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Chapter

Microemulsions as Nanotemplates: A Soft and Versatile Approach

Rohini Kanwar, Jyoti Rathee, Madhuri Tanaji Patil and Surinder Kumar Mehta

Abstract

Template efficacy of microemulsions in generating nanoparticles has garnered considerable attention in the world of colloidal science. A microemulsion is an optically isotropic and thermodynamically stable colloidal dispersion, which possess spherical droplets (either of W/O or O/W) of the size <50 nm. In microemulsions, the spontaneous formation of domains of nanometric dimensions significantly facilitates their exploitation as potential nanoreactors for the production of stable nanoparticles (due to their cost-effectiveness and ease of preparation). The present chapter provides an overview of microemulsions as efficient nanotemplates, with a detailed account of plausible nanomaterials, i.e., metallic nanoparticles, quantum dots, polymeric nanoparticles, mesoporous silica nanoparticles, solid lipid nanoparticles, nanostructured lipid carriers, etc. Based on the high surface area, good crystallinity, controllable particle size, outstanding catalytic, and magnetic properties, the exploitation of nanoparticles as efficient catalysts and drug delivery modules has also been highlighted.

Keywords: microemulsions, nanotemplates, metallic nanoparticles, quantum dots, polymeric nanoparticles, mesoporous silica nanoparticles, solid lipid nanoparticles, nanostructured lipid carriers

1. Introduction

Microemulsions are thermodynamically stable, optically isotropic and spontaneously formed colloidal dispersed system of two immiscible liquids (such as oil and water), which are stabilized by the interfacial film of a surfactant (and co-surfactant) [1]. The formation of microemulsion was first described by Hoar and Shulman in 1943, after observing a spontaneous and well-defined transformation of an opaque emulsion to a transparent solution upon addition of medium chain alcohol (co-surfactant) [2]. However, it was the year 1959, when Shulman et al. [3] coined the term called "microemulsion." A microemulsion is a macroscopically homogeneous system and possesses spherical droplets of the size <50 nm that do not require the higher input of energy and shear reaction conditions, in contrast to conventional emulsions, which are cloudy, kinetically stable and thermodynamically unstable systems [4]. Microemulsions can be considered akin to micellar solutions that solubilize the oil domain into the nonpolar surfactant tail region to give stable microstructure.

Basically, a microemulsion comprises of three components, namely a polar phase (water), a nonpolar phase (oil) and an emulsifier. On a microscopic level, the emulsifier molecules form an interfacial film, which separates the polar and the nonpolar domains. The formed interfacial layer leads to different microstructures ranging from oil-swollen direct micelles dispersed in water (O/W microemulsion) over a bicontinuous "sponge" to water-swollen inverse micelles dispersed in oil (W/O microemulsion) phase. Depending on the hydrophilic-lipophilic balance (HLB) value of the surfactant and the oil/water ratio, the formed microstructure can exist in oil-in-water (O/W), water-in-oil (W/O), hexagonal, reverse hexagonal, or a mixture of (O/W and W/O) called bicontinuous/lamellar phase. In general, the surfactants having HLB of 3–6 promote the formation of W/O microemulsions whereas with HLB of 8–18 facilitate the formation of O/W microemulsions [5]. The W/O microemulsion is generally termed as "reverse micelles" in which water swollen micelles are dispersed into the oil phase, and polar head groups of the surfactant are attracted by the aqueous phase, whereas the hydrocarbon chain is attracted by the oil phase. The reverse micelles obtained are of spherical shape, monodispersed that can easily control the size of the aqueous core up to 5–10 nm. On the other hand, in O/W microemulsion, the size of droplets can be tailored up to 1–100 nm by varying the concentration of the dispersed phase and the surfactants.

Figure 1 shows the ternary phase diagram, the three edges of which represents the components of a microemulsion, namely, oil, water, surfactant (and a co-surfactant, referred as a pseudocomponent is added).

In literature, different theories are documented illustrating the spontaneous formation of microemulsion such as interfacial, solubilization and thermodynamic theories, etc., out of which few main theories are described below. In 1955, the first theory, i.e., mixed film theory was proposed, which considered the interfacial film as a duplex film, i.e., interface is the third phase and have two-dimensional region bounded by oil on one side and water on the other [6]. It was postulated that the spontaneous formation of the microemulsion is attributed to the interactions at the interphase, where the interfacial tension between oil and water phase is brought down to zero. However, only on the basis of molecular interactions across the duplex film, the formation of microemulsion could be ensured rather than other liquid crystalline phases, in which one bulk phase gets enclosed in the other (in the form of spheres). Based on the mixed film theory, Robbins [7] devised a theory of phase behavior of microemulsions, which stated that interactions in a mixed film direct the direction and extent of curvature, by which the type and size of droplets

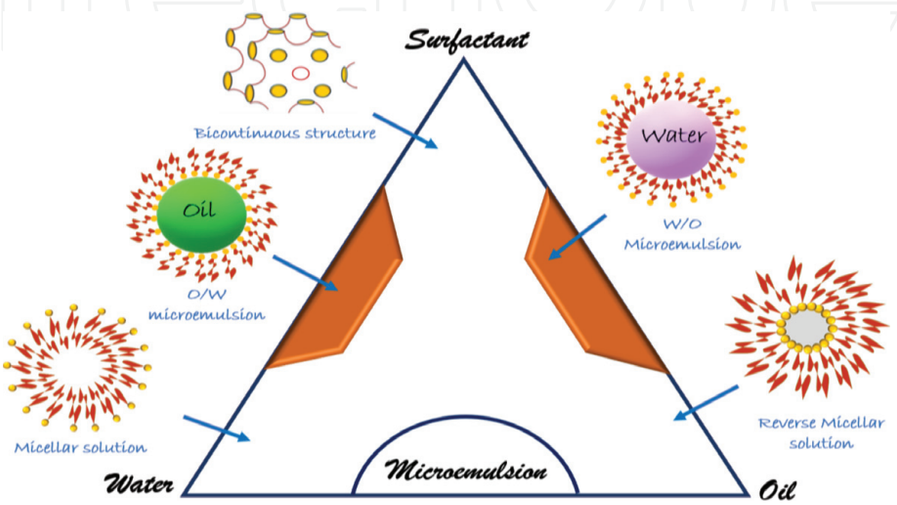

Figure 1.
Ternary phase diagram representing three components of the microemulsion.

of the microemulsions can be estimated. Later, the solubilization theory was proposed, which regarded microemulsions as the swollen micellar systems. In 1969, Adamson [8] gave a model in which the W/O emulsion was said to be formed due to the balancing of Laplace and osmotic pressure. The thermodynamic theory showcased that the free energy of formation of microemulsions consists of interfacial energy and energy of the clustering droplets. It is the reduction in the interfacial free energy that facilitates the spontaneous formation of the thermodynamically stable microemulsion. Also, with the thermodynamic approach, the information related to the stability and size of droplets in microemulsion can be deduced. Another important theory was given by Schulman and his co-workers [3], who reported that the negative interfacial tension is a transient phenomenon for the spontaneous uptake of water or oil in microemulsion and it is the interfacial charge, which controls the phase continuity.

Based on the positive attributes of microemulsions such as spontaneity, thermodynamic stability, and solubilization potential (illustrated by the theories), the developed assembly acts as a potential template for the fabrication of diverse nanoparticles.

2. Microemulsions as efficient nanotemplates

Microemulsion, a soft and versatile approach, has the distinct ability to modulate the particle properties such as the morphology, geometry, surface properties (activity and selectivity), surface area, stability, and homogeneity of the formed nanoparticles (NPs). It is a unique method to regulate the kinetics of the NPs formation and growth (controlled by thermodynamic stabilization with surfactant molecule) by altering the physiochemical properties of the microemulsion. Microemulsions are dynamic systems, in which formed droplets frequently collide, coalesce with each other due to the continuous Brownian motion. They tend to merge among themselves to form transient dimers, which break apart the surfactant layer, and thereby induce the micellar exchange within the interior of the droplets. The droplet content exchange phenomena occur in the order of millisecond to microsecond time scale. From this, it can be inferred that the microemulsion can act as an efficient "nanoreactors" or excellent reaction site, which can facilitate the synthesis of diverse NPs (owing to its dynamicity). These surfactant-covered water pools/oil pools offer a unique microenvironment for the formation of NPs (where the surfactant layer prevents the NPs from aggregation by its steric stabilization property) [9].

2.1 Basics of NPs formation

Microemulsions can act as efficient templates to synthesize NPs via. Two routes: (A) one microemulsion method and (B) two microemulsion method [10]. **Figure 2** shows the mechanism involved behind the formation of NPs from the microemulsion methods. In one microemulsion method, a triggering agent is a prerequisite to initiate the nucleation reaction, which can be either present within the single microemulsion (containing the precursor) or added externally into the microemulsion (as a second reactant) (**Figure 2A**). For the synthesis of NPs, the triggering reactant has to diffuse through the interfacial wall of the microemulsion, i.e., why one microemulsion method is a diffusion-controlled process.

However, in the two microemulsion methods, the two microemulsions (consisting of separate reactants) are mixed together in suitable ratios, in which the Brownian motion of the micelles brings them in contact with each other. Because of

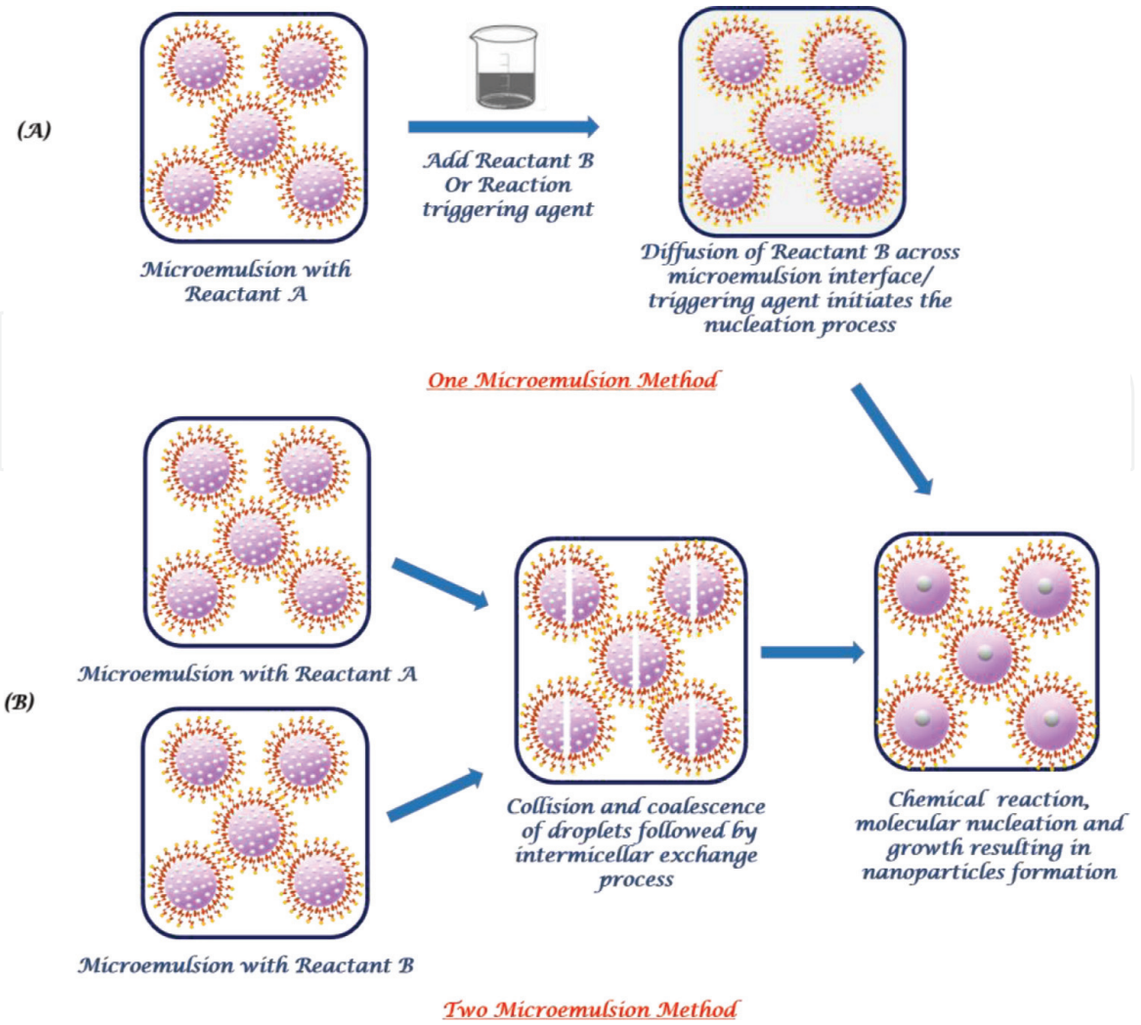

Figure 2.
Mechanism involved behind nanoparticles preparation from microemulsion method: (A) mixing of two microemulsions and (B) direct addition of reducing agent to the microemulsion.

which intermicellar collisions and sufficiently energetic collisions happen, thereby, leading to the mixing of the micellar components (**Figure 2B**). The chemical reaction happens, when both the reactants come in the same vicinity. And when the critical number of molecules is attained inside the micellar units, the nucleation process progresses followed by growth and coagulation of primary particles, resulting in the NP formation.

2.2 Different types of NPs (developed from the microemulsion method)

Microemulsions are potent chemical nanoreactors with distinct interfacial properties providing which provides an intimate contact of hydrophilic and hydrophobic domains at the nanoscale level. By utilizing microemulsions, various nanomaterials have been synthesized such as metallic NPs, quantum dots, polymeric NPs, mesoporous silica NPs, solid lipid NPs, nanostructured lipid carriers, etc. (**Figure 3**).

2.2.1 Metallic nanoparticles

Metallic NPs such as silver (Ag), gold (Au), platinum (Pt), palladium (Pd), copper (Cu), nickel (Ni), molybdenum (Mo), ruthenium (Ru), selenium (Se), iron (Fe), cerium (Ce) and their oxides, sulfides, fluorides, chromates, phosphates, etc.

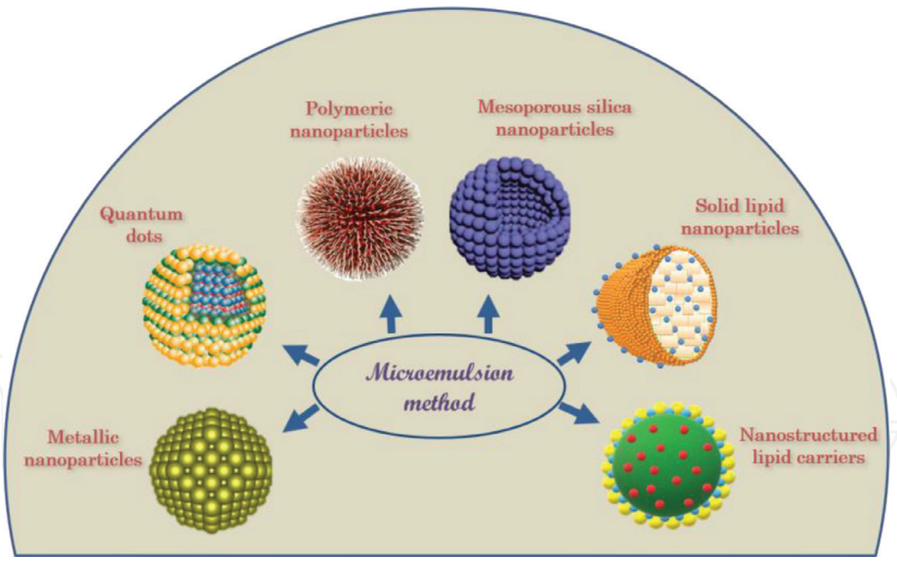

Figure 3.
Structure of nanoparticles (NPs) prepared using microemulsion method.

have drawn significant attention because of their emerging applications in the field of catalysis, clinical diagnostics, and therapy. For the synthesis of metallic NPs using microemulsion, two schemes have been identified [11]: (a) O/W microemulsion in which ionic salt (metallic precursor) as the precursor is dissolved in the continuous aqueous phase and (b) W/O approach in which organometallic salt (metallic precursor) is dissolved in the oil phase of microemulsion.

In 1982, for the first time, Boutonnet et al. [12] recognized microemulsions as the convenient template for the synthesis of metal NPs using W/O microemulsion. They synthesized the monodispersed Pt, Pd, Rh, and Ir NPs within the size range of 2–5 nm by reducing the corresponding salt of these metals in water pool of O/W emulsion (by hydrogen gas). They showed that in order to achieve the stability and minimize the water content of the microemulsion, a high concentration of reducing agent is needed. Following the pioneering work of Boutonnet, the exploitation of microemulsion for the synthesis of NPs gained considerable momentum in the scientific arena [11, 13, 14]. Pileni and Lisiecki [14] prepared Cu NPs using sodium dioctyl sulfosuccinate (AOT)-based W/O microemulsion, where they changed the shape of NPs by varying the ratio of water/surfactant in the microemulsion system. Tianimoghadam and Salabat [15] fabricated monodispersed thiol-functionalized Au NPs (having diameter 3–4 nm) by using W/O microemulsion (toluene/tetraoctylammonium bromide/water) where $HAuCl_4$ was employed as a precursor and $NaBH_4$ as a reducing agent. Perez-Coronado and co-workers [16] synthesized Pd NPs using W/O microemulsion (AOT/iso-octane system/water) and used them as a catalyst for reduction of bromate with H_2 in water. An inverse microemulsion method was utilized to fabricate Ni, Mo, Fe NPs (of size 2.0–2.5 nm and agglomerates <50 nm having spherical morphology) at room temperature and exploited to heavy crude oil *in situ* hydroprocessing and to enhance their physiochemical properties [17]. Yamagishi et al. [18] established that it is the interaction between the metal salt and micellar components, which directs the capacity of the microemulsion to solubilize the metal salts in it. Furthermore, Destrée and Nagy [13] as well as Lopez-Quintela [19] proposed the mechanism of NPs formation using W/O microemulsion.

Later, in 2005, Ge et al. [20] described the potential of O/W microemulsion for the preparation of different inorganic NPs such as metal NPs (Cu, Ag), fluorides (CaF_2, YF_3, PrF_3, NdF_3), semiconductors (ZnS, Ag_2S, CdS, PbS, CdSe, PbSe), chromates ($BaCrO_4$ and $PbCrO_4$), and phosphates ($CePO_4$ and $HoPO_4$) in the size range

of 2–13 nm. They proposed that the metal cation gets adsorbed at the oil-water interface of the preformed O/W microemulsion because of the Coulombic attraction between the metal ion and the linoleate anion from the surfactant. Due to the strong solvation of ions in the polar solvents, they favor being positioned at the interface of O/W microemulsion; however, this balance gets destroyed upon addition of the precipitating agent, and thereby, leads to the formation of smaller sized particles. Furthermore, Sanchez-Dominguez and co-workers [21] synthesized Pt, Pd, or Rh NPs using O/W microemulsion and from the color change (from gray to brown) determined the formation of metallic NPs. Li et al. [22] reported the synthesis of Co-B NPs using O/W microemulsion (cyclohexane/polyethylene glycol/water) with controllable size (6–20 nm) and used it as a catalyst for the hydrogenation process. Ce oxide and mixed Cu/Ce oxide NPs (size 2–3 nm) with low polydispersity were synthesized by Pemartin-Biernath and co-workers [23]. Furthermore, a novel method to synthesize Fe NPs *in situ* in O/W microemulsion (Brime/n-hexane/SDS and span 80 mixture/isopropyl alcohol) was developed by Hu et al. [24] to increase their performance in oil recovery. Rivera-Rangel and coworkers [25] fabricated the Ag NPs by using the O/W microemulsion (Brij 96/1, 2-hexanediol/castor oil, extract of geranium leaf as a reducing agent) method as a template. They found that in the microemulsion method, the obtained Ag NPs were of a controllable size and the method was more eco-friendly as compared to the nanoemulsion method.

Among these two approaches, O/W is found more convenient and an environment-friendly approach (having water as the major (continuous) phase) as compared to W/O, which includes the use of oil in a larger amount resulting in a small yield of NPs per microemulsion volume and hindering the applications at industrial scale.

2.2.2 Quantum dots

In the last few decades, scientists have shown enormous interest in the field of nanostructured materials called "quantum dots." Quantum dots (QDs) are inorganic nanocrystals that act as fluorophores and finds plenty of applications in electronics, biosensing, *in vivo* imaging, chemical, and biomedical researches. QDs are basically zero-dimensional entities consisting of a semiconductor core (<30 nm size), coated by a shell and an organic cap or an inorganic layer (a material having larger band gap), which enhances its solubility in aqueous buffer solutions [26]. So far, a wide range of quantum dots has been synthesized such as CdX (X = S, Se, Te), carbon dots, Si QDs, graphene QDs, Ag_2Se, Ag_2S, ZnS, InP, etc., because of their good biocompatibility and excellent optical properties [27, 28]. Optoelectric properties of QDs were found directly dependent upon the size and shape of QDs, as large quantum dots (5–6 nm size) emit longer wavelength with an emission color of orange/red, whereas smaller quantum dots (2–3 nm size) emit a small wavelength of blue/green color [29].

Among the various methods, the reverse microemulsion technique (the bottom-up approach) is considered as the most convenient and popular method approach, as one can easily tune the size of QDs (by altering the surfactant/water molar ratio) and NPs with narrow size distribution can be prepared. To synthesize the QDs, the nanometric-sized water droplets are dispersed in n-alkane solutions using surfactants like AOT, cetyltrimethylammonium bromide (CTAB), sodium dodecyl sulfate (SDS), or triton-X. Shakur [30] fabricated ZnS QDs by reverse microemulsion method (using pyrrolidone as the surfactant) having the cubic structure of size 2.1 nm, the lattice parameter of 5.4 Å, and specific surface area of 1.81 cm^2/g. Yang and coworkers [31] synthesized ZnSe and Fe-doped ZnSe QDs using W/O microemulsion hydrothermal technique of spherical shape having zinc blende structure and

monodispersed nature. CdS QDs of 3.8 nm size and cubic phase nanocrystals were developed by using reverse microemulsion (cetylpyridinium chloride/1-pentanol/water/heptane, and $CdCl_2$ and Na_2S) at 303 K [32]. The microemulsion-mediated hydrothermal method was utilized by Chen and co-workers [33] in which CdS QDs with controllable size and crystallinity were fabricated by a chemical reaction of cadmium acetate dehydrate and thioacetamide CdS. Tarkas et al. [34] synthesized monomorphic SnS QDs using the surfactant-free microemulsion (chlorobenzene/methanol/ethylene glycol). They showed that the microemulsion concentration (primary factor) and microemulsion temperature (secondary factor) are the important parameters that can influence the diameter of QDs.

2.2.3 Polymeric nanoparticles

Polymeric nanoparticles (PNPs) have attracted substantial attention due to their distinct optical, electrical, optoelectrical attributes and interesting applications in biomedical sciences, catalysis, sensing, etc. [35]. PNPs are defined as solid NPs or particulate dispersions, which are prepared from biocompatible and biodegradable polymers in the size range of 10–1000 nm [36]. Generally, the preparation of PNPs include two main steps: (1) preparation of emulsified system (emulsions or microemulsions or nanoemulsions) and (2) secondly, the formation of NPs either by the precipitation or polymerization of the monomers or the gelation of polymer. For the synthesis of PNPs, the most commonly exploited natural polymers are chitosan, gelatin, sodium alginate, and albumin and synthetic polymers are polyactides, polyaniline (PAni), polyglycolides, poly(lactic co-glycolides), polyorthoesters, polycaprolactone, polyglutamic acid, polymalic acid, poly(vinyl alcohol), poly(methyl methacrylate) (PMMA), and many more [37].

Microemulsion polymerization is regarded as one of the convenient and effective approach for the preparation of PNPs (producing colloidal polymer particles of high molar mass) in order to modulate the structural properties and obtain the smaller and narrow size distribution of PNPs. Briefly, an initiator (water soluble) is added to the aqueous phase (of the thermodynamically stable microemulsion) comprising swollen micelles, which initiates the polymerization process. Due to the utilization of a high amount of surfactant, the formed PNPs get completely covered with the surfactant, which enhances the stability. Initially, in some droplets, the polymer chains are formed (as simultaneous initiation in all the microdroplets is not possible). Furthermore, it is the osmotic and elastic influence of the polymeric chains that destabilizes the susceptible microemulsions resulting in the increased particle size, empty micelles formation, and secondary nucleation. The kinetics of microemulsion polymerization and properties of PNPs are entirely dependent on the type of initiator and its concentration, monomer, surfactant, and reaction temperature [36].

In the early 1980s, Stoffer and Bone [38] reported the first microemulsion polymerization of methyl methacrylate using W/O microemulsion yielding stable polymer latexes of the size 10–100 nm. Furthermore, Ming and co-workers [39] used low surfactant/monomer ratio of 0.09 (w/w%) and developed 6–24 (w/w%) PMMA latex of the size 33–46 nm. Thereafter, Gan et al. [40] and Selvan et al. [41], for the first time reported the preparation of PAni NPs by employing (sodium bis(2-ethylhexyl) sulfosuccinate (AOT)-water-cyclohexane) microemulsion. However, the polymerization rate was slow and the morphology of PNPs was not uniform. So, as to overcome this problem long-term stable polymer/nanosilica composite latex was prepared under ultrasonic irradiation [42, 43]. A new method: ultrasonic assisted inverse microemulsion (CTAB/n-hexanol/concentered HCl) polymerization method was developed to prepare conducting PAni NPs with uniform shape

and size ranging between 10 and 100 nm [35]. Polyacrylamide NPs (with size <100 nm) were prepared using the reverse micelle (Aerosol/n-hexane/acrylamide/N,N′ methylene bisacrylamide) by Munshi and co-workers [44]. Chitosan magnetic NPs were prepared *in situ* within the size range of 10–80 nm in the microreactor of tiny water pools of W/O microemulsion (Triton X-100/cyclohexane/n-hexanol/hydrochloric acid) [45]. Ge and co-workers [46] prepared the biodegradable NPs by precipitating the W/O microemulsion (RNA aqueous solution/dichloromethane (poly(L-lactic acid)-poly(ethylene glycol)/n-octyl β-D-glucopyranoside/n-butanol) in supercritical CO_2. Ahmad et al. [47] prepared chitosan coated poly-lactide-*co*-glycolide NPs using O/W microemulsion system and reported better results (entrapment efficiency, *in vitro* release and *in vitro* cytotoxicity) than conventional drug solution and unloaded NPs.

2.2.4 Mesoporous silica nanoparticles

Advancement in the field of mesoporous silica nanoparticles (MSN) has increased dramatically owing to its various advantages such as large surface area and pore volume (which makes its potential candidate for drug adsorption and loading within the pore channels), excellent mesoporous structure and adjustable pore size, and easily modifiable surface structure. Initially, MSN were synthesized and reported by the research groups of Cia, Mann, and Ostafn; however, after the work of Victor Lin, the term MSN became more familiar [48]. There are various methods reported for the synthesis of MSN such as sol-gel process, reverse microemulsion, flame synthesis, and many more. But among those methods, reverse microemulsion method is the most widely exploited method. Briefly, the surfactant molecules are dissolved in the organic solvents to form the spherical micelles, and in the presence of water, the polar head group of the surfactant organizes itself to form microcavities containing water called "reverse micelles." In microemulsion, the nucleation and growth of particles are restricted within the water core of the inverse micelles that leads to the synthesis of MSN with specific size and morphology. Furthermore, there are two prerequisite conditions that need to be taken into account during the synthesis of MSN, i.e., firstly, the well-controlled nucleation growth rate of MSN and secondly, the nonsticky nature of MSN [49].

The common type of mesoporous silica includes 2D hexagonal mobile crystalline material (MCM)-41 and a 3D cubic Santa Barbara amorphous (SBA)-15 having a pore size between 2 and 10 nm. Tetraethyl orthosilicate (TEOS) is exploited as the common source of silicon alkoxide (by adding into the reverse microemulsion) for the synthesis of spherical silica NPs in the desired size range. Finnie and co-workers [50] synthesized the MSN by the reaction of TEOS inside the water droplets of W/O microemulsion (nonylphenylether/cyclohexane/water) under both acidic and basic conditions, and controlled the NPs formation, optimized the yield and the release rate of the encapsulated drug. Furthermore, Kao and Mou [51] reported the synthesis of MSN using O/W microemulsion (CTAB/decane/ethanol) having a tunable pore size and showed high adsorption capacity of MSN for the lysozyme. Shang et al. [52] fabricated the MSN of reverse bumpy ball structure (RBBS) by using O/W microemulsion (CTAB/bromide/polydecane/cyclohexane) and TEOS. And furthermore, they established that the RBBS containing Pt-γ-Fe_2O_3 dimers shows an excellent catalytic performance for the reduction of *p*-nitrophenol (by H_2).

2.2.5 Solid lipid nanoparticles

Solid lipid nanoparticles (SLNs) are termed as first generation of lipid NPs, which are developed to overcome the disadvantages associated with the emulsions

(such as drug degradation, high drug payload, etc.) by replacing the liquid state of the lipid with the solid state (both at room temperature and body temperature) of the lipid. In the year 1990, the research group of Gasco (Turin, Italy), Müller (Berlin, Germany) and Westesen (Braunschweig, Germany) actively engaged in developing the SLNs corresponding to the size range of 10–1000 nm. In literature, different methods are documented for the fabrication of SLNs; however, the microemulsification method is regarded as the most promising route for the synthesis of SLNs because of its simplicity, cost effectiveness, enhanced drug stability, high drug payload, and controlled drug release. The most commonly exploited solid lipids are triacylglycerols, triglycerides, acylglycerols, fatty acids, waxes, and others. Basically, the microemulsion method involves two steps: (i) the melted lipid matrix is dispersed into an aqueous surfactant solution under constant stirring and a hot microemulsion is developed and (ii) then it is quenched into cold water (2–3°C) to solidify the lipid droplets [53].

There exists an extensive literature for SLNs prepared using microemulsion method. For the first time, Morel and co-workers [54, 55] employed SLNs to encapsulate peptide drugs ([$_{D}$-Trp-6] LHRH and thymopentin) using W/O/W microemulsion-based technique. Then, Ugazio and co-workers [56] incorporated the hydrophobic peptide using W/O microemulsion technique (with a matrix comprising of stearic acid, phosphatidylcholine, taurocholate; encapsulating up to 13% of cyclosporine A) and prepared cyclosporine A loaded SLNs. Furthermore, SLNs consisting of excipients: stearic acid, emulsifying wax, octadecyl alcohol, and cetyl palmitate were fabricated and employed for delivery of anticancer drugs [57]. Kuo and Chung [58] formulated SLNs having spheroidal morphology with shallow surface pits using the complex core of Compritol 888 ATO, tripalmitin, and cacao butter, and finally, targeted for antiretroviral drugs like stavudine, delavirdine, and saquinavir. Mehrad and co-workers [59] prepared SLNs having size <220 nm with spherical morphology using microemulsification method. They employed palmitic acid as the solid lipid and stabilized it with whey protein isolate (surfactant) for enhancing the physicochemical stability of β-carotene by encapsulating into SLNs. However, recently, Kanwar et al. [60] exploited the potential of SLNs as an efficient template for synthesizing the CuO-embedded meso-macroporous silica framework. They employed the ascribed catalyst for the reduction of *p*-nitrophenol to *p*-aminophenol and hexacyanoferrate (III) ions to hexacyanoferrate (II) ions, which showed promising results in the field of nanocatalysis than other available catalysts.

2.2.6 Nanostructured lipid carriers

Nanostructured lipid carriers (NLCs) are considered as the second generation of lipid NPs, which are developed to overcome the problems associated with SLNs (such as increasing the loading capacity and preventing the drug expulsion). In the year 1999, Müller et al. introduced NLCs comprising a mixture of solid lipid and liquid lipid in order to create more imperfection in the matrix of NLCs. Following the similar procedure of SLNs, NLCs were developed mainly by the microemulsion method. Doktorovova et al. [61] fabricated NLCs using microemulsion method (with excipients: precirol ATO 5, labrasol, Tween 80, and soybean lecithin), which exhibited excellent stability and entrapment efficiency for fluticasone propionate. Kuo and Chung [62] synthesized NLCs of 160 nm size, with uniform size distribution using excipients: stearic acid, Compritol 888, oleic acid, and Tween 80 and reported the efficient delivery of nevirapine for viral therapy. Khurana et al. [63] fabricated the meloxicam-loaded NLCs using microemulsion template strategy and showed the sustained release of meloxicam from SLNs. Shao and coworkers [64] synthesized the transferrin-decorated NLCs for the delivery of the paclitaxel by

microemulsion technique (glyceryl monostearate/oleic acid/soy lecithin). Kanwar et al. [65] for the first time employed the cationic lipid (didodecylammonium bromide) as the core lipid and formulated its cationic NLCs (of the size 160 nm and >30 mV zeta potential) using microemulsification method. Chanburee and Tiyaboonchai [66] fabricated curcumin-loaded NLCs (consisting of AOT, Tween 80, ethanol as the water phase; and Emulmetik 900, glyceryl monostearate, stearic acid, lexol as the oil phase) and simultaneously prepared polymer-coated NLCs (using polyvinyl alcohol, polyethylene glycol, and chitosan as the polymers). They showed that the polymer-coated NLCs exhibit greater mucoadhesion properties and physical stability than the uncoated NLCs.

3. Applications

Microemulsions as nanotemplates have engraved a prominent place despite the presence of innumerable methods for fabrication of NPs. Exploiting the microemulsion technique, distinct NPs, *viz.* metallic NPs, PNPs, QDs, MSN, SLNs, NLCs, etc., have been reported. The synthesized NPs have found applications in various fields like catalysis, delivery of drugs and diagnostics, sensing, etc. The recent trend of NPs derived from microemulsion method has been tabulated in **Table 1**.

S. no.	Type of nanoparticles	Microemulsion system (surfactant/ cosurfactant/oil/water)	Application of nanoparticles	Reference
1.	Ag	(n-Hexane/ethanol/water), silver nitrate as precursor and sodium borohydride as reducing agent	Catalysis	[67]
2.	Ni, Mo, Fe (transition nanoparticles)	(Sodium dodecyl-benzenesulfonate/citric acid/ toulene/1-hexanol), nickel (II) nitrate hexahydrate, iron(III) nitrate nonahydrate, ammonium molybdate tetrahydrate as precursor and sodium borohydride as reducing agent	*In situ* hydroprocessing of crude oil	[17]
3.	PMMA	Tween 80/ammonium persulfate/methyl methacrylate/quercetin hydrate	Drug delivery	[68]
4.	PAni and Ag/ PAni	Aniline/ammonium peroxydisulfate in W/O microemulsion(triton X 100/cyclohexane/1-butanol), silver nitrate, sodium borohydride as reducing agent	Antibacterial activity	[69]
5.	Silica-coated CdSe/ZnS QDs	Triton X-100/1-hexyl alcohol/cyclohexane/ hydrophobic CdSe/ZnS QDs	Sensing	[70, 71]
6.	MSN	CTAB/polydecene/cyclohexane and TEOS	Catalysis	[52]
7.	SLNs	Glyceryl monostearate/poloxamer 123	Catalysis	[60]
8.	SLNs	α-Tocopheryl linoleate/Tween 20/1-butanol/ biliary salt/α-linolenic acid/water	Drug Delivery	[72]
9.	NLCs	Stearic acid/castor oil/Imwitor 900/Tween 80/ sodium deoxy cholate	Drug delivery	[73]
10.	NLCs	Glyceryl monostearate/oleic acid/soy lecithin	Drug delivery	[74]

Table 1.
Recent overview of nanoparticles derived from the microemulsion method.

4. Conclusion

Microemulsions as nanotemplates have emerged as a soft and versatile approach for the fabrication of distinct nanoassemblies owing to their special ability to tune the particle properties such as the morphology, particle size, geometry, surface properties (activity and selectivity), etc. In this present chapter, a brief description of microemulsions as nanoreactors has been highlighted, stating the type of microemulsions (W/O or bicontinuous or O/W microemulsions) employed for generating different nanoparticles, including the mechanism involved behind the formation of nanoparticles using the microemulsion method. A detailed account of numerous nanoparticles such as metallic nanoparticles, quantum dots, polymeric nanoparticles, mesoporous silica nanoparticles, solid lipid nanoparticles, and nanostructured lipid carriers prepared from microemulsion method have been discussed, comprising their history, evolution, preparation, and applications. Although innumerable applications of the fabricated nanoassemblies have been reported, however, still the inbuilt potential of these exuberant nanocarriers has not been exploited completely.

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Conflict of interest

No conflict of interests is there to be declared.

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