risk of temperature rise, low energy consumption	Low productivity, low viscosity systems are suited	12

Characterization Techniques Used For Pickering Emulsion

Characterization techniques provide a comprehensive understanding of stability, performance and efficacy of Pickering emulsions in pharmaceutical formulations.

Droplet size and particle size distribution: dynamic light scattering or laser diffraction can be used to measure average droplet diameter as well as particle size distribution. This is an important factor that affects the drug release rate, stability as well as bioavailability. Smaller and uniform droplet favors stability.

Zeta potential: electrophoretic light scattering using a zeta sizer assesses the surface charge of emulsion droplets. High zeta potential suggests good stability due to repulsion among droplets.

Interfacial tension: pendent drop method using tensiometer or goniometer measure the tension between oil and water phases. The adsorption of particles at the interface reduces interfacial tension, indicating effective stabilization.

Rheology: rotational rheometer evaluates viscosity, shear thinning, thixotropy and viscoelastic properties. It is widely used to predict the injectability or spreadability of topical formulations.

Encapsulation efficiency: can be performed using centrifugation or dialysis followed by drug quantification using UV-Visible spectrophotometry or HPLC.

In-vitro drug release: measured using dialysis bag method, Franz diffusion cell or USP dissolution apparatus. Samples are withdrawn periodically followed by UV/Visible or HPLC

analysis, which evaluated the release kinetics to understand controlled release behavior.[13]

Applications Of Pickering Emulsion

Table 3: Application of Pickering emulsion in various fields

Field	Application
Pharmaceutical	▪ Controlled drug delivery (e.g., fluconazole, curcumin, metronidazole) ▪ Vaccine adjuvants – topical creams with enhanced stability
Food	▪ Fat replacement, ▪ encapsulation of flavors or nutrients ▪ prolonged shelf-life via oxidation resistance
Cosmetics	▪ Creams and lotions with improved stability and mildness ▪ Natural, mild formulations, free of synthetic surfactants
Environment	▪ Oil spill remediation, ▪ encapsulation of hazardous waste
Agrochemical	▪ Controlled release of pesticides and fertilizers ▪ Reduced environmental impact due to slow degradation

Applications Of Pickering Emulsion In Pharmaceuticals

Pickering emulsions serve as a robust platform in pharmaceutical formulations, demonstrating superior stability and reduced toxicity compared to surfactant-based systems. They are shown to be effective in controlled drug release, tissue targeting, and encapsulation.

Drug Delivery Systems

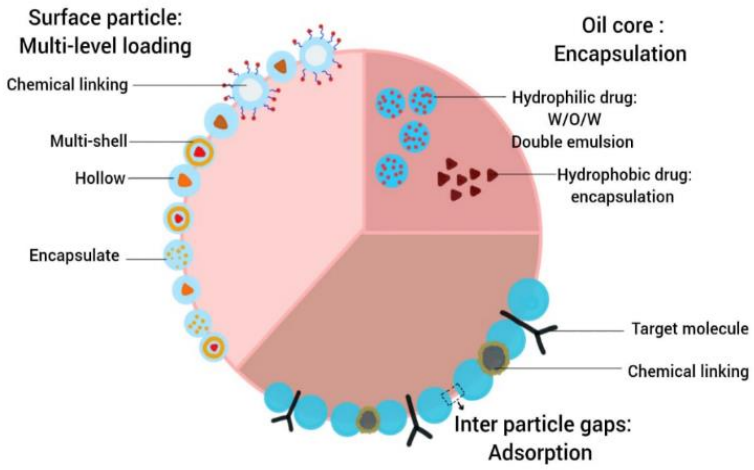

Figure 2: Drug Delivery Systems Using Multi-Level Loading[14]

Pickering emulsions can be produced by mounting the interfacial-aggregated particles on the oil droplet, allowing large amounts of hydrophobic components to be encapsulated within oil nuclei. Also, the particulate O/W interface presented high specific surface areas for the efficient adsorption of a variety of macromolecules, such as antibodies, antigens, or therapeutic proteins. Moreover, the compactly packed particles could be exploited

with the hierarchical structure (hollow or porous particles), as well as the tunable surface properties. These unique features enabled key drug loading via the hydrophobic interactions, chemical linking, or electrostatic adsorptions on the surface. For example, through the use of cashew gum nanoparticle-stabilized droplets, hydrophobic indomethacin was encapsulated within the oil core, with the encapsulation efficiencies up to 52%. In addition, Han et al. achieved up to 94% curcumin encapsulation in the inner oil containing medium chain triglyceride by using a chitosan/gum arabic nanoparticle-stabilized oil-in-water Pickering emulsion. Moreover, with the multi-level structures, Pickering emulsion can be utilized as potent multi-drug delivery systems. Cocktail therapy, which involves the co-administration of multiple drugs (such as cancer vaccines along with photothermal therapy, and chemotherapeutics), has often been shown to be a promising treatment for tumor regression and for multi drug resistance. But the main challenge was to spatiotemporally deliver multiple drugs with varied hydrophobicity and target sites. For example, the near infrared dye indocyanine green, which was regularly used in photothermal therapy, was a hydrophobic active component, while most of the targeted antibodies were hydrophilic molecules. A simple mixture of the hydrophobic drugs and antibodies can hardly bring about potent anti-tumor effect. Thus, it is very essential to develop multi-drug delivery systems for higher bioavailability as well as efficacy. The multi-level structure of Pickering emulsion may create the way for the strategic loading of multiple components with varying hydrophobicities or charges, thereby maximizing the overall benefit. In a recent study by Zhang et al., co-encapsulated betanin and curcumin through a type of water-in-oil-in-water (W/O/W) Pickering emulsion were stabilized by sugar beet pectin-bovine serum albumin nanoparticles (SBNPs). First, betanin was loaded in the inner water phase (W_1) and curcumin was loaded in the oil phase. Then, W_1/O emulsions were stabilized by polyglycerol polyricinoleate in the oil phase, and SBNPs dispersed in the outer water phase were homogenized with W_1/O emulsions to form the double emulsion. Here, betanin was encapsulated within the internal water phase (encapsulation efficiency was 65.3%), whereas curcumin was in the oil phase (encapsulation efficiency was 84.1%). Furthermore, betanin and curcumin achieved a synergistic effect by hindering the A549 cell growth.[14]

Oral Route of Drug Delivery

Table 4: Examples of oral delivery of Pickering emulsions

Type	Emulsion		Drug/localisation	Functional changes	Reference
	Particles	Droplet Size			
O/W	Eudragit RL100 nanoparticles	≈220nm	Ketoprofen/oil	Controlled release	15
O/W	Acetylated cellulose nanocrystals	1-5µm	Decane/oil	-	16
O/W	Zein nanoparticles coated with bioactive glycyrrhizic acid and tannic acid	-	Curcumin/oil	Gastrointestinal pH sensitive	17
O/W	Magnesium oxide nanoparticles	≈666nm	Caffeine/water	Sustained release	18
O/W	Chitosan hydrochloride/ carboxymethyl starch complex	≈5-8µm	Beta-carotene/oil	-	19

O/W	Silybin nanocrystals	≈24.2-30.4 µm	Silybin/nanoparticles	Self-stabilized Pickering emulsion	20
O/W	Pea protein isolate protein	≈3-8µm	Beta-carotene/oil	Stimulus responsive and targeted delivery	21
W/O	Kafirin nanoparticles	-	Curcumin/kafirin nanoparticles	Protection against photooxidation of curcumin	22

Topical Route of Drug Delivery

Table 5: Examples of topical delivery of Pickering emulsions

Type	Emulsion		Drug/localisation	Functional changes	Reference
	Particles	Droplet Size			
O/W	Silica particles	≈2-4µm	Retinol/ oil	Sustained release	23
W/O	Aluminium starch octenyl succinate particles	-	Minocycline hydrochloride/ water	Controlled release	24
W/O	Chitosan/ collagen peptide nanoparticles	≈7.63=-15.72µm	-	-	25
O/W	Carboxymethyl chitosan/ sodium alginate nanoprticles	≈5µm	Curcumin/ oil	Controlled release	26
W/O	Silica prticles	≈100-200nm	Caffeine	Enhanced permeation	27
O/W	Cyclodextrin	-	Econazole/ cyclodextrin oil nanoparticles	-	28
W/O	Starch	≈10-20µm	-	-	29

Parenteral Route of Drug Delivery

Table 6: Examples Of Parenteral Delivery of Pickering Emulsions

SC/IV	Type	Emulsion		Drug/localisation	Functional changes	Reference
		Particles	Droplet Size			
SC	O/W	PLGA-PEG-mannose nanoparticles	≈1µm	Lipopeptide ovalbumin/ oil water interface	Targeted delivery	30
	O/W	Alum microgels	≈4µm	SARS-CoV_2 spike protein/ oil water interface	Targeted delivery	31
IV	O/W	Poly (N-isopropylacrylamide-co-allylamine) nanogels	≈1.5µm	Paclitaxel/ oil	Sustained release/ Targeted delivery	32

	O/W	CTAB and LA	≈294-502nm	CTAB & LA/ nanoparticle	Targeted delivery/ stimuli response	33
	W/O	PLGA nanoparticles	-	Oxaliplatin/ water	Sustained release	34
	O/W	Poly (N-isopropylacrylamide-co-acrylic acid)	≈1-10µm	-	Sustained release	35
	O/W	Solid lipid nanoparticles	≈40-160nm	-	Temperature sensitive delivery	36

Vaccine Delivery

Pickering emulsions can be used for the administration of vaccines. It is now been expolerd as a potential adjuvent for vaccines.

Table 7: Examples of Pickering emulsions (PE) used for vaccine delivery

Pickering emulsion	Delivered substance	Advantages	Reference
Chinese yam polysaccharide PLGA stabilized PE ajuvant system	Porcine circovirus 2 vaccine	High antigen uptaake efficiency by macrophages	37
PE based nanovaccine using manganese particle mineralized human serum albumin (MnHSA) and antigen ovalbumin (OVA) as stabilizers	OVA/ MnHSA nanoemulsion	Increased antigen encapsulation efficiency	38
PE guided monophosphoryl lipid A monomeric delivery system	Monophosphoryl lipid A	Elicit robust cellular immune response, enhanced cancer immunotherapy	39
Lentinan PLGA stabilized PE loading ovalbumin antigen	Lentinan/ ovalbumin	Activation of dentritic cells, strong humoral and cellular immune response	40

Cancer Therapy

Table 8: Examples of Pickering emulsions used for cancer therapy

Pickering emulsion	Route of administration	Advantages	Reference
Ultrastable iodinated oil-based PE for local sustained co-delivery of HIF-1 inhibitor of acriflavine and doxorubicin	Intratumoral	Long term sustained release	41
Fe_2O_4 cellulose nanocrystal stabilized PE containing curcumin for colon cancer	-	Stimuli responsive drug release (magnetically triggered)	42
PE of anti-CLTA4 antibodies formulated with radioopaque ethiodized oil and PLGA nanoparticles	Intratumoral/ intra-arterial	Delivery of novel cancer immunotherapy agents	43
Pickering nanoemulsion with multi-sensitive nanogels with pH-responsive, hydrophilicity-hydrophobicity switch, and	-	Ph resposive delivery, enhanced tumor	44

redox-responding properties as an oil/water interfacial stabilizer and doxorubicin and ICP inhibitor HY19991		penetration of doxorubicin	

Wound Healing

Pickering emulsions can also be utilized for wound healing application.

Table 9: Examples of Pickering emulsions used for wound healing

Pickering emulsion	Advantages	Reference
Pickering emulsion composed of chitosan nanoparticles, tea tree oil and curcumin	Sustained release of therapeutic agents, promote fibroblast proliferation	45
Rutin loaded novel Pickering emulsion stabilized by self-aggregated chitosan particles	Sustained release of therapeutic agent	46
Pickering emulsion composite hydrogels based on carboxymethyl chitosan - sodium alginate nanoparticles stabilized Pickering emulsions, poloxamer 407, and curcumin	protecting bioactive components and wound care management	47
Novel Pickering emulsion with thyme essential oil encapsulated in shell of functional tea polyphenol-curcumin nanoparticles	rapid angiogenesis, collagen deposition, and skin regeneration	48

Advantages Of Pickering Emulsion

Pickering emulsions have high stability as the particles do not desorb easily. When compared to conventional emulsions, these are stable against Ostwald ripening and coalescence. Biocompatibility can be obtained using food or pharma grade particles. Low toxicity is achieved especially when surfactants are not desirable. Most of the particles used for formulating Pickering emulsion are biodegradable in nature, therefore has environmental sustainability. Also, the surface properties of particles can be tailored for smart functions to improve customizability. Most importantly these particles are highly tunable based on the application, functionalization can be performed to meet the needs.[2,4]

Limitations

Even though Pickering emulsions offers various advantages like enhanced stability, reduced dependence on synthetic surfactants and tunable release properties, they also face some limitations that can influence their formulation, scalability as well as practical applications. The major limitation is limited particle availability, only some solid particles can be suited for preparing Pickering emulsions that meets the criteria of biodegradability, compatibility and non-toxicity. The surface modification of the particle is practically difficult, requires complex chemical modification, which is time consuming, costly and may induce safety concerns for human use. These particles are typically irreversible due to strong adsorption at the interface, which makes them difficult to re-emulsify, causing challenges like redispersion after drying. Because of their high viscosity in highly concentrated Pickering emulsion, it is difficult to formulate in injectable form and to apply as topical form. Poor distribution and strong interaction among particles can limit bioavailability and drug release. High energy emulsification is utilized for preparation which may not be practical and economical for industrial scale, which hinders it's scale up. Also,

achieving uniform particle size distribution and emulsion droplet size is challenging on a larger scale. The use of novel nanoparticles requires strict regulatory scrutiny, which obstructs its wide scale applications.[3,5]

Future Prospectives

Currently, there is no FDA-approved drug labelled as Pickering emulsion. Many stabilizing particles used in Pickering emulsions are labelled as GRAS (generally regarded as safe) or FDA-approved. Formulations using Pickering emulsions are under clinical trials or in the preclinical stage of development. In future more and more Pickering emulsions containing solid adsorbed particles could be developed with more stability and practical application.

CONCLUSION

In conclusion, Pickering emulsions' improved stability, biocompatibility, and capacity to encapsulate and protect active medicinal components have made them a potential platform in pharmaceutical applications. Their use of solid particles as stabilizers makes them a safer and more environmentally friendly substitute for conventional surfactants, which makes them suitable for topical formulations, controlled release applications, and drug delivery systems. Pickering emulsions' adjustable characteristics facilitate the development of novel treatment approaches by enabling the modification of drug release profiles, enhanced bioavailability, and targeted delivery. In order to fully utilize their potential in commercial pharmaceutical formulations, more research and optimization are required.

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