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Polymer nanoparticles: Preparation techniques and size-control parameters

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ABSTRACT

Polymer nanoparticles have attracted the interest of many research groups and have been utilized in an increasing number of fields during the last decades. Generally, two main strategies are employed for their preparation: the dispersion of preformed polymers and the polymerization of monomers. Various techniques can be used to produce polymer nanoparticles, such as solvent evaporation, salting-out, dialysis, supercritical fluid technology, micro-emulsion, mini-emulsion, surfactant-free emulsion, and interfacial polymerization. The choice of method depends on a number of factors, such as, particle size, particle size distribution, area of application, etc. This review covers the general description of the preparation of polymer nanoparticles and the detailed description of the crucial parameters involved in techniques designed to obtain the desired properties.

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Abbreviations: AA, acrylic acid; AAm, acrylamide; ACPA, 4,4′-azobis(4-cyanopentanoic acid); AIBN, 2,2′-azobisisobutyronitrile; AOT, sodium bis(2-ethylhexyl) sulfosuccinate; AMA-80, sodium dihexyl sulfosuccinate; Amphi-Dex, amphiphilic derivative of dextran; AN, acrylonitrile; Ani, aniline; APS, ammonium persulfate; ASPS, alkali soluble polymeric surfactant; ATRP, atom transfer radical polymerization; BA, butyl acrylate; BCA, n-butyl cyanoacrylate; BMA, butyl methacrylate; BPO, benzoyl peroxide; BPMODA, bis(2-pyridylmethyl)-octadecylamine; Brij 30, polyoxyethylene-4-lauryl ether; $[C_4mim]PF_6$, 1-butyl-3-methylimidazolium hexafluorophosphate; CA897, poly(oxyethylene) octyl phenyl ether; $CaCl_2$, calcium chloride; CAN, cerium ammonium nitrate; CH, cyclohexane; CH_2Cl_2, methylene chloride; $C_4H_6O_2$, methacrylic acid; C/LRP, controlled/living radical polymerization; CMC-A9, polymeric surfactant based on carboxymethyl cellulose and alkyl poly(etheroxy)acrylate; CMPEG, carboxymethylated poly(ethylene glycol); CMS, chloromethyl styrene; CO_2, carbon dioxide; CPDB, 2-cyanoprop-2-yl dithiobenzoate; CTAB, cetyltrimethylammonium bromide; CTMA-Cl, cetyltrimethylammonium chloride; $CuSO_4.5H_2O$, cupric sulfate; DDAB, didodecyldimethylammonium bromide; DDA-HEEE, dodecanoic acid 2-(2-hydroxyethoxy)ethyl ester (neutral surfactant); DeTAB, decyltrimethylammonioumbromide; DDM, dodecyl mercaptane; DexEst, dextran ester; DIAMA-Na, SG1-based difunctional alkoxyamine; DMAc, dimethyl acetamide; DMA, dodecyl methacrylate; DMAEMA, (dimethylamino)ethyl methacrylate; DMF, dimethylformamide; DMMA-PS, 3-(N,N-dimethylmyristylammonio) Propanosulfonate (zwitterionic salt); DMSO, dimethyl sulfoxide; $C_{12}H_{26}S$, dodecyl mercaptane; Dowfax 8390, a mixture of mono- and dihexadecyl disulfonated diphenyloxide disodium salts; DTAB, dodecyltrimethylammonioumbromide; $C_4H_8O_2$, ethyl

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1. Introduction

The field of polymer nanoparticles (PNP) is quickly expanding and playing a pivotal role in a wide spectrum of areas ranging from electronics to photonics, conducting materials to sensors, medicine to biotechnology, pollution control to environmental technology, and so forth, during the past decades [1–9]. This fact can be realized from the ever increasing number of publications as depicted in Fig. 1. This trend is based on their unique properties, which meet a wide range of applications and market needs.

The properties of PNPs have to be optimized depending on the particular application. In order to achieve the properties of interest, the mode of preparation plays a vital role. Thus, it is highly advantageous to have preparation techniques at hand to obtain PNPs with the desired properties for a particular application. Although some information regarding preparation techniques of PNPs is available, it is scattered in the literature and restricted to a few areas. For example, there are a few individual reviews on techniques such as emulsion polymerization and nanoencapsulation [10–19], but none for other techniques and none integrating all these techniques and considering the size control parameters. Therefore, the objective in this review was to collect and compile this missing information, to update the few previous reviews made on this subject, and also to highlight recent developments.

The aim of this review article is primarily not to provide comprehensive information about a particular method of PNP preparation, but to provide and explain vital crite-

acetate; EBiB, ethyl 2-bromoisobutyrate; ECNA, ethyl cyanoacrylate; EG, ethylene glycol; EUDRAGIT L100-55, methacrylic acid copolymer Type C USP/NF; $FeCl_3.6H_2O$, ferric chloride; GMA, glycidyl methacrylate; HO-EBiB, 2-hydroxyethyl 2-bromoisobutyrate; H_2O_2, hydrogen peroxide; HCl, hydrochloric acid; HD, hexadecane; HEMA, hydroxylethyl methacrylate; HMA, hexyl methacrylate; IP, interfacial polymerization; IPDI, isophorone diisocyanate; K_2CO_3, potassium carbonate; KLE3729, poly(ethylene-co-butylene)-b-poly(ethylene oxide); KPS, potassium persulfate; LMA, lauryl methacrylate; MAMA, SG1-based water-soluble alkoxyamine derived from methacrylic acid (also called BlocBuilder); $Mg(CH_3COO)_2{\cdot}4H_2O$, magnesium acetate tetrahydrate; $MgCl_2$, magnesium chloride; $MgCl_2{\cdot}6\ H_2O$, magnesium chloride hexahydrate; Miglyol 812, mixture of triglycerides; MIM, macroinimer; MONAMS, SG1-based alkoxyamine derived from methyl acrylate; mPEG, monomethoxy-poly(ethylene glycol); mPEO-PLA, monomethoxy-poly(ethylene oxide)-poly(lactic acid); MMA, methyl methacrylate; MMCO, molar mass cut-off; NaCl, sodium chloride; $NaHCO_3$, sodium bicarbonate; $Na_2S_2O_3$, Sodium Thiosulphate; NaSS, 4-styrenesulfonic acid sodium salt hydrate; $(NH_4)_2S_2O_8$, ammonium persulfate; NMA, N-methylolacrylamide; NMPy, N-methyl-2-pyrrolidone; NMP, nitroxide-mediated polymerization; NPA, N-propargylamide; NVP, N-vinyl pyrrolidone; OEOMA, oligo(ethylene oxide) monomethyl ether methacrylate; OTAB, octyl trimethyl ammonium bromide; (o/w), oil-in-water; PA, pullulan acetate; PAK-02, photocurable monomer; PANI-PSS, polyaniline-poly(styrenesulfonic acid); P(B/E-b-EO), poly(butylenes-co-ethylene)-b-poly(ethylene oxide); PBG-PEO, poly(γ-benzyl-L-glutamate)-b-poly(ethylene oxide); PCL, poly(ε-caprolactum); PDMAAm-TTC, poly(N,N-dimethylacrylamide)s (PDMAAm) with a reactive trithiocarbonate; PE/F68, poly(oxyethylene)-poly(oxypropylene) copolymer; PEO, poly(ethylene oxide); PEG, poly(ethyleneglycol); PHB, poly(hydroxyl butyrate); PHDFDA, poly(heptadecafluorodecylacrylate); PHEMA, poly(hydroxyethyl methacrylate); PLAF, poly(lactide-fumarate); PLGA, poly(D,L-lactic acid-co-glycolic acid); PLGF, poly(lactide-co-glycolide fumarate); PLLA, poly(L-lactic acid); Pluronic F-108, non-ionic surfactant; PMA, poly(α,β-L-malic acid); PMMA, poly(methyl methacrylate); P(MAA-co-S)-SG1 Macroinitiator, SG1 nitroxide-capped poly(methacrylic acid-*co*-styrene) macroalkoxyamines; P(NIPAM-MAA), poly(N-isopropylacrylamide-co-methacrylic acid); Poloxamine 908, poly(ethylene oxide)-poly(propylene oxide) ethylene diamine co-polymer; PNP, polymer nanoparticles; POP, Poly(organophosphazene); PSFTE, poly[2-(3-thienyl) acetyl-3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanoate]; PSS, poly(styrenesulfonic acid); PTMC, poly(trimethylene carbonate); PVA, poly(vinyl alcohol); Py, pyrrole; RAFT, reversible addition and fragmentation transfer; RESOLV, rapid expansion of supercritical solution into liquid solvent; RESS, rapid expansion of supercritical solution; Rh-Catyl, rhodium based catalyst; SABS, sodium 4-(ν-acryloyloxyalkyl) oxy benzene sulfonate; SDS, sodium dodecyl sulfate; SEM, scanning electron microscopy; SG1 (trade name of the Arkema group), N-tert-butyl-N-(1-diethyl-phosphono-2,2-dimethylpropyl) nitroxide; SHOA, sodium 12-hexinoyloxy-9-octadecenate; SLS, sodium lauryl sulfate; SOBS, sodiumoctylbenzene sulfonate; SMA, stearyl methacrylate; SMTAPE, 5-sulfoisophthalic acid dimethyl ester sodium salt modified tetracarboxylic acid-terminated polyester; Span 40, sorbitan monopalmitate; Span 80, sorbitan monooleate; Span 85, sorbitane trioleate; SPS, sodium persulfate; St, styrene; SWNT, single-walled carbon nanotube; TEM, transmission electron microscopy; Th, thiophene; THF, tetrahydrofuran; TMEDA, tetramethylethylenediamine; TosDex, tosyl dextran; TPGS, D-α-tocopheryl poly(ethylene glycol); TPMA, tris[(2-pyridyl)methyl]amine; Tween 80, non-ionic surfactant; VA, vinyl acetate; VA-044, 2,2′-azobis[2-(2-imidazolin-2-yl)propane]dihydrochloride; V-50, 2,2′-azobis(2-amidinopropane) dichloride; (w/o)/w, (water-in-oil)-in-water.

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