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Review Article

Mesoporous Silica: A Review

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Abstract

Mesoporous silica is a mesoporous form of silica and a recent development in nanotechnology. The most common types of mesoporous nanoparticles are MCM-41 and SBA-15.Mesoporous materials consist of inorganic metal oxides, like silica or alumina, and have pore sizes in the range of between 2 and 50 nm. They are synthesized by using a surfactant forming regularly aligned assemblies that are used as a template for the metal oxide, followed by template removal. They are also water soluble, chemically and thermally stable with mechanical strength and are toxicologically safe. In this review focused on components of mesoporous silica and its mechanism of synthesis process.

Key words: Mesoporous silica, surfactants, Mechanism of synthesis.

INTRODUCTION

Mesoporous materials with regular geometries are generating a lotof attention owing to their great potentials in practical applicationssuch as catalysis, adsorption, sensing, medical usage, ecology,nanotechnology [1-15], Chemical and biological separations,chromatography, photonic and electronic devices, drug delivery, andenergy storage[16]. Mesoporous materials are classified under porousmaterial and these porous materials are classified according to theirpore diameter [17] (table-1). Researchers had taken great efforts tosynthesize mesoporous materials such as silicas [18], transitional aluminas [19] and pillard clays. In fact, in 1990, Yanagisawa and co-workers[20, 21], described the preparation of mesoporous silicas withuniform pore size. However, the pores in these materials weregenerally irregularly spaced and broadly distributed in size.

In 1992, a research team from Mobil Oil Company synthesized anew family of materials, the so-called M41S [22-25] that presentsordered pore distributions, with homogeneous sizes rangingbetween 2 nm -10 nm, including different materials likehexagonal-MCM-41, cubic-MCM-48, and lamellar-MCM-50.Themesoporous materials were basically prepared through silicaformation around template micelle [26, 27] assemblies followedby template removal by appropriate methods such as calcinations and solvent evaporation. Different mesoporous materials are listed in Table 2.

These pioneering findings were followed by various kinds ofmesoporous materials. For example, hexagonal mesoporous silica(HMS) prepared using neutral amine as template possesses slightlydisordered hexagonal structure and thicker walls, superior thermalstability upon calcination in air, and a smaller crystallite size, whichaffords complementary textural mesoporosity for improved accessto the framework-confined mesopores[28]. Michigan State University(MSU-1) synthesized by using polyethylene oxide (PEO) as astructure directing agent also has a disordered channel structure [29].This material possesses large wall thickness and small particle sizewith considerable textural mesoporosity due to pores formedbetween the relatively small particles.

Silicas exhibit higher loading of drugs and provide a controlled drug release if modified by functionalization. Numerous interesting drugdelivery applications of mesoporous materials have beendemonstrated. Different Mesoporous material like MCM-41, SBA-15, TUD, MCM- 50, HMS, TMS etc have many important propertiesadvantageous to drug delivery applications.

Table 1: Classification of porous materials

Types of porous material	Diameter of pores (nm)	Examples
Micrporous Mesoporous Macroporous	Diameter < 2 2 < Diameter < 50 Diameter > 50	Zeolites, AlPO4 HMS,MCM-41,SBA-15 Porous gel, Porous Glasses

Table 2: Different mesoporous materials

Mesoporous material	Full name
MSU	Michigan State University
SBA	Santa Barbara Amorphous
MCM	Mobil Crystalline Matter/ Mobil Composite Matter
HMS	Hollow Mesoporous Silica
OMS	Ordered Mesoporous Silica
TUD	Technische Universiteit Delft
MCF	Meso Cellular Form
FSM	Folded Sheet Mesoporous

Fig1: Schematic representation of theformation of MCM-41 materials. [33]

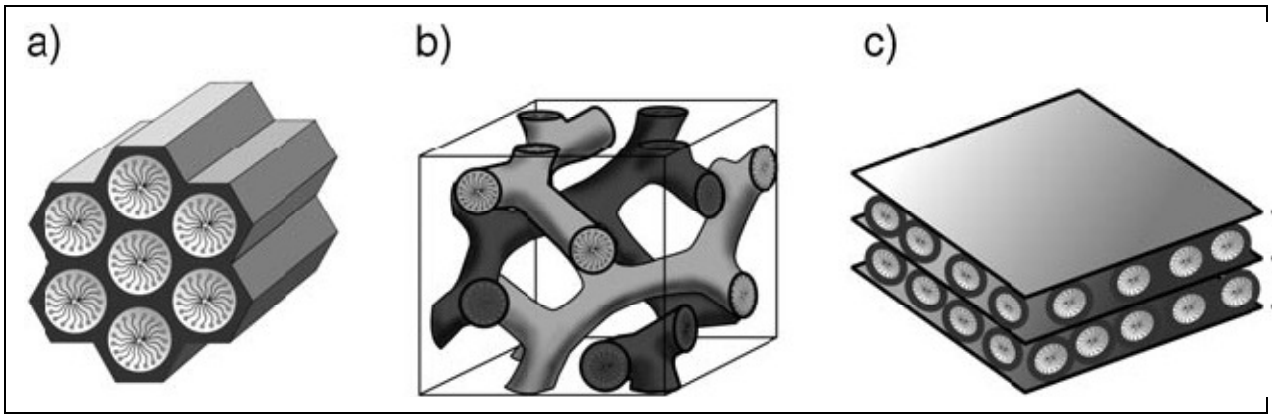

Fig 2: Structures of mesoporous M41S materials: a) MCM-41 (2D hexagonal, space group p6mm), b) MCM-48 (cubic, space group Ia3¯d), and c) MCM-50 (lamellar, space group p2).[31]

The small size of the pores confines the space of a drug and engages the effects of surface interactions of the drug molecules and the porewall. The size of the pores and the surface chemistry of the pore-walls may be easily changed and controlled. Depending on the size and the surface chemistry of

the pores, increased or sustainedrelease of the loaded drug can be obtained. Sensitive therapeuticcompounds susceptible to degradation, like peptides and proteinsare also effectively loaded with mesoporous material. This article reviews the fabrication and chemistry of mesoporous MCM- 41 forbiomedical applications, and also the potential advantages ofmesoporous MCM- 41 in drug delivery.

Introduction to mesoporous silica

Mesoporous materials consist of inorganic metal oxides, like silica or alumina, and have pore sizes in the range of between 2 and 50 nm. They are synthesized by using a surfactant forming regularly aligned assemblies that are used as a template for the metal oxide, followed by template removal. They are also water soluble, chemically and thermally stable with mechanical strength and are toxicologically safe. At the surface of the mesoporous silica materials there are silanol groups that can be utilized for enzyme immobilization by hydrogen bonding between hydroxyl groups and carbonyl or amino groups on enzyme molecules. The surfactant is crucial in the synthesis since it will decide the size of the formed pores and a wide variety of different surfactants can be used. The main surfactant used in mesoporous synthesis is non-ionic block copolymers.

This mechanism was proposed by *E. Davis et al.* in 1993 [32], where silica is arranged in liquid crystal template, made by CTAB. It could be interesting to do a fast and simple classification of mesoporous materials according to this work. Silica Mesoporous Materials are synthesized using amphiphilic molecules as a template for their internal structure. At the beginning cationic surfactants were used to create these materials. Varying the conditions of the syntheses we could obtain two different types of internal structures: two-dimensional hexagonal structure (*p6mm*) also known as MCM-41[33,34] tridimensional cubic structure (*Ia d*), known as MCM-48. When we got a two-dimensional hexagonal structure, but instead of a cationic surfactant we use a tribloc copolymers such Pluronic P123, that material is also called as SBA-15[35,36]. SBA materials have been reported as hydrothermally more stable due to their thicker walls [36]. The structure of the surfactants used in these materials is *(EO)x-(PO)y-(EO)x*. When *x* has a value between 17 and 37, then we get SBA-15 materials. X also affects on the wall thickness. The value of *y* has more relation with the pore size of the material. Another advantage of SBA-15 materials is that they have disordered micropores, which allows the connection between mesopores [36].

Surfactants

Surface active agents, or also known as surfactants are molecules that have tendency to adsorb at the surfaces and interfaces. They have a dual chemical structure, one part of the molecule is hydrophilic and the other is hydrophobic. Surfactant with amphiphilic character adsorb on the interface to reduce the free energy of phase boundary. Basically, the surfactants could be in three forms: some solubilised in water as singlemolecules; others are in the interface water-air and they could be in the interface watersolidrecipient. After reached the saturation of all those interfaces, the entire surfactantremaining in the water is on form of clusters called micelles. This point, when the firstmicelle is formed, is called Critical Micelle Concentration (also known as CMC). The CMCdepends on chemical structure of each compound, for instance, on the length of thehydrophobic tail, as much longer, lower the CMC. This phenomenon can be explainedbecause the longer carbon chains are trying to get together, this implies a lower energyand therefore more stable systems. CMC is a really important value for surfactants. [37] One popular way to classify the surfactants is according to their charge in the polarhead. Then, we can make these 4 groups:

Anionics

This family of surfactants has negatively charged polar head groups. The non-polar group is used to be a large hydrocarbon chain between C12 and C18 range. The polar groups mostly used in this kind of surfactants are carboxylates, sulphates, sulfonates and phosphates.

Cationics

They have a positive charged polar head group and a large alkyl chain as a non-polar group. This family is based on nitrogen atom. Amine and quaternary ammonium-based products are common as a head group.

Non-ionics

Non-ionic surfactants have a polyether or a poly-hydroxyl unit as the polar group. Actually the poly(ethylene oxide) is the most common polar group. As a non-polar group poly(propylene oxide) is probably the most common. In this family, we should emphasize on the block copolymers. These copolymers have a relatively low molar mass. They are composed by blocks of different polymerized monomers.

Zwitterionics

This is the last family of surfactants. They have two different charges of different sign on their head group giving a neutral charge. The most common positive charge is given by an ammonium group, the source of negative charge may vary, but carboxylate is by far the most common.[38]

Different types of Synthesis of Mesoporous Silica

The synthesis of MCM - 41 (Mobil Composition of Matter) is the initial name given for a series ofmesoporous materials that were first synthesized by Mobil's researchers in 1992. MCM - 41 (Mobil Composition of Matter No. 41 or Mobile Crystalline Material) is reminiscent of the synthesis of zeolites with a self-assembled surfactant molecular array forming the template. These surfactants are burned off at a later stage of preparation in order to yield the mesoporous MCM-41. Liquid extraction is another method to recover the surfactant from the assynthesized MCM-41, and it allows the surfactant to be recovered for reuse. Depending on extraction conditions, MCM-41 materials after Kawi and Lai (2002) claims that Supercritical Fluid Extraction (SFE) can retain their uniform pore-size distribution and high surface areas and have a larger pore size than the calcined MCM-41. The extracted template is also unmodified and may be reused in future synthesis. SFE also allows much faster extraction as compared to conventional liquid extraction[39].

Samata *et al.* (2003) synthesized iron-rich highly ordered mesoporous Fe-MCM - 41. Ziolek *et al.* (2004) synthesized templates for MCM-41 mesoporous molecular sieves using transition metals like copper, iron, niobium, vanadium and molybdenum[40]. Yaofeng shao *et al.* (2005) synthesized hydrothermally stable and long range ordered Ce-MCM-48 and Fe-MCM-48 materials. Ying Li *et al*.[41](2005) performed direct synthesis of highly ordered iron-substituted SBA-15 (Fe-SBA-15) material under weak acidic conditions.The concept on microwave heating was introduced by Zaki Seddegi *et al*.[42] (2002). MCM-41 samples with smaller pore diameters and thinner walls were achieved by microwave heating than the materials synthesized using conventional heating. They have also showed that MCM-41 with all-silica composition catalyzes the cracking of high-density polyethylene. The cracking activity of the catalyst increases with its crystalinity. MCM-41 with small pore diameter gave higher activity than that with large pore diameter. There are two major pathways by which these ordered mesoporous materials are synthesized. (i) a hydrothermal synthesis in which the products precipitate from inorganic surfactant aqueous solutions under alkaline or acidic conditions at temperatures as high as 373 K and (ii) a solvent evaporation method in which the source solution is concentrated with the evaporation of the solvent to form an ordered inorganic surfactant mesostructure. Using these methods small scale production only can be done.

Whereas Akira Endo *et al.* (2006), found a method for large scale and continuous formation of Mesoporous silica. There are two rate processes in their synthesis method (i) the rate of solvent evaporation includes the self-assembly of the surfactant micelles and (ii) the rate of polycondensation of the silica species. It is considered that the well orderd mesostructures can be obtained only when these two rate processes are well balanced. To produce the large amount of the products within a short time, it is necessary to evaporate the solvent rapidly without change.[43]

Yeping Xu *et al.* (2008) have suggested a novel, fast and environmentally benign synthetic pathway for the synthesis of pure and functionalized mesoporous silica. This pathway employs hyper branched polyglycerol (PG) with average molecular weights of 5000 and 6000 g mol-1 as templating agents. This low cost template is innocuous, biocompatible, and works without requiring organic solvents. The templating mechanism was based on the size of hyper branched PGs revealed from small-angle neutron scattering (SANS) measurements. They

have shown that single-particle PG dendrimers that can be adjusted from 2 to 5 nm, which corresponds to molecular weights of 2,000 to 10,000 gmol-1.The expected template size of PG with an average molecular weight of 6,000 gmol-1 is around 4 nm based on SANS measurements. As a template, hyper branched PG differs greatly from the surfactants described above. Owing to its almost spherical structure, it cannot form micelles or large-scale clusters. As a result of the good water solubility of PG, the template can be removed by water extraction without the need for organic solvents[44].

Mechanism of Synthesis of Mesoporous Silica MCM41

The synthesis of mesoporous material is one of the most importantsubjects in modern pharmaceutical science. The synthesis andapplications of mesoporous materials prepared using surfactant astemplates have attracted great attention since the discovery of theM41S family of mesoporous molecular sieves by scientists at theMobil Corporation. The main characteristics of MCM-41 materialsare their high thermal stability, large surface area and narrow poresize distribution.Different synthesis strategies have been proposed and successfullyused. However, there is one thing all these procedures have incommon next to the obvious presence of a source of silica, viz. atemplating agent. A template is a structure-directing agent, which isusually a relatively simple molecule or ion, around which aframework is built up. The most common templates for the synthesisof MCM-41 are quaternary ammonium ions with long alkyl chain,generally a hexadecyl group.The energetically most favourable form of micelles is spherical,because in this geometry the surface energy is minimised mostefficiently.

According to Myers [45], the particular phase present in a surfactant aqueous solution at a given concentration depends not only on the concentrations but also on the nature of itself (the length of the hydrophobic carbon chain, hydrophilic head group, and counterion) and the environmental parameters (pH, temperature, the ionic strength, effect of stirring, effect of addition of silica source and other additives). Once MCM-41 has been formed its pores are filled with template and in order to obtain a completely mesoporous support material the micelles must be removed. The most elegant solution to this demand is removal by means of repeated washing with (slightly acidified) mixtures of organic solvent and water, resulting in extraction of the template. The resulting solutions, containing the template, can be evaporated to dryness, which leads to recovery of the template. If the synthesis conditions were relatively mild the template will not have decomposed and can be re-used for a next synthesis. A simpler method for template removal is calcination. During this process template is decomposed into CO2, some NOx and steam. Certain factors greatly affect the properties and characteristics of mesoporous MCM- 41, some of the factors are discussed below. The most frequently used template for the synthesis of MCM-41 is hexadecyl (cetyl) trimethyl ammonium bromide (or chloride), i.e. a template with an alkyl chain containing sixteen -CH2 moieties. This template yields MCM-41 with a uniform pore size. Using templates with longer or shorter alkyl chains the pore size of MCM- 41 can be influenced.

Different research articles revealed the use of cationic surfactant for the synthesis of mesoporous silica, though several articles imposed the use of anionic surfactant as well as non ionic surfactant also [46,47]. The variation in the sizes and shapes of the templates leads to the formation of mesoporous materials with different pore sizes and structures. The mesoporous materials that are prepared using anionic surfactants show chiral properties in their pores, and thus, they attract much attention as adsorbents that are useful in the separation of chiral drug molecules [48,49]. Cationic surfactants with increased carbon chains length show increase in the size of micelles [50,51]. Although the increase in the length of the carbon chains of anionic surfactants definitely results in the enlargement of the mesopores, the extent of the enlargement is not sufficient due to the difficulty in the preparation of long chain surfactants.

Furthermore,the addition of alkylbenzenes and amines to the synthetic mixtures of mesoporous materials containing anionic surfactants is usually ineffective in enlarging their pore sizes. One research article imparts that, when ordered mesoporous materials have been synthesized using mixture of surfactants such as cationic/nonionic [52] and cationic/anionic surfactants [53], give rise to meso-

porous materials with well-defined pore sizes and morphologies. Mixtures of surfactants with different charges allow a wide variety of silica sources and synthetic conditions for the preparation of mesoporous materials. The surface properties of the pore walls are also differentaccording to the type of surfactant used. Silanol groups on the pore walls are also susceptible of undergoing a chemical modification with a large variety of organic groups through functionalization process.

The result shows that drug loading increased from 14% (unmodified) to 37% (modified) for grafted materials MCM-41. The pH of the synthesis procedure also has influence on pore size and volume of MCM-41. Cheng and his colleague studied the post synthesis structural modulation of silica by the treatments with the ammonia solution of NH4OH and the aqueous solution of H2SO4. Their investigation revealed that NH4OH treated silicas generally have smaller unit cell parameters, smaller mesopores sizes and lower pore volumes, while the H2SO4 treatment gave materials with larger mesopores sizes and pore entrances but very low pore volumes [54].

Organically Functionalized Mesoporous Silica-Phases

The combination of the properties of organic and inorganic building blocks within a single material is particularly attractive from the viewpoint of materials scientists because of the possibility to combine the enormous functional variation of organic chemistry with the advantages of a thermally stable and robust inorganic substrate. This isparticularly applicable to heterogeneous catalysis. The symbiosis of organic and inorganic components can lead to materials whose properties differ considerably from those of their individual, isolated components.

Adjustment of the polarity of the pore surfaces of an inorganic matrix by the addition of organic building blocks extends considerably the range of materials that can be used, for example, in chromatography. Equally interesting is modification with organic functionalities such as C-C multiple bonds, alcohols, thiols, sulfonic and carboxylic acids, and amines, etc., which allow, for example, localized organic or biochemical reactions to be carried out on a stable, solid inorganic matrix. Three pathways are available for the synthesis of porous hybrid materials based on organosilica units:

Postsynthetic Functionalization of Silicas ("Grafting")

Grafting refers to the subsequent modification of the inner surfaces of mesostructured silica phases with organic groups. This process is carried out primarily by reaction of organosilanes of the type (R'O)3SiR, or less frequently chlorosilanes ClSiR3 or silazanes HN(SiR3)3, with the free silanol groups of the pore surfaces (Figure 4). In principle, functionalization with a variety of organic groups can be realized in this way by variation of the organic residue R. This method of modification has the advantage that, under the synthetic conditions used, the mesostructure of the starting silica phase is usually retained, whereas the lining of the walls is accompanied by a reduction in the porosity of the hybrid material (albeit depending upon the size of the organic residue and the degree of occupation). If the organosilanes react preferentially at the pore openings during the initial stages of the synthetic process, the diffusion of further molecules into the center of the pores can be impaired, which can in turn lead to a nonhomogeneous distribution of the organic groups within the pores and a lower degree of occupation. In extreme cases (e.g., with very bulky grafting species), this can lead to complete closure of the pores (pore blocking). The process of grafting is frequently erroneously called immobilization, which is a term that we believe should be reserved for adsorptive methods (e.g., the removal of toxic or environmentally relevant contaminants by adsorbent materials, or the separation of proteins and biocatalysts by restriction of the freedom of movement). 2.2. Co-Condensation (Direct Synthesis) An alternative method to synthesize organically functionalized mesoporous silica phases is the co-condensation method (one-pot synthesis). It is possible to prepare mesostructured silica phases by the co condensation of tetraalkoxysilanes [(RO)4Si (TEOS or TMOS)] with terminal trialkoxyorganosilanes of the type (R'O)3SiR in the presence of structure-directing agents leading to materials with organic residues anchored covalently to the pore walls (Figure 5).

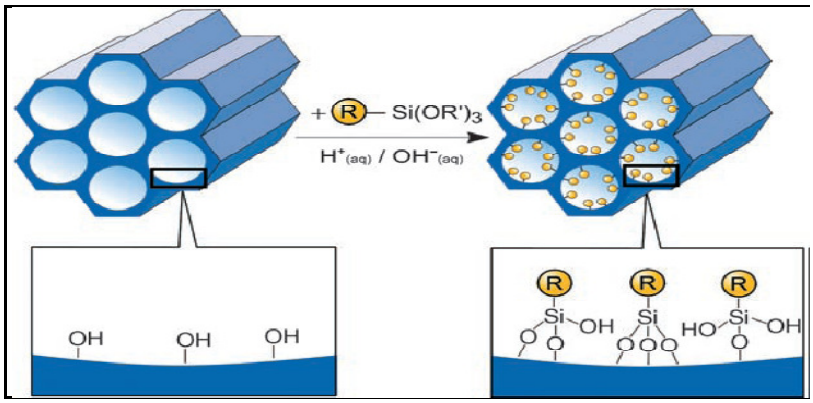

Fig 3: Grafting (postsynthetic functionalization) for organic modificationof mesoporous pure silica phases with terminal organosilanesof the type (R'O)3SiR. R=organic functional group.

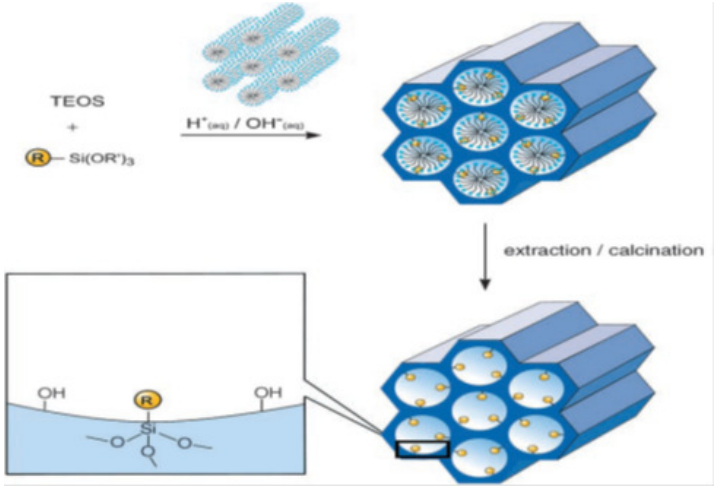

Fig4: Co-condensationmethod (direct synthesis) for the organicmodification of mesoporous pure silica phases. R=organic functionalgroup.

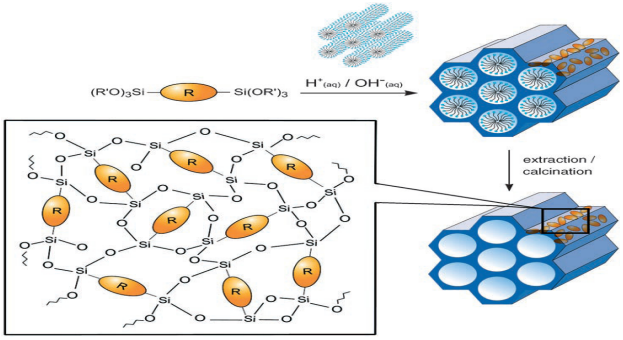

Fig5: General synthetic pathway to PMOs that are constructed frombissilylated organic bridging units. R=organic bridge.

2. Co-Condensation (Direct Synthesis)

Alternative method to synthesize organically functionalized mesoporous silica phases is the co- condensation method (one-pot synthesis). It is possible to prepare mesostructured silica phases by the co-condensation of tetraalkoxysilanes [(RO)4Si (TEOS or TMOS)] with terminal trialkoxyorganosilanes of the type (R'O)3SiR in the presence of structure-directing agents leading to materials with organic residues anchored covalently to the pore walls (Figure 5). By using structure-directing agents

known from the synthesis of pure mesoporous silica phases (e.g., MCM or SBA silica phases), organically modified silicas can be prepared in such a way that the organic functionalities project into the pores. Since the organic functionalities are direct components of the silica matrix, pore blocking is not a problem in the cocondensation method. Furthermore, the organic units are generally more homogeneously distributed than in materials synthesized with the grafting process.

However, the cocondensation method also has a number of disadvantages: in general, the degree of mesoscopic order of the products decreases with increasing concentration of (R'O)3SiR in the reaction mixture, which ultimately leads to totally disordered products. Consequently, the content of organic functionalities in the modified silica phases does not normally exceed 40 mol%. Furthermore, the proportion of terminal organic groups that are incorporated into the pore-wall network is generally lower than would correspond to the starting concentration of the reaction mixture. These observations can be explained by the fact that an increasing proportion of (R'O)3SiR in the reaction mixture favors homocondensation reactions—at the cost of cross-linking co-condensation reactions with the silica precursors.

3. Preparation of Periodic Mesoporous Organosilicas (PMOs)

The synthesis of organic–inorganic hybrid materials by hydrolysis and condensation reactions of bridged organosilica precursors of the type (R'O)3Si_R_Si(OR')3 has been known for a long time from sol–gel chemistry.[55,56] In contrast to the organically functionalized silica phases, which are obtained by postsynthetic or direct synthesis, the organic units in this case are incorporated in the three-dimensional network structure of the silica matrix through two covalent bonds and thus distributed totally homogeneously in the pore walls.

The transfer of the concept of the structure-directed synthesis of pure silica mesophases by surfactants to the bissilylatedorganosilica precursors described above allows the construction of a new class of mesostructured organic– inorganic hybrid materials—periodic mesoporous organosilicas (PMOs)—in which the organic bridges are integral components of the silica network (Figure 6). In contrast to amorphous aero- and xerogels, PMOs are characterized by a periodically organized pore system and a very narrow pore radius distribution. The first PMOwas synthesized in 1999 by three research groups working independently of one another.[57,58]PMOmaterials are considered as highly promising candidates for a series of technical applications, for example, in the areas of catalysis, adsorption, chromatography, nanoelectronics, or the preparation of active compound release-systems.

Method of Drug Loading

1. Physical Adsorption Method

2. Organic Solvent Immersion/ Adsorption Method

3. Incipient Wetness Impregnation Method

4.Melt Method

5. Liquid and SC-CO2 Loading

6. Physical Mixing

Physical Adsorption Method

Physical adsorption is most widely used method for loading of drug molecules into mesoporous material from organic solution.TheSi-OH (Silanol) group of silica surface acts as adsorption sites, usually 2-4 groups of silanol present per nm of mesoporous silica.At isoelectric point where surface charge is zero at pH 2-3 i.e. in absence of specific ion adsorption, the silica surface is negatively charged under biological conditions. Therefore electrostatic adsorption if positively charged adsorbate is a prominent method for incorporating watersoluble drug in mesoporous material. The extent of adsorption can be further increased by incorporating functional groups onto silica surface, which can be used to tune the effective surface charge under given pH conditions. Hydrophobic drugs are typically adsorbed from organic solvent followed by vacuum drying to remove solvent from carrier material.[59]

Organic Solvent Immersion/ Adsorption Method

This method can be categorized into following steps; In 1st step the incorporation/immersion of mesoporous material into concentrated drug solution and filling of the pores through capillary action. 2nd steps the diffusion of drug molecules into the mesopores and adsorbed on the pore walls of

mesoporous material. In 3rd steps the recovery of drug loaded matrix from solution by filtration.[59]

Incipient Wetness Impregnation Method

In this method concentrated drug solution prepared by using organic solvent to obtained high degree of loading.The volume of drug solution equals to the pore volume of mesoporous carriers, as compared to immersion method. In both cases the pores of mesoporous material filled by capillary action. This method advantageous when small amount of drug is available and easy to determine the amount of the loaded drug but drawback is the difficulty to control the uniformity of the drug distribution. Furthermore the remaining drug recrystallizes on the external surface of mesoporous material after solvent evaporation.[59]

Melt Method

In this method the blend of drug and mesoporous material is heated until drug melts and enters into the pores of carrier material. But many drugs cannot withstand melting without any degradation or deterioration and also high viscosity of melted drug can be unfavorable for successful drug loading.[59]

Liquid and SC-CO2 Loading

The drug and mesoporous material were mixed or combined in a BC 316 High Pressure Reactor and stirred by using magnetic stirrer. The cell was heated to 25^{o}c using heating tape and maintained constant for whole experiment. The reactor cell was filled with liquid CO2. A High Pressure Pump was then used to pump additional CO2 to a final processing pressure i.e. 27.58 MPa. The cell was depressurized rapidly by venting the CO2 at the end of process or experiment. The SC-CO2 loading process followed same above procedure but instead of heating cell 25^{o}c, it is heated up to 40^{o}c.[59]

Physical Mixing

In this method the drug and mesoporous material mixed together by blending drug and SBA-15 for 30 min at 100 rpm.

Applications

Silica Mesoporous Materials can provide our society with several advantages.Mesoporous silicates synthesized by using a surfactant template method are reallystable, and they have narrow pore sizes. They can be used in different fields, suchseparation techniques, adsorption, catalysis, drug delivery, sensors, or photonics forinstance.In the field of biocatalysis or drug delivery, these materials are interesting due to theycould be used to encapsulate proteins inside their pore structure. If these proteins wereencapsulated into mesoporous materials, their stability would be increased (due to theprotection that the mesoporous materials provide) as well as recycling possibilities.[45,47]

The characteristics for these mesoporous silicates have to be optimum in order toprotect the enzymes but at the same time allow some movement of the enzymes anddiffusion of substrate into the pores. That requires an optimum pore size. If the porediameter is large, the diffusion rate of the substrate into the pores is high and we canreach a higher product formation, on the other hand large pore sizes contributes toincrease the leaching of the enzymes since they are weakly adsorbed to the surface. Ifthe pore diameter is narrower, the lipases would be more protected, the leaching wouldbe reduced as well as we will get an enhanced hydrothermal stability but at thesame time they will block the pass of the reactants trough the pores.We should talk about the particle size and its importance. During encapsulationenzymes only reach short distance down the pore, it means that with smaller particleswe would get a higher loading capacity. In addition reducing the particles size we areincreasing the contact area.[45]

Future Potential

Nanotechnology is a fast-growing area, involving the fabrication and use of nano-sized materials and devices. Various nanocomposite materials play a number of important roles in modern science and technology. Porous inorganic nanoparticles are of particular importance due to their broad range of potential applications. The synthesis of the mesoporous silicas MCM-41 and MCM-48 in 1992, using a supramolecular surfactant system as a template, provoked a boom in mesoporous materials. Mesoporous materials (MCM-41), the basis for nano-technologies, are one of the fastest developing fields in pharmaceutical science. It has been shown that ordered mesoporous silica with stable mesoporous structure, large surface area, good biocompatibility and tailored size of mesopores and func-

tionalisation has exhibited promising application as drug delivery system. The mesoporous silica demonstrates higher drug loading followed by controlledsustained release as well as immediate release. The drug release rate is governs by pore size and functional groups on the wall. Functionalisation of MCM-41 leads to cover the walls of silicaresulting in pore size decrease and lower drug loading; however, it brings in controlled drug release. In most cases, drug release is a diffusion-controlled process and exhibits a two-stage profile. However, few investigations have been attempted to explore the drug release kinetics and more work should be focused because the understanding of kinetics will help in the achievement of controlled drug release. Surface functionalisation with various groups can change electrostatic, hydrophobic/hydrophilic forces, and the adhesive interactions of drug and matrix, inducing varying drug loading and delivery rate.

Moreover, functionalization with differentgroups will make the systems attached to cell and biological species such as proteins and enzymes. Future work should be directed to development of non-immunogenic polymer/mesoporous solid as drug carrier, which will show more advantages than glass-polymersystems. There are also many emerging biotechnologies that can benefit from the mesoporous materials-based drug delivery. Bone tissue engineering is an emerging area directed towards the design of materials that will help an organism to improve its ability of regeneration by recovering both the structure and also its function. Biocompatible and bioactive mesoporous materials with controlled drug delivery will favour the cellular growth and bone regeneration.Research should be directed towards finding suitable combination of bioactivity and controlled drug delivery kinetics. For direct drug delivery, nanosize particles have been attracted much attention. These nanoparticle carriers can effectively penetrate or pass through the cell membrane into cells, achieving controlled cellular delivery. Although a lot of inorganic nanoparticles have been produced, little work has been done in synthesis of nanosizemesoporous silica particles. The combination of the mesoporous characteristics and the properties of nanoparticles will provide a fascinating application of nanoparticles for biotechnology and biomedicine and more efforts should be attempted. Many potential applications of mesoporous MCM-41 have beenexplored, from catalysis, separation, biology, environmental monitoring, and pharmaceuticals to clinical toxicology, but a gap in real industrial applications still exists. The great challenge facing the mesoporous materials community now is to transfer laboratory studies to industrial applications. Although the potential applications of such materials have been widely studied in many areas, more efforts are still needed for the continuing study of their practical applications to commercialize mesoporous materials in the future.

Conclusion

In a nutshell, MSN has been noticed innanoscience and biomedical science for its versatileusage. The biocompatibility nature of MSN draws aspecial attention in drug delivery. The porous nature ofthe material helps to create biosensors, to immobilizeenzymes and to create stationary phase in HPLC.Also porous nature makes MSN as molecular sieves.Apart from this, thermal stability with vast surface areaof MSN allows it to be a very good catalyst forcracking of polymer. Different synthesis methodsincluding, cost effective methods and methods forachieving different pore shapes have been discussed inthis over view. Finally, MSN is a multiple abilitymaterial which can be used in many branches ofscience.

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