Chemical Sciences Journal
ISSN: 2150-3494

Kaur and Singh, Chem Sci J 2018, 9:3
DOI: 10.4172/2150-3494.1000192

Research Article Open Access

A Brief Review of Construction, Working and Applications of Nanoreactors

Mandeep Kaur[1] **and Bahaderjeet Singh**[2*]

[1]*Department of Applied Chemistry, MRSPTU, Bathinda, Punjab, India*

[2]*Department of Agriculture, Guru Kashi University, Talwandi Sabo, India*

[*]**Corresponding author:** Singh B, Department of Agriculture, Guru Kashi University, Talwandi Sabo, India, Tel: 011-9417552552; E-mail: sidhubahaderjit@yahoo.in

Received date: June 26, 2018; **Accepted date:** July 25, 2018; **Published date:** July 30, 2018

Abstract

This review aims to summarize the broad range of nanoreactors that have been constructed from artificial and biological materials using covalent and non-covalent approaches. The main center of attention is on self-assembled systems that are variable in size from a few nanometers to micrometers. The major advantage of self-assembled nanoreactors, is their ability to mimics a cell easily and contain a cavity which provide surface area to take place a chemical reaction. This account also summarizes their synthesis, characteristic features, and important biological applications in the field of Diagnosis, Theragnostics and Therapeutics. Block copolymers have inherent ability to self-aggregate in well-defined micelles which show excellent ability as nanoreactors to synthesize Au NPs. A fine grouping of micelle and nanoparticles makes them fine target delivery vehicles in various biological systems but the primary requirement to achieve the desired results in case of chemotherapy, cytotoxicity and other biological applications, is to use them in a highly precise manner. Hollow mesoporous @M/CeO_2 (M=Au, Pd and Au-Pd) nanospheres can be used as effective nanoreactors with superior catalytic activity and stability for reduction of 4-nitrophenol due to their hollow mesoporous structural features.

Keywords: Nanoreactors; Micelle; Nanoscale; Polymers; Biosensors; Vesicles; Polymersomes

Introduction

Nanoreactors are small sized chemical reactors predominantly used in the field of nanotechnology and nanobiotechnology, known for their high activities due to their large surface area. However, their blend is often complicated in term of stability and reproducibility. But chemists can synthesize artificial nanoreactors to control chemical reactions [1]. The rise of nanotechnology has independently developed the new branch of chemistry which deals with different types of synthetically generated nanoreactors i.e., nanopores, hollow nanoparticles, nanoholes, and tubular nanostructures [2]. Nanoreactors change the basic chemical nature of molecules and an element within them and alter how they behave in chemical reactions. They can be used not only to speed up a reaction, but also to gain new fundamental understanding of a chemical system. Fundamental chemical principles change when systems are restricted to spaces with nanoscale dimensions [3]. Nanoreactors have an ability to create unique chemical environment which is different from the surrounding bulk space [4]. They are minute systems which make possible a specific chemical reaction, as a catalyst does. Many are found in biological systems, such as certain proteins [5].

Nanoreactors are the result of new and exciting research that provides vessels that carry out chemical reactions on a nanoscale [6]. They can create isolated environments for specific reactions and regulate them to the tiny space inside the shell. Organic reaction occurs in organic nanoreactors, the spotlight is on their properties and uses and of known, little examined nanoreactor compounds and Porous materials such as organic compounds containing a cavity which can encapsule one or more molecules [4]. Restrained space within a nanoreactor can isolate the molecules/compounds from the outer mass and affects the reaction inside the nanoreactor. Proteins pores and channels are popular nanoreactors because they can be formed in lipid bilayers and have constant and well-defined volumes [7].

Nano-bioreactors can be built by controlling the position of two enzymes in the central reservoir or in a membrane of synthetic nanoscopic material. They develop a new class of biomimetic compounds those have various significant applications in the synthesis of nanomaterials, catalyzing reactions inside the cell, enzyme therapy, etc. [7]. They make an appearance and promising new molecular technology for Nanocatalysis in which catalysis nanoparticles are confined in hollow nanostructures by permeable shells that can be used to control the catalytic processes. The highly confined atmosphere of a nanoreactor can result in considerable changes to chemistry in contrast to that observed in surroundings [8]. For example, fluorescence was observed for the system involving the synthetic construct and naturally occurring protein, highlighting how confinement can be used to selectively control the interaction of molecules that give rise to fundamental physical properties [9].

Roy et al. investigated that dynamics of water changes within the gyroid phase of Gemini surfactant [10]. Tomas and colleagues showed that catalytic reactions can also be assisted inside nanoreactors [11]. Pileni et al. displayed that the applicability of nanoreactors is no limited to chemical reactions between molecules [12]. In their systems, nanocrystals growth into complex colloidal supracrystals was achieved through superlattice- matched epitaxial overgrowth along colloidosomal nanoreactors. Palivan et al. introduced another important type of nanoreactors- a polymer template in which binding site is between 4.3 and 31.5 nm apart [13].

Nanoreactors are ideal candidates for applications in various domains, for example, biosensors for the diagnosis of diseases,

analytical tools to study chemical reactions etc. [14,15]. Nanoreactors can have various applications in effluent treatment of industrial waste as they can emulsify water, create hydrofuels etc. Nanoreactors have various applications food and beverage industries to improve food processing, develop cooking bases for soup, emulsifying non- alcoholic beverages.

Types of Nanoreactors

Molecular nanoreactor

Capsules and boxes, covalent system: The most proficient catalysts are enzymes, their properties such as high selectivity and efficiency has derived the chemists to generate synthetic catalytic system. The most important characteristic of an enzyme is that the activated complex is generally more stable than the enzyme-substrate complex itself. Using this property of enzymes as a blueprint, various approaches has been to produce low molecular weight catalyst which contain a substrate binding site that recognizes substrates next to an active site. First example of nano-bioreactor was crown ethers and cryptands with contain catalytically active functional groups arranged in the correct position of a complexed substrate, close to the reacting group [16]. Cyclodextrins (CDs) are natural molecules those contain cavity, so they have been extensively used as binding sites in supramolecular catalysts [17]. A myriad of a catalytically active CDs has shown to be selective catalysts in ester hydrolysis reaction [18]. Other examples are iron porphyrins attached to one [19] or more CDs, by varying selectivity and efficiency of substrate that are bound in the CD cavity, they have been used as oxidation catalysts [20].

Non-covalent system: Covalently built capsules have established their values as catalyst. However, as the complexity and size of the target product of their reactions increases, quick preparation and design of a capsule-shaped catalysts in a covalent manner is very complicated, it involves costly multistep synthesis that produce only little yield of material. The catalysts produced in covalent fashion are not very adaptable because they are highly precise to catalyze limited number of reactions. "Molecular softball" prepared by the assembly of extensive subunits of glycoluril moieties connected across seven fused rings, is a typical example of a large capsules. The softball was able of encapsulate two aromatic solvent molecules [21] and this tendency encouraged the researchers to use it as a microreactor for biology e.g., Diels-Alder reaction between p-benzoquinone [21] and cyclohexadiene [22]. In the presence of the 20-20 capsules, the reaction rate increases 200 in p-xylene-d10 solution. Illustration from this was made that both starting materials are complexed within the capsule and their closeness based on chemical properties which helps to increase the reaction rate.

Micelle-based systems: Micelles are generally spherical complexes, in comparison with vesicles or self-assembled capsules they are not well-defined systems. A typical micelle forms an aggregate of hydrophilic "head" regions in contact with surrounding solvent in aqueous solution and sequester of hydrophobic tail regions in the micelle centre as shown in Figure 1 [22]. The transition metal-catalyzed reactions in water in the presence of surfactants were first published by Menger et al. [23]. Recently, the biomimetic oxidation reactions in aqueous micelles were reported by Rabion et al. they explain a methane monooxygenase enzyme model consisting of iron complexes, which in the presence of cetyltrimethylammonium hydrogensulfate oxidize cyclohexane with the help of tert-butylhydroperoxide to form cyclohexanol and cyclohexanone [24]. Various acid-catalyzed reactions in water in the presence of surfactants studied by Kobayashi et al. [25].

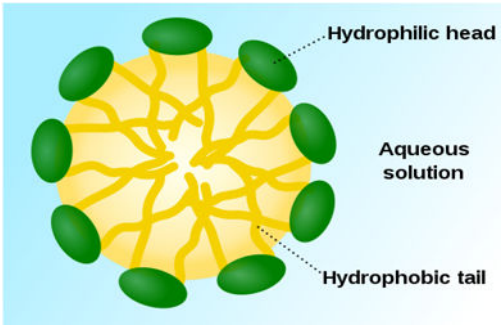

Figure 1: Structure of micelle formation in an aqueous solution.

Vesicle-based systems: In 1973, the importance of vesicle as possible membrane models was first documented by Gebicki and Hicks [26,27]. They arranged closed bilayer structures by shaking thin films of oleic acid and linoleic acid in an aqueous solution (Figure 2). The first example of vesicle formation by a completely synthetic amphiphile i.e., DDDAB was first given Kunitake et al. [28]. This study helps to explore detailed properties of biomembranes and mimic their functions, by using a various of synthetic surfactants. The iron (III) tetrakis which contain different metals in its central core was used to create a self-assembled system, 20 mol of acetophenone per mol of Mn from ethylbenzene can be produced by reductive activation of molecular oxygen. The interaction between a cell-membrane and a membrane-bound enzyme is even more complex than the interaction of synthetic catalysts with micelles or vesicles.

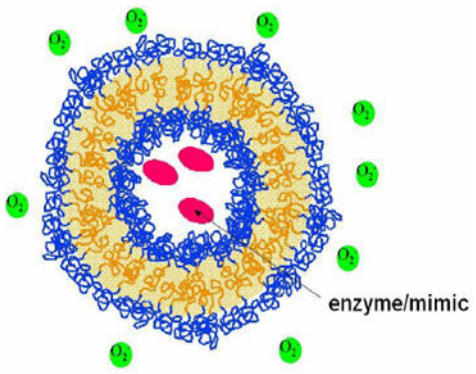

Figure 2: Scheme of vesicle formation on which nanoreactors are based.

Macromolecular nanoreactors

Polymersomes as nanoreactors: Polymersomes also called Polymer vesicles, are spherical compartments formed by a polymer membrane that separates an inner aqueous pool from the environment as shown in Figure 3. Polymersomes feature the advantage of a dual-carrier role they can serve as hosts to hydrophilic molecules inside their cavities and to hydrophobic molecules in their membranes [29,30]. The

permeability of the membranes of block copolymers vesicles is reduced because of their higher thickness and their membranes have less fluidic character as compared to liposome's [31]. The advantage of Polymersomes over liposome is that they are more stable and rigid of their membrane system, which increases their lifetime. The Polymersomes are even stable in blood and do not react with white blood cells (WBCs) and cultured cells. Meier et al. have developed a nanoreactor by incorporating the OmpF channel protein in the membrane and enzyme (lactamase) inside the water pool of polymersomes from the amphiphilic triblock copolymer like poly(2-methyloxazoline)-b-poly(dimethylsiloxane)-b-poly(2methyloxazoline) (PMOXA-PDMS-PMOXA) [32]. With increase in the transmemebrane potential above 100 mV, the OmpF channel protein got closed. Because the molecules over 400 g mol^{-1} are unable to pass through the membrane. The activity of lactamase was resolute by external addition of substrate ampicillin to a nanoreactor in the presence of starch-iodine solution. The ampicillin is hydrolyzed by lactamase to ampicilloniic acid and only latter is capable to reduce iodine to iodide, resulting in decolourization of the starch-iodine solution.

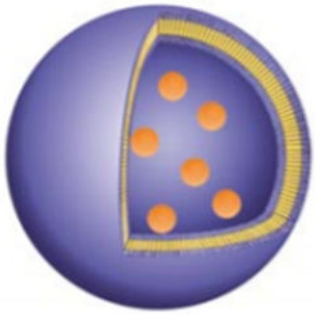

Figure 3: Polymer supramolecular structure in the nanometer range, which allow encapsulation of active compounds and development of nanoreactors.

Polymer micelles as nanoreactors

Antonietti et al. illustrated the applications of micelle-forming amphiphilic block co-polymers in the stabilization of metal nanoparticles [33,34]. The block co-polymer micelles can certainly be considered as nanoreactors because metal nanoparticles are synthesized inside the micelle. The nanosize proportions of the metal particles give rise number of magnetic, electronic, optical and catalytic properties, which is the result of size quantization effects and the high number of surface atoms as compared to the number of atoms in the bulk of the particle [35]. To acquire established hybrid polymer material, there must be adequate adhesion between the metal particles and polymer chains. Metal colloids are formed inside the micelles by performing a chemical reaction, typically a reduction. The formed metal particles subsequently aggregate and produce large particles by nucleation. Depending on the degree of super saturation with the metal particles forming salt, the interfacial tension of the metal particle interface, and the diffusivity of the metal ions, one or more nanoclusters are formed within a micelle. Not only metal colloids, but also metal oxides [36]. like ZnO, TiO_2, Fe_2O_3 and metal sulphides [37] for example CdS, CuS, FeS, PbS, and ZnS, can be formed within micellar nanoreactors.

Unimolecular nanoreactors

Polymeric micelles are sensitive to environmental conditions because of their dynamic nature. To overcome this, covalent systems such as dendrimers, hyper branched polymers and star polymers have lately been introduced and they act as stabilizers in the formation of nanoparticles. A dendrimer is a single molecule with a central core from which branches emerge radially in a regular fashion as shown in Figure 4. Most dendrimers have elastic structures, but to increase in their rigidity sometimes they adopt a globular shape at a certain generation [38]. The active compounds are inserted in the dendrimers architecture via hydrophobic interactions. Dendrimers can be generally divided into three categories (a) dendrimers with a catalytically active core [39] (b) free-energy driven dendrimer nanoreactors, which are not directly involved in the reaction [40] (c) dendrimers that stabilize a catalytically active metal nanoparticle [41].

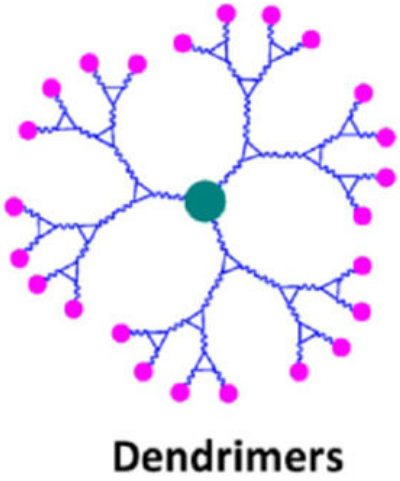

Figure 4: Unimolecular structure in the nanometer range, Dendrimer.

Multienzyme nanoreactors

Weissmann and Sessa studied the incorporation of lysozyme into liposomes in 1970. The encapsulation of enzymes inside nanocarriers has been extensively explored [42,43]. However, it lasted until 2005 when Choi and Montemagno reported about a nanoreactor capable of performing a two step reaction. They embedded a light-driven proton pump protein bacteriorhodopsin (BR) and an F0F1-ATP synthase in the membrane of a polymeric vesicle. BR generated a constant pH gradient over the membrane under the influence of light which was used by the ATP synthase to synthesize ATP from ADP and inorganic phosphate [44].

Hollow mesoporous ceria nanoreactors

The hollow mesoporous @M/CeO_2 nanospheres were used as nanoreactors, and their catalytic performance was evaluated by using model reaction of the reduction of 4-nitrophenol (4-NP) to 4-aminophenol (4-AP) with $NaBH_4$ aqueous solution at room temperature. The better catalytic performance of @M/CeO_2 nanosphere catalysts is due to their distinctive hollow mesoporous structures (Figure 5). First, the mesoporous CeO_2 shells favour the

rapid diusion of reactants and products from active sites loaded in the inner walls, which is important for heterogeneous catalysis [45]. Second, the hollow structure of @M/CeO_2 catalysts leads to captivity of the reactants into the inner space, resulting in the higher concentration of reactants and products in the nanoreactors providing a driving force to speed up the catalytic reaction [46]. Third, the synergistic eect between the NMNPs and the CeO_2 shells will speed up the rate of charge transfer and reduce catalyst poisoning, accelerating the reduction of 4-NP to 4-AP.

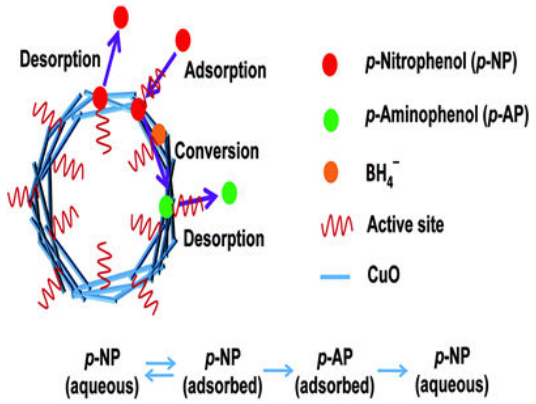

Figure 5: Schematic illustration showing the catalytic reaction of the reduction of 4-NP to 4-AP with $NaBH_4$ aqueous solution at room temperature on the @M/CeO_2 catalyst.

Applications of nanoreactors

The application of nanoreactors is a relatively new area in which, much progress has been made during the last decade. This review highlights the most important application of such polymeric nanoreactors in several domains including medicine, ecology, biotechnology, and material science and pay attention to the advantages and drawbacks related with them. While in most cases the active components of nanoreactors are enzymes, there are also some examples where the nanostructure itself serves as a template, for example, to produce gold nanoparticles [47,48].

Applications for nanoreactors in medicine and diagnosis

Nanoreactors are able to provide more precise and early diagnostics, can support surgery through fine localization of tumors, decrease side effects while increasing efficiency in drug therapy and show the way to development of new medical devices due to its sensitivity, specificity and rapid response [49]. However, a complex situation of requirements must be fulfilled by nanoreactors if medical applications are to be realized (a) the chemical nature and properties of polymers and their assemblies must be modified to avoid impairing the required biological activity; (b) non-toxicity with low immunogenicity; (c) biodistribution, bioaccumulation, and degradation in the human body should be controllable in the lab before clinical trials.

Diagnostic applications: Accurate and non-invasive diagnosis is necessary to prevent disease progression. Various physical, chemical, and biochemical techniques have been developed for rapid estimation of biochemical status in biological fluids like blood, urine, stool, or saliva, for measurements of various physical properties in the body for example temperature and electrical currents and for imaging techniques like optical, ultrasound, magnetic, and nuclear resonance [48]. Nanoreactors were able to detect small changes in physical properties of the surface or the presence of biological molecules with high precision. Polymeric nanoreactors containing acid phosphate immobilized on a glass surface were shown to convert a non-fluorescent substrate to a fluorescent product [50].

Nanodevices can detect specific, meaningful analytes related with pathology, to visualize the location and distribution of affected cells, and to report the activity of a therapeutic agent are highly desirable. To enhance the sensitivity and resolution in medical testing and for special imaging methods, various contrast agents are essential. But their use is limited due to the intrinsic toxicity of some of these agents like Fe-salts for MRI which derives from the necessity of high dosages [48]. The polymeric nanoreactors that produce large quantities of contrast agents enzymatically and simultaneously protect these agents inside their structures represent perfect candidates to counter this disadvantage. For example, a nanoreactor with a possible application in diagnostics that enzymatically produced Gd phosphate in polymersomes to avoid the intrinsic toxicity of free Gd ions [51]. As Gd phosphate is highly insoluble in water, it precipitates inside the cavity of the nanoreactor and in this way its toxicity is significantly reduced.

Theragnostics: Nanoreactors that contain various hydrophilic and hydrophobic compounds are potential candidates for theragnostic applications, providing a possible step toward modified medicine. By combining diagnostic techniques like ultrasound and MRI together with enzymes in one nanoreactor, overall patient treatment will become more effective and appropriate [52]. For example, a nanoreactor proposed for theragnostic application is based on the concept of an enzymatic cascade reaction taking place inside the cavity of polymeric vesicles, to simultaneously detect and combat oxidative stress as shown in Figure 6. In this, combination of enzymes SOD (C) and lactoperoxidase (E) act inside polymeric vesicles in a cascade reaction with substrate Amplex-Red (D) and product resorufin (F) to detoxify reactive oxygen species (A) [53]. Firstly, SOD detoxified superoxide radicals to hydrogen peroxide then lactoperoxidase converted the substrate (Amplex-Red), together with hydrogen peroxide, to a fluorescent product (resorufin). The final products of the cascade reaction were water and oxygen. The process of detoxification of oxygen species was monitored in real time, and the system behaved like an artificial organelle in different cell lines.

Therapeutics: Based on the advantages of nanoreactors like protection, transport and functionality, they should be considered for use in various therapeutic domains, including enzyme replacement therapy (ERT), prodrug therapy and oxygen therapy.

ERT is a medical treatment which replaces an enzyme that is deficient and absent in the body. This is done by giving the patient an intravenous infusion of a solution containing the enzyme. Nanoreactors based on PMOXA-PDMS-PMOXA polymer vesicles that encapsulate 10% of thymidine phosphorylase (TP) have been proposed in ERT for a disease in which TP enzyme activity is reduced and plasma thymidine and deoxyuridine are elevated dramatically, leading to toxic effects [53,54].

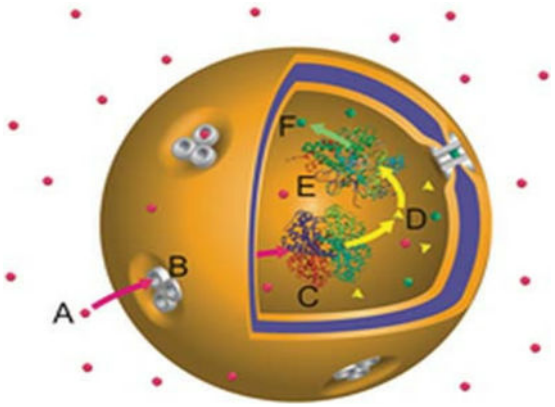

Figure 6: Systematic representation of enzymatic reactions inside polymeric vesicles.

Enzyme prodrug therapy is a treatment by which enzymatic activation of a nontoxic drug precursor at the target site increases the local concentration of a cytotoxin, inducing an increase in the therapeutic effect and simultaneously decreasing harmful side effects [55]. Enzyme prodrug nanoreactors are used for the treatment of cancer cell. They are based on PMOXA-PDMS-PMOXA vesicles with their membrane incorporating OmpF channel proteins, contains *Trypanosoma vivax* nucleoside hydrolase (TvNH) in the reactor wall as shown in Figure 7. The purine-specific nucleoside hydrolase of *Trypanosoma vivax* is used as the prodrug activating enzyme to convert ribonucleosides to nucleic bases, which are known as malignant cell chemo toxins in cancer treatment [56].

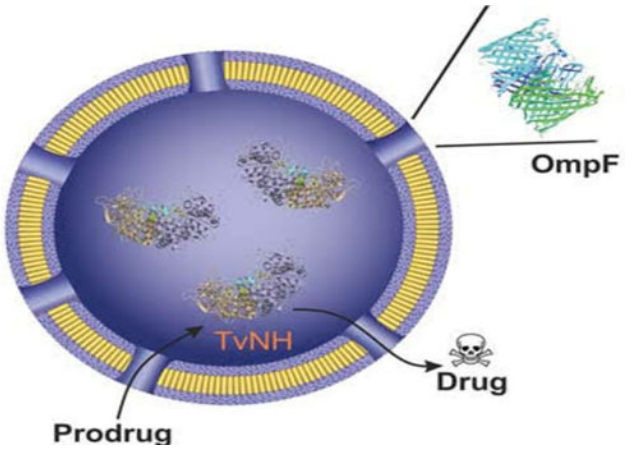

Figure 7: Schematic representation of nanoreactor for prodrug application.

The use of oxygen-carrying blood substitutes is called oxygen therapeutics, which differentiates it from transfusion. Oxygen therapy also known as supplemental oxygen, is the use of oxygen as a medical treatment. This can include for low blood oxygen, carbon monoxide toxicity, cluster headaches and to maintain enough oxygen while inhaled anaesthetics are given. Nanoreactors used for *in vivo* oxygen therapy are based on the encapsulation of myoglobin (Mb) inside PICsomes formed by a pair of oppositely charged block ionomers [56,57]. The biocompatible nature of this Mb-loaded PICsomes, composed of poly (amino acid) s and a bio inert PEG shell, makes this type of nanoreactor a good candidate for oxygen therapy.

Environmental applications of nanoreactors

Today's major problems are the depletion of natural resources and excessive levels of environmental pollutants. Nanoreactor technology is the exploratory phase of research in terms of presenting innovative concepts for alternative sources of energy. They will certainly provide help to the problems like reduction in pollution, and development of "green industry". The nanoreactors can be used for decontamination processes. But the problem related with the use of enzymes for decontamination purpose is the presence of water, which is not suitable for some applications such as use in the cleaning of electronic equipment's.

Encapsulation of lysozyme in reverse micelles will allowed distribution between a water phase and an organic phase that contains surfactant [58]. Reverse micelles are used to increase the confined concentration of lysozyme and reduce the water usage. Reverse micelles containing lysozyme are used to decontaminate various surfaces, contaminated with Gram-positive and Gram-negative bacteria. The encapsulated enzyme can be used directly for the electronic devices. Nanoreactors can selectively detect and recover compounds in complex mixtures like contaminated soil and mine slimes, should be ideal candidates for downstream processing.

Other applications of nanoreactors

Cascade reactions in nanoreactors: In most reactions, catalysts are not attuned with each other. Various arrays of nanoreactors have been developed to uphold the catalyst activity. Multienzyme nanoreactors and enzyme/metal catalyst systems have shown great potential in cascade reactions. compartmentalization technique has been generally applied to prevent catalyst inactivation. For a long time, Chemists have been tried to mimic these compartmentalization statergies by selective encapsulation of catalyst in nanoreactors. For example, Kuiper et al. exploited the porous nature of poly (isocya-noalanine (2-thiophen-3-yl) amide) polymersomes to construct an enzyme containing nanoreactors that could catalyze a tendem reaction [59]. They loaded glucose oxidase (GOx) and horseradish peroxidise (HRP) in separate polymersomes, mixed them together with glucose and 2,20-azino-bis (3-ethylbenzthia-zoline-6-sulfonic acid) (ABTS). After glucose was converted to gluconolactone by GOx then H_2O_2 was used by HRP as a substrate for the oxidation of ABTS into ABTS+.

Tanner et al. conducted a nanoreactor that could combat oxidative stress [60]. They verified that in poly(2-methyloxazoline)-poly-(dimethylsiloxane)-poly(2-methyloxazoline) (PMOXA-PDMS-PMOXA) polymersomes the coen-capsulation of copper-zinc superoxide (Cu, Zn-SOD) and lactoperoxidase (LPO), provided an effective device to detoxify reactive oxygen species (ROS). Firstly, the superoxide radical ion was converted into hydrogen peroxide by Cu, Zn-SOD which subsequently acts as substrate for LPO to convert amplex red into resorufin. Confocal fluorescence measurements revealed that the system could be used for both the complete detoxification of ROS under the conditions of oxidative stress.

Yang et al. employed yolk-shell nanoparticles (YSNs) in a deacetylization-Henry cascade reaction [61]. The YSNs consisted of a silica core, functionalized with primary amines, and a permeable silica

shell, functionalized with sulfonic acid groups. The core and shell could be separated from each other because of organosilane- assisted etching procedure. The YSNs gave a maximal conversion to the nitro styrene product (>99%) when applied on deacetylization- Henry cascade reaction of benzaldehyde dimethyle acetal.

Colloidal micelles of co-polymers as nanoreactors: Block copolymers have ability to self-aggregate in well-defined micelles which shows ability as nanoreactors to synthesize Au NPs. Au NPs make use of the micelles as soft templates to self-assemble which generate hybrid morphologies on the basis of their mutual symbiotic relationship. Water soluble non-ionic block copolymers shows potential industrial uses because of their special architecture of three blocks (triblock copolymers, TBPs) arranged in an alternative arrangement of polyethylene (PEO) and polypropylene oxides (PPO) units as in the case of pluronics [62]. A TBP becomes predominantly hydrophilic when number of PEO units exceeds and acquires a predominant hydrophobic nature when PPO units exceed [60]. A TBP micelle formation is also triggered by variation in temperature. Predominantly hydrophobic PPO units to aggregate in the core of micelle while predominantly hydrophilic PEO units aggregate themselves in the corona as shown in Figure 8. The temperature at which micelle formation occur is called critical micelle temperature (CMT) [62]. Arrangement of PEO units leads to formation of surface cavities to accommodate guest molecules [63-65]. Surface cavities are surrounded with electron donating ether oxygen's and hence participate in the redox reactions [62]. As one polymer molecule contributing towards the formation of one surface cavity, due to this it accepts only one guest ion (oxidizing agent) per cavity. Complex gold ions ($AuClO_4$) act as an oxidizing agent; interact with the surface cavities to get reduce from Au (III) into Au (0) and initiate the surface redox reaction to produce gold nanoparticles (Au NPs).

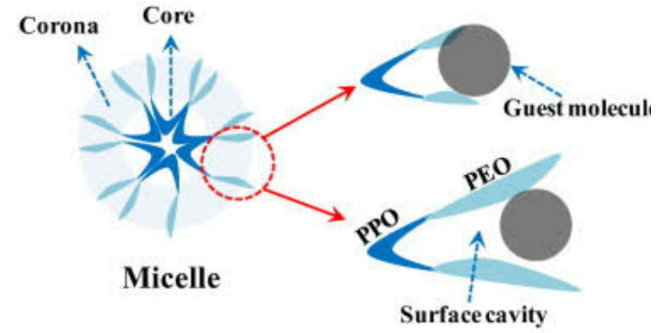

Figure 8: Schematic representation of a TBP micelle showing core and corona. Core is mainly made up of PPO and corona by PEO units.

Conclusion

Many novel approaches have been applied to develop more and more efficient nanoreactors. One was to use of simple surfactants for the construction of micellar or emulsion reactions in chronological order. In the second half of the 20th century, the application of lipid-based assemblies as potential cell membrane mimics and subsequently as enzyme and catalyst-containing nanoreactors received considerable attention. The concept of the nanoreactor has been successfully brought to completion by combining supramolecular assemblies (dendrimers, micelles, vesicles, and capsules), natural (enzymes, proteins) and synthetic (mimics of enzymes) compounds. Properly designed, nanoreactors allow the encapsulation/insertion of both hydrophobic and hydrophilic compounds, thereby supporting the development of the multifunctional systems that are in focus today in various fields. In this respect because of morphology, size, and general properties-polymersomes are currently show the way especially for therapeutic applications. Introducing multifunctionality through cascade reactions, targeting distinct locations in biocompartments, and immobilization on surfaces are the various directions of research being taken today. These will provide a diversity of technical approaches that should yield nanoreactors that are simple, robust solutions, as required today in medicine, catalysis, environmental or food science.

References

1. Wang LP, Titov A, McGibbon R, Liu F, Pande VS, et al. (2014) Discovering chemistry with an ab initio nanoreactor. Nat Chem 6: 1044-1048.
2. Wang X, Li Z, Shi J, Yu Y (2014) One-dimensional titanium dioxide nanomaterials: nanowires, nanorods, and nanobelts. Chem Rev 114: 9346-9384.
3. Petrosko S, Johnson R, White H, Mirkin C (2016) Nanoreactors: Small Spaces, Big Implications in Chemistry. J Am Chem Soc 138: 7443-7745.
4. Martino MTD, Abdelmohsen LKEA, Rutjes FPJT, van Hest JCM (2018) J Org Chem 14: 716-733.
5. Gaur R, Yadav M, Gupta R, Arora G, Rana P, et al. (2018) Aerobic Oxidation of Thiols to Disulfides by Silver-Based Magnetic Catalyst. Chem Select 2: 10871-10879.
6. Peters RW, Louzao I, Hest JCMV (2012) From polymeric nanoreactors to artificial organelles. Chem Sci 2 : 335.
7. Alves NJ, Turner KB, Daniele MA, Oh E, Medintz IL, et al. (2015) Bacterial nanobioreactors-directing enzyme packaging into bacterial outer membrane vesicles. ACS Appl Mater Interfaces 7: 24963-24972
8. Deng FYD, Pan X, Fu Q, Bao X (2015) Nat Sci Rev 2: 183-201.
9. Williams DE, Dolgopolova EA, Pellechia PJ, Palukoshka A, Wilson TJ, et al. (2015) Mimic of the Green Fluorescent Protein β-Barrel: Photophysics and Dynamics of Confined Chromophores Defined by a Rigid Porous Scaffold. J Am Chem Soc 137: 2223-2226.
10. Roy S, Skoff D, Perroni DV, Mondal J, Yethirajn A (2016) Water Dynamics in Gyroid Phases of Self-Assembled Gemini Surfactants. J Am Chem Soc 138: 2472-2475.
11. Grochmal A, Prout L, Taylor RM, Prohens R, Tomas S (2015) Modulation of reactivity in the cavity of liposomes promotes the formation of peptide bonds. J Am Chem Soc 137: 12269-12275.
12. Yang Z, Altantzis T, Zanaga D, Bals S, Tendeloo GV, et al. (2016) Supracrystalline Colloidal Eggs: Epitaxial Growth and Freestanding Three-Dimensional Supracrystals in Nanoscaled Colloidosomes. J Am Chem Soc 138: 3493-3500.
13. Liu J, Spulber M, Wu D, Talom RM, Palivan CG, et al. (2014) Poly(N-isopropylacrylamide-co-tris-nitrilotriacetic acid acrylamide) for a Combined Study of Molecular Recognition and Spatial Constraints in Protein Binding and Interactions. J Am Chem Soc 136: 12607-12614.
14. Petrosko SH, Johnson R, White H, Mirkin CA (2016) Nanoreactors: Small Spaces, Big Implications in Chemistry. J Am Chem Soc 138: 7443-7445.
15. Gaitzsch J, Huang X, Voit B (2016) Engineering Functional Polymer Capsules toward Smart Nanoreactors. Chem Rev 116: 1053-1093.
16. Angew JML (1988) Chem, Int Ed Engl 27: 89.
17. Angew GW (1994) Chem Int Ed Engl 33: 803.
18. Breslow R, Schmuck C (1996) Goodness of fit in complexes between substrates and ribonuclease mimics: Effects on binding, catalytic rate constants, and regiochemistry. J Am Chem Soc 118: 6601-6605.

19. Weber L, Imiolczyk I, Haufe G, Rehorek D, Hennig H (1992) J Chem Soc Chem Commun, p: 301.
20. Kuroda Y, Sera T, Ogoshi H (1991) Regioselectivities and stereoselectivities of singlet oxygen generated by cyclodextrin-sandwiched porphyrin sensitization. Lipoxygenase-like activity. J Am Chem Soc 113: 2793-2794.
21. Kang J, Rebek J (1996) Entropically driven binding in a self-assembling molecular capsule. Nature 382: 239-241.
22. Kang J, Hilmersson G, Santamarıa J, Rebek J (1998) Diels-Alder reactions through reversible encapsulation. J Am Chem Soc 120: 3650-3656.
23. Menger FM, Rhee HK (1975) Applications of surfactants to synthetic organic chemistry. J Org Chem 40: 3803-3805.
24. Rabion A, Buchanan RM, Seris JL, Fish RH (1997) Biomimetic oxidation studies. 10. Cyclohexane oxidation reactions with active site methane monooxygenase enzyme models and t-butyl hydroperoxide in aqueous micelles: Mechanistic insights and the role of t-butoxy radicals in the C⊠H functionalization reaction. Journal of Molecular Catalysis A: Chemical 116: 43-47.
25. Kobayashi S, Manabe K (2002) Development of novel Lewis acid catalysts for selective organic reactions in aqueous media. Acc Chem Res 35: 209-21.
26. Hamley W, Mcbain JW (1913) Mobility of Highly-Charged Micelles. Trans Faraday Soc 9: 99.
27. Gebicki JM, Hicks M (1973) Ufasomes are stable particles surrounded by unsaturated fatty acid membranes. Nature volume 243: 232-234.
28. Kunitake T, Okahata Y (1977) A totally synthetic bilayer membrane. J Am Chem Soc 99: 3860-3861.
29. Balasubramanian V, Axthelm OFF, Palivan CG (2013) J Adv M Optoelectron 1: 1083-1087.
30. Dongen SFMV, Nallani M, Cornelissen JLLM, Nolte RJM, Hest JCMV, et al. (2009) A thre-enzyme cascade reaction through positional assembly of enzymes in a polymersome nanoreactor. Chem Eur J 15: 1107.
31. Discher DE, Eisenberg A (2002) Polymer Vesicles. Science Partner Journal 5583: 967-973.
32. Nardin C, Widmer J, Winterhalter M, Meier W (2001) Amphiphilic block copolymer nanocontainers as bioreactors. The European Physical Journal E 4: 403-410.
33. Edlinger C, Zhang X, Fischer O (2013) Department of Chemistry, University of Basel, Switzerland.
34. Klingelho S, Heitz W, Greiner A, Oestreich S, Forster S, Antonietti M (1997) Preparation of Palladium Colloids in Block Copolymer Micelles and Their Use for the Catalysis of the Heck Reaction. J Am Chem Soc 119: 10116-10120.
35. ABR (2001) Mayer Colloidal metal nanoparticles dispersed in amphiphilic polymers. Polym Adv Technol 12: 96.
36. Spatz J, Mossmer S, Moller M, Kocher M, Neher D, Wegner G (1998) Controlled Mineralization and Assembly of Hydrolysis-Based Nanoparticles in Organic Solvents Combining Polymer Micelles and Microwave Techniques. Adv Mater 10: 473.
37. Moffit M, McMahon L, Pessel V, Eisenberg A (1995) Size Control of Nanoparticles in Semiconductor-Polymer Composites to Control via Sizes of Spherical Ionic Microdomains in Styrene-Based Diblock Ionomers. Chem Mater 7: 185-1192.
38. Bosman W, Janssen HM, Meijer EW (1999) About dendrimers: structure, physical properties, and applications. Chem Rev 99: 1665-1688.
39. Heerbeek R, Kamer PCJ, Leeuwen PWNM, Reek JNH (2002) Dendrimers as Support for Recoverable Catalysts and Reagents. Chem Rev 102: 3717-3756.
40. Chen Z, Cui Z, Niu F, Jiang L (2010) Pd nanoparticles in silica hollow spheres with mesoporous walls: a nanoreactor with extremely high activity. Chem Commun 46: 6524.
41. Bian SW, Ma Z, Zhang LS, Niu F, Song WG (2009) Silica nanotubes with mesoporous walls and various internal morphologies using hard/soft dual templates. Chem Commun 1261.
42. Singh K, Landfester A, Chandra R, Espi M (2015) A new approach for crystallization of copper (II) oxide hollow nanostructures with superior catalytic and magnetic response. Nanoscale 7: 19250-19258.
43. Yu X, Yue K, Hsieh IF, Li Y, Dong XH, Liu C, Xin Y, Wang HF, Shi AC, Newkome GR, Chen EQ, Zhang WB, Cheng SZD (2013) Giant surfactants provide a versatile platform for sub-10-nm nanostructure engineering. Proc Nat Acad Sci 110: 10078-10083.
44. Crooks RM, Zhao M, Sun L, Chechik VLK (2001) Dendrimer-encapsulated metal nanoparticles: synthesis, characterization and applications to catalysis. Acc Chem Res 34: 181-190.
45. Ornelas C, Ruiz J, Belin CD (2009) Giant dendritic molecular electrochrome batteries with ferrocenyl and pentamethylferrocenyl termini. J Am Chem Soc 131: 590-601.
46. Zimmerman SC, Wendland MS, Rakow NA, Zharov I, Suslick KS (2002) Synthetic hosts by monomolecular imprinting inside dendrimers Nature 418: 399-403.
47. Deraedt C, Salmon L, Etienne L, Ruiz JD (2013) Click dendrimers as efficient nanoreactors in aqueous solvent: Pd nanoparticle stabilization for sub-ppm Pd catalysis of Suzuki-Miyaura reactions of aryl bromides. Astruc Chem Commun 49: 8169.
48. Caruthers SD, Wickline SA, Lanza GM (2007) Nanotechnological applications in medicine. Curr Opin Biotechnol 18: 26-30.
49. Hilt JZ (2004) Nanotechnology and biomimetic methods in therapeutics: molecular scale control with some help from nature. Adv Drug Deliver Rev 11: 1533-1536.
50. Grzelakowski M, Onaca O, Rigler P, Kumar M, Meier W (2009) Immobilized Protein-Polymer Nanoreactors Small 5: 2545.
51. Broz P, Haim NB, Santini F, Marsch S, Scheffler K, Meier W, Hunzikern P (2009) Nano Imaging Technologies: Polymer vesicles loaded with precipitated gadolinium nanoparticles: A novel target-specific contrast agent for magnetic resonance imaging. Eur J Nanomed 2: 43.
52. Janib SM, Moses AS, MacKay A (2010) Imaging and drug delivery using theranostic nanoparticles. Adv Drug Deliver Rev 62: 1052-1063.
53. Graff A, Ailhas CF, Palivan CG, Grzelakowski M, Friedrich T, et al. (2010) Macromol Chem Phys 211: 229-238.
54. De Vocht D, Ranquin A, Willaert R, Ginderachter JAV, Vanhaecke T, et al. (2010) Assessment of stability, toxicity and immunogenicity of new polymeric nanoreactors for use in enzyme replacement therapy of MNGIE. J Control Release 137: 246-254.
55. Ranquin A, Versees W, Meier W, Steyaert J, Gelder PV (2005) Therapeutic Nanoreactors: Combining Chemistry and Biology in a Novel Triblock Copolymer Drug Delivery System. Nano Lett 5: 2220-2224.
56. Anrakun Y, Kishimura A, Oba M, Yamasaki Y, Kataoka K (2010) Spontaneous Formation of Nanosized Unilamellar Polyion Complex Vesicles with Tunable Size and Properties. J Am Chem Soc 132: 1631-1636.
57. Kishimura A, Koide A, Osada K, Yamasaki Y, Kataoka K (2007) Self-assembled encapsulation of myoglobin in to pegylated polyion complex vesicles (picsomes) made from a pair of oppositely charged block ionomers: a physiologically available oxygen carrier. Angew Chem Int Ed 46: 6085-6088.
58. Kishimura A, Liamsuwan S, Matsuda H, Dong WF, Osada K, et al. (2009) pH-dependent permeability change and reversible structural transition of PEGylated polyion complex vesicles (PICsomes) in aqueous media. Soft Matter 5: 529-532.
59. Bermudez O, Forciniti D (2004) Decontamination of surfaces by lysozyme encapsulated in reverse micelles. Journal of Chromatography B 807: 95-103.
60. Kuiper SM, Nallani M, Vriezema DM, Hest JCMV, Nolte RJM, et al. (2008) Org Biomol Chem 6: 4315-4318.
61. Yang Y, Liu X, Zhao J, Bai SY, Liu J, et al. (2012) A yolk-shell nanoreactor with a basic core and an acidic shell for cascade reactions. Angew Chem Int Ed 51: 9164-9168.

62. Bakshi MS, Kaurav A, Kaur G (2006) Effect of temperature on the unfavorable mixing between tetraethylene glycol dodecyl ether and Pluronic P103. Journal of Colloid and Interface Science 296: 370-373.

63. Khullar P, Singh V, Mahal A, Kumar H, Kaur G, et al. (2013) Block Copolymer Micelles as Nanoreactors for Self-Assembled Morphologies of Gold Nanoparticles. J Phys Chem 117: 3028-3039.

64. Khullar P, Singh V, Mahal A, Kaur H, Singh V, et al. (2011) Tuning the Shape and Size of Gold Nanoparticles with Triblock Polymer Micelle Structure Transitions and Environments. J Phys Chem 115: 10442-10454.

65. Sakai T, Alexandridis P (2005) Mechanism of Gold Metal Ion Reduction, Nanoparticle Growth and Size Control in Aqueous Amphiphilic Block Copolymer Solutions at Ambient Conditions. J Phys Chem 109: 7766-7777.