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Chemoselective polymerization platform for flow synthesis of functional polymers and nanoparticles

Ning Zhu,[a] Weijun Huang,[a] Xin Hu,[b] Yihuan Liu,[a] Zheng Fang,[a] and Kai Guo[a,c]*

[a] *College of Biotechnology and Pharmaceutical Engineering,* [b] *College of Materials Science and Engineering,* [c] *State Key Laboratory of Materials-Oriented Chemical Engineering, Nanjing Tech University, Nanjing 211800, China*

Corresponding author: guok@njtech.edu.cn

Abstract

A chemoselective polymerization platform was designed for flow synthesis of telechelic thiol-functional polymers, amphiphilic block copolymers and noble metal nanoparticles. By assembling Novozyme435 packed tubular reactor, α-thiol-ω-hydroxyl telechelic poly(ε-caprolactone) were efficiently obtained via metal-free and protecting-group-free ring-opening polymerizations. Fast polymerization, high end group fidelity, controlled molecular weight and distribution were achieved under the flow conditions. The resultant mercapto-polymer solution derived from the enzymatic process was directly pumped into the subsequent microreactor system (isolation-step-free) to prepare amphiphilic poly(*N*-vinylpyrrolidone)-*block*-poly(ε-caprolactone). Relative narrower molecular weight distribution was observed in contrast to the batch mode. Moreover, silver nanoparticles were facilely fabricated in flow fashion by using mercapto-polymer solution as stabilizer without isolation. Surface plasma resonance band absorption of nanoparticles could be adjusted by regulating the flow rates. This chemoselective polymerization platform would provide a powerful toolbox for the novel polymer and nanomaterial preparations.

Keywords: Mircroreactor; Enzyme catalysis; Chemoselectivity; Ring-opening polymerization; Thiol-functionalized polymer; Nanoparticles

Introduction

Chemoselective reactions have drawn significant interests in chemical science, e. g. natural product total synthesis and functional polymer preparation.[1-3] Protecting-group-free method is the pursuit of chemists for developing the efficient and sustainable chemistry. Currently, chemoselective polymerization in the presence of multifunctional initiator/monomer is the ideal yet challenging synthesis protocol to yield well-defined functional polymers with broad applications in many areas.[4-5]

As an important functional group, thiol (mercapto) showed special chemical and physical activities in radical trapping,[6] metal surface modification,[7] reversible disulfide bond formation[8] and click chemistry[9]. Besides, thiol could also initiate ring-opening polymerization (ROP) of cyclic monomers like hydroxyl group. Thiol-functionalized polymers would not be easily afforded by using mercapto-alcohol as the multifunctional initiator, accompanied with byproducts having no mercapto group.[10] Tedious protecting/deprotecting steps were required during the polymerization process.[11-13]

Development of chemoselective polymerization methodology is highly desirable to well-defined thiol-functionalized polymers. *Candida antartica* lipase B (CALB),[14] lipase from *Candida* sp. 99-125,[15] $Sn(OTf)_2$[16] and rare earth phenolates[17] have been investigated to mediate protecting-group-free ROP to give mercapto-polyesters. However, scientific and engineering problems remained including but not limited to the low end group fidelity, limited molecular weight range, wide molecular weight distribution, long-time consuming process and batch-batch variety, *etc*. The resultant mercapto-polyesters could widely be used in synthesis of block copolymer[18] and metal nanoparticle,[19] etc. Meanwhile, these batchwise processes suffered from the low level control of reaction condition and structure-activity.

Flow chemistry in a microreactor has been identified as the powerful tool to perform organic and polymeric reactions.[20-22] In contrast to the traditional batch reactor, e.g. flasks and ampoules, microreactors with huge surface-to-volume ratio and continuous flow characteristics exhibited great benefits including improved heat/mass transfer efficiency, high selectivity and safe operation. Remarkably, microreactors could enable chemical reactions that cannot be done in batch.[23] Protecting-group-free synthetic approach using organolithium reagents were successfully achieved by employing the microflow technology.[24] The combination of flow chemistry and polymerization has been proved to be an alternative methodology to improve the polymerization process,[25] including anionic polymerization,[26] cationic polymerization,[27] free radical polymerization,[28] copper mediated reversible deactivation radical polymerization,[29-30] reversible addition-fragmentation chain transfer (RAFT)[31-32] polymerization and ring-opening polymerization.[33-36] Besides, nanomaterial preparation by using microreactors showed good structure-activity control.[37-38]

Here, we took the research plan to establish a novel chemoselective polymerization platform based on the flow chemistry. Enzyme immobilized tubular reactor was chosen to address the challenge of chemoselective ROP in the presence of mercapto alcohol as the multifunctional initiator. Moreover, coupled tubular reactor systems were developed to make the combination of chemoselective ROP and other transformations (free radical polymerization or metal nanoparticles fabricating). To the best of our knowledge, it is the first chemoselective polymerization platform for flow synthesis of telechelic mercapto-polymer, amphiphilic block copolymer and noble metal nanoparticle.