

# Study of Encapsulation of Quantum Dots in Polystyrene and Poly ( $\epsilon$ -Caprolactone) Microreactors Prepared by Microvolcanic Eruption of Freeze Dried Microspheres

Deepak Kukkar, Inderpreet Kaur, Jagtar Singh, Lalit M Bharadwaj

**Abstract**—Polymeric microreactors have emerged as a new generation of carriers that hold tremendous promise in the areas of cancer therapy, controlled delivery of drugs, for removal of pollutants etc. Present work reports a simple and convenient methodology for synthesis of polystyrene and poly caprolactone microreactors. An aqueous suspension of carboxylated (1 $\mu$ m) polystyrene latex particles was mixed with toluene solution followed by freezing with liquid nitrogen. Frozen particles were incubated at -20°C and characterized for formation of voids on the surface of polymer microspheres by Field Emission Scanning Electron Microscope. The hollow particles were then overnight incubated at 40°C with unfunctionalized quantum dots (QDs) in 5:1 ratio. QDs Encapsulated polystyrene microcapsules were characterized by fluorescence microscopy.

Likewise Poly  $\epsilon$ -caprolactone microreactors were prepared by micro-volcanic rupture of freeze dried microspheres synthesized using emulsification of polymer with aqueous Poly vinyl alcohol and frozen with liquid nitrogen. Microreactors were examined with Field Emission Scanning Electron Microscope for size and morphology. Current study is an attempt to create hollow polymer particles which can be employed for microencapsulation of nanoparticles and drug molecules.

**Keywords**—FE-SEM, Microreactors, Microvolcanic rupture, Poly ( $\epsilon$ -caprolactone), Polystyrene

## I. INTRODUCTION

IN the past decade interest on polymeric microparticles has led to many new and exciting innovations (Faraji et al, 2009) [1]. One of the major motivations is to develop new materials which can serve as sophisticated systems for controlled and targeted drug delivery (Nair et al, 2007) [2]. The major challenge is to control the size and morphology at micronic or submicronic scale. Currently a wide variety of vector moieties such as polymeric microreactors,

microspheres, liposomes, nanoparticles etc are employed for above applications. Out of these, polymeric microreactors or nanoreactors, characterized by a polymeric shell surrounding a void, are of great importance because they can be used as reservoir systems for drug delivery applications, biochemical reactions and for removal of pollutants (Ding et al, 2009) [3]. Usually microreactors are prepared by coating of desired material on colloidal templates followed by sacrificial removal of the template (Boyer et al, 2010) [4]. Other methods such as emulsion polymerization (Musyanovych et al, 2007) [5], and phase separation (Pekarek et al 1994) [6], have been reported. All the above mentioned hollow structures are characterized by core shell configuration so the desired material to be encapsulated into these structures can only be introduced by diffusion which is a slow phenomenon. To overcome this predicament a new method based upon freeze drying of polystyrene has been reported (Im et al, 2005) [7]. This method relies upon removal of solvent from freeze dried polymer droplets under vacuum which results in formation of voids over the surface of polymer microbeads. The material in question can be directly loaded through voids, followed by temperature or solvent induced closing.

Herein we study the synthesis of Polystyrene (PS) and Poly  $\epsilon$ -Caprolactone (PCL) microreactors by micro-volcanic rupture of polymer wall caused by outward flow of solvent flux under thermal shock.

## II. EXPERIMENTAL

### Materials

Poly ( $\epsilon$ -caprolactone) (PCL, Mn 60,000 Da), poly (vinyl alcohol) (PVA, Mn 13,000- 23,000 Da; 98% hydrolyzed) dichloromethane (DCM, anhydrous 99.8%) were purchased from Aldrich (USA) and polystyrene (PS) were from polysciences (USA). Quantum dots were from ocean nanotech (USA) All other chemicals were of analytical grade unless otherwise stated. Deionized water (ELGA, USA) having 18 M $\Omega$  resistance was used in all the experiments.

### Methodology

#### A. Preparation of Polystyrene Microreactors

Polystyrene microreactors were prepared from pre synthesized latex beads of 1 $\mu$ , 3 $\mu$  (carboxylated). For this 50  $\mu$ l aqueous suspension of polystyrene was added to mixture of

Deepak Kukkar, Biomolecular Electronics & Nanotechnology, Central Scientific Instruments Organisation, Chandigarh, India (phone: +91-172-2637311; fax: - +91-172-2657082); e-mail: deepakukkar@gmail.com.

Inderpreet Kaur, Biomolecular Electronics & Nanotechnology, Central Scientific Instruments Organisation, Chandigarh, India (phone: +91-172-2637311; fax: - +91-172-2657082); e-mail: inderpreety@yahoo.co.in.

Jagtar Singh, Deptt of Biotechnology, Panjab University, Chandigarh, India (phone: +91-172- 2534065); e-mail: jagtar@rediffmail.com.

Lalit M Bharadwaj, Biomolecular Electronics & Nanotechnology, Central Scientific Instruments Organisation, Chandigarh, India (phone: +91-172-2637311; fax: - +91-172-2657082); e-mail: lalitmbaradwaj@hotmail.com.

\*To whom correspondence should be addressed

5 ml deionised water and 50  $\mu$ l toluene. The suspension was then magnetically stirred for 30 minutes at RT. Finally the suspension was dropwise added into liquid nitrogen ( $\text{LN}_2$ ) bath and kept under vacuum for 15-18 hrs.

#### B. Preparation of Poly ( $\epsilon$ -Caprolactone) Microreactors

PCL hollow particles or microreactors were prepared by freeze drying of oil emulsion droplets of polymer microspheres in aqueous PVA.

#### C. Encapsulation of Quantum Dots

The microreactors can serve as reservoir device for protecting the fluorescent and mechanical properties of fluorescent molecules, drug delivery disease diagnosis etc. To examine their application for protection of fluorescent compounds, 100  $\mu$ l aqueous suspension of CdSe quantum dots (10  $\mu$ M) was added to 250  $\mu$ l aqueous suspension of dried polystyrene microreactors. The solution was sonicated for few seconds and further shaken at 100 rpm for 1.5 hrs. Encapsulation of quantum dots was assessed by epifluorescence microscope (Axiovert 200, Zeiss).

### III. RESULTS AND DISCUSSIONS

#### A. Preparation of Polystyrene Microreactors

In the present study we first examined the formation of polystyrene microreactors. For this 50  $\mu$ l aqueous suspension of 3  $\mu$ m aminated polymer beads was added to the mixture of 5 ml deionised water and 50  $\mu$ l toluene. Introduction of toluene into the aqueous dispersion of the polymer leads to the swelling of the polymer beads. When the suspension of swollen beads was added dropwise into a  $\text{LN}_2$  bath, it resulted in immediate freezing of the system. When the frozen system was kept under vacuum for 15-18 hrs below  $0^\circ\text{C}$ , it resulted in the formation of a micrometer sized pore in the wall of the hollow bead. Structure and morphology of the swollen particles was maintained due to the presence of ice around each swollen bead. Fig. 1 shows FESEM images of 3  $\mu$ m aminated polystyrene microreactors. The microreactors were characterized by the presence of an opening on their surface.

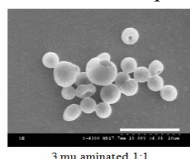


Fig. 1 Polystyrene microreactors with an opening on their surface. Scale bar corresponds to 3  $\mu$ m

#### B. Preparation of Poly ( $\epsilon$ -Caprolactone) Microreactors

PCL being a biodegradable polymer has numerous healthcare applications. In the current study PCL microreactors were prepared by microvolcanic rupture of microspheres synthesized by emulsification of organic PCL using aqueous PVA. PVA solution stabilizes and readily disperses PCL microspheres in aqueous medium. Freezing of the microspheres by liquid nitrogen quickly resulted in solidification of the emulsion. When the frozen content is placed under vacuum at  $-20^\circ\text{C}$ , it results in melting of DCM ( $T_m = -96.7^\circ\text{C}$ ), hence increasing its density. Thus rise in

density of DCM drives outward flow of the solvent from polymer core and creates micrometer and nanometer sized pores on the surface of the microspheres.

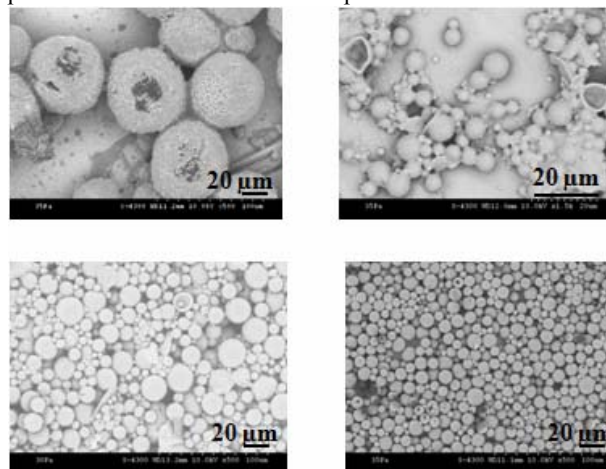
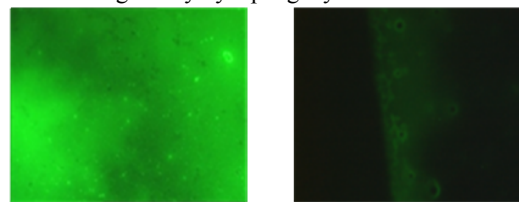


Fig. 2a-2d PCL microreactors prepared by emulsification of organic PCL with aqueous PVA

#### C. Encapsulation of Quantum Dots

Polymer microreactors can have widespread healthcare applications in drug delivery and disease diagnosis. To examine this, polystyrene microreactors solution was suspended in quantum dots solution for 1.5 hrs. The sample was then characterized by epifluorescence microscope to assess the encapsulation of quantum dots in polystyrene microreactors. Fig. 5a shows epifluorescence image of quantum dots while that in Fig. 5b shows quantum dots encapsulated in polystyrene microreactors. Reduction in fluorescence intensity clearly indicates encapsulation of quantum dots in polymer microreactors. Addition of toluene causes reduction of surface tension between the outer and inner surface of the microreactors and thereby results in closing of holes. This mechanism is very much similar to that of uptake of foreign body by a phagocytic cell.



a Quantum dots b) Quantum dots encapsulated in polymer microcapsules

Fig. 5 a) Fluorescence micrograph of quantum dots, b) Fluorescence micrograph of quantum dots encapsulated in polystyrene microreactors

### IV. CONCLUSION

Present work describes synthesis of polystyrene and poly ( $\epsilon$ -caprolactone) microreactors by micro-volcanic rupture of microspheres freeze dried with liquid nitrogen. PS microreactors were prepared from readily available microspheres while PCL microspheres were prepared by emulsification of organic PCL solution. The effect of parameters viz PCL concentration, PVA concentration and stirring speed on formation of

microreactors was studied. It was observed that average diameter of microreactors increased with increasing PCL concentration. Porous structures were observed at 0.5-1% PCL concentration while single hole structures were formed from 2-7% PCL concentration. On the other hand increase in PVA concentration resulted in decrease in average diameter of microreactors. Core shell structures were observed at 1% PVA concentration while bowl shape structures were observed from 4-10% PVA concentration. Likewise increase in stirring speed was also accompanied by decrease in average diameter of microreactors with smoother outer surface and comparatively less polydispersed. These microreactors can be utilized for microencapsulation of drugs and nanoparticles for health care applications. For this, quantum dots were encapsulated in polystyrene microreactors. It was confirmed by fluorescence microscope.

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