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Unexpected Effects of Seed Polymer on the Porous Structures of Poly(methyl methacrylate-ethylene glycol dimethacrylate) Particles

Ken HOSOYA,* Yutaka KISHII, Nobuo TANAKA, Kazuhiro KIMATA,
Satoshi MARUYA, Takeo ARAKI, and Jean M. J. FRÉCHET†
Department of Polymer Science and Engineering, Kyoto Institute of Technology,
Matsugasaki, Sakyo-ku, Kyoto 606
†Department of Chemistry, Baker Laboratory, Cornell University, Ithaca, NY 14853-1301, U.S.A

Size monodispersed poly(methyl methacrylate-ethylene glycol dimethacrylate) packing materials were prepared by a multi-step swelling and polymerization method with cyclohexanol or toluene as porogenic solvent. When toluene was applied as a porogen, the seed polymer severely affected the porous structure, while no effect was observed with cyclohexanol compared chromatographically with those prepared by the corresponding suspension polymerization methods.

A multi-step swelling and polymerization method has been utilized to prepare size monodispersed polymer particles.[1] A crosslinking agent and some porogenic solvent can be applied with the monomers to afford the size monodispersed porous polymer particles which are suitable for separation media for high performance liquid chromatography (HPLC).[2,3] Usually, polystyrene seed particles prepared by an emulsifier free emulsion polymerization are utilized as a seed polymer and size monodispersed poly(styrene-divinylbenzene) particles have been prepared through this method to utilize as a packing material in HPLC.[4] These size monodispersed polymer packing materials showed excellent column efficiency with very low column pressure drop even in a reversed phase mode due to their good size monodispersity without any fines,[5] however, the polystyrene seed polymer acted as a porogenic solvent to afford a larger contribution of macro pore region than those prepared by the corresponding suspension polymerization method.[5,6] These findings may be explained based on a solubility of seed polymer into the monomers and porogenic solvent which are applied to the swelling method.

Usually, porogenic solvents involving large molecular weight moiety such as linear polymer afford the porous particles with very large pores and this influence of the polymeric seed is reported to be very sensitive by a change of an amount of polymer as well as a molecular weight of polymer.[3,7] Therefore, it is very important to investigate the influence of seed polymer on porous structure of size monodispersed particles in the swelling method because the combinations and ratio of monomers and porogenic solvents tend to be decided based on the knowledge of the traditional suspension polymerization in which any seed polymer is not usually utilized. Here, the influences of seed polymer on the porous structure of the size monodispersed poly(methyl methacrylate-ethylene glycol dimethacrylate) particles (Ma-gel) were investigated using toluene and cyclohexanol.

Polystyrene seed polymer (1 μm in a diameter) was prepared by a typical emulsifier free emulsion polymerization.[8] Size monodispersed poly(methyl methacrylate-ethylene glycol dimethacrylate) particles were prepared by a multi-step swelling and polymerization method (MSP) using cyclohexanol or toluene as the porogen[9] and the calculated size of the final swollen particle was 6 μm in diameter. The corresponding suspension polymerization (SPM) was also utilized to the preparation of the size polydispersed Ma-gel without the use of the seed polymer and the particles were used without size classifications. For the investigation of the porous structure of the particles, chromatographic characterization is applied because actual properties in chromatographic separations give more realistic information of the particles as separation media.

First of all, pore size and pore size distribution were determined in a size exclusion mode using polystyrene standard samples as well as alkylbenzenes in tetrahydrofuran (THF). Two kinds of Ma-gels were prepared by MSP and SPM and the calibration curves on the total four Ma-gels are depicted in Figs. 1 and 2.

The Ma-gels prepared using cyclohexanol as a porogen showed no differences in pore size distribution and a volume of pores between MSP and SPM (Fig.1), however, those prepared with toluene as a porogen provided severe differences (Fig.2). Since methyl methacrylate, ethylene glycol dimethacrylate, and cyclohexanol are not good solvent to polystyrene, the seed particle is not dissolved in the oil droplet consisting of the monomers and the porogen,[10] which results in completely same properties in pore size and pore size distribution as well as the volume of pores in both methods. On the other hand, when a good solvent to the polystyrene seed, toluene is involved in the swollen particles, the seed polymer is dissolved in the oil droplet in MSP to afford porous particles with relatively large pores, while SPM gives almost non-porous particles in spite of the use of toluene as a porogenic solvent. The similar non-porous particles were also obtained by SPM using xylene or ethylbenzene as a porogenic solvent and an unexpected appearance of these non-porous particles in SPM can be only explained by a complete phase separation between the monomers and the porogenic solvent which means toluene dose not work as a porogen. Since only one difference in both methods is the use of polystyrene seed polymer in MSP, it is clear that toluene involving the dissolved polystyrene seed polymer acts as a porogenic solvent to provide porous structures.[11]

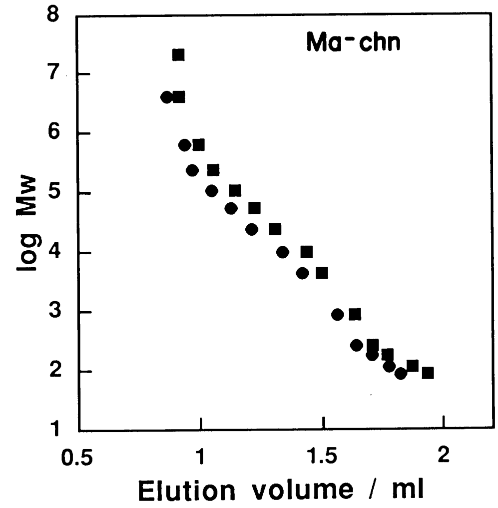

Fig.1. Calibration curve (cyclohexanol).
■; MSP, ●; SPM, Mobile phase; THF,
Flow rate; 0.5 ml/min. Detection; UV 254 nm.

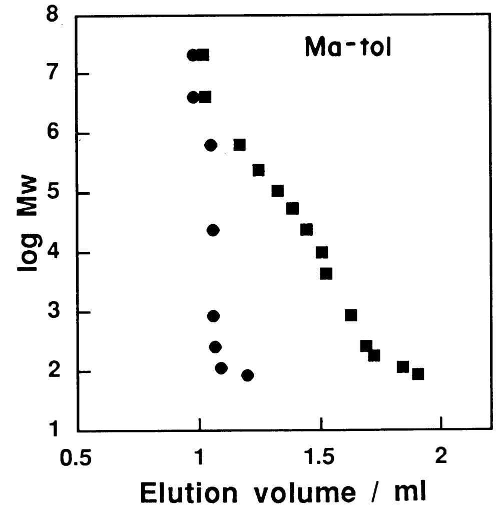

Fig.2. Calibration curve (toluene).
■; MSP, ●; SPM, Mobile phase; THF,
Flow rate; 0.5 ml/min. Detection; UV 254 nm.

A retention selectivity in a reversed phase mode also indicated a very interesting phenomenon (Fig. 3). A retention selectivity on both of Ma-gel with toluene (Ma-tol-MSP) and with cyclohexanol (Ma-chn-MSP) was similar, because chemical composition and surface chemistry[9] were almost identical, however, the Ma-tol-MSP showed preferable retention to polycyclic aromatic hydrocarbons (PAH) in a aqueous acetonitrile. Since the Ma-gel does not include an aromatic functional group, this interesting retention selectivity is archived mainly by the difference in the nature of porogenic solvents that is an influence of seed polymer.

In a multi-step swelling and polymerization method, hydrophilic monomer and/or solvent tend to labilize the dispersion of the swollen particles due to the solubility. Therefore, toluene, xylene, and cyclohexane have been usually applied as the porogenic solvents. Although cyclohexanol is a very suitable porogenic solvent to methyl methacrylate gels[12] and applicable to the swelling method, the size monodispersity of the final particles become worse mainly due to an ease of coalesce of the swollen particles. Actually, a rapid stirring of the dispersion of the swollen particles and/or long swelling time resulted in the particles with much worse size monodispersity in Ma-chn-MSP than that in Ma-tol-MSP. So that, if Ma-tol-MSP affords better chromatographic properties than Ma-chn-MSP, it must be a very useful method to prepare poly(methyl methacrylate-ethylene glycol dimethacrylate) packing materials with excellent size monodispersity.

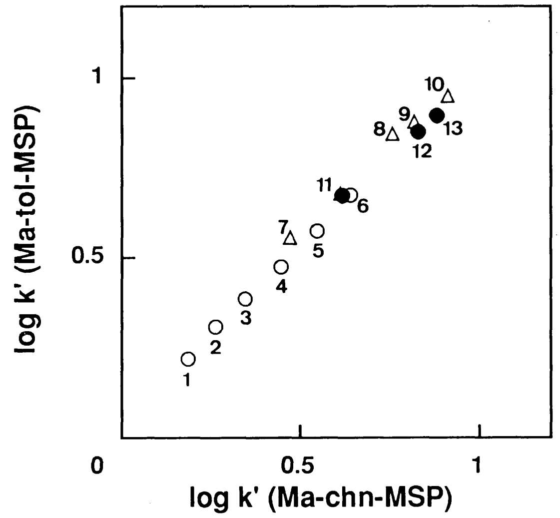

Fig.3. Retention selectivity in 60% acetonitrile. 1; benzene, 2; toluene, 3; ethylbenzene, 4; propylbenzene, 5; butylbenzene, 6; amylbenzene, 7; naphthalene, 8; anthracene, 9; pyrene, 10; triphenylene, 11; diphenylmethane, 12; o-terphenyl, 13; triphenylmethane.

An application of Ma-gel is of course a separation of polypeptide in a reversed phase gradient mode.[13] A very nice commercial Ma-gel, Shodex DE 613 can not provide good separation of a mixture of polypeptide due to the micro porosity of the particle. A large molecular weight peptide BSA (MW = 68,000) was reported to be excluded from the pores.[13] Both of Ma-gels using toluene and cyclohexanol provided a separation of polypeptide, however, the Ma-gel with cyclohexanol showed worse peak shape especially for cytochrome C (Fig. 4). These findings are explained based on a difference in pore size distribution of both particles and Ma-gel with toluene is clearly a better separation medium for the separation of polypeptide.

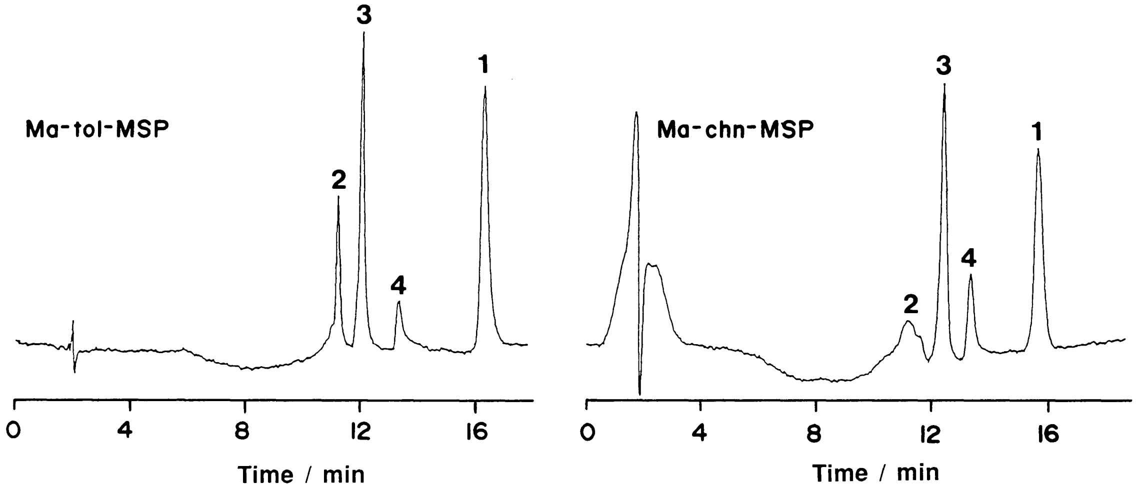

Fig.4. Separation of polypeptide.
1; naphthalenemethanol, 2; cytochrome C, 3; lysozyme, 4; BSA, Mobile phase; A; 20% acetonitrile with 0.1% trifluoroacetic acid, B; 60% acetonitrile with 0.1% trifluoroacetic acid, Gradient; from 100% A to 100% B in 20 min. Detection; UV 280 nm.

Here, the unexpected effect of the seed polymer is turned into a good method to prepare the good Ma-gel for the polypeptide separation.

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8) 10 ml of the purified styrene, 0.07 g of sodium Chloride, and 0.05 g of potassium peroxidesurfate were admixed in 100 ml of distilled water and the polymerization was carried out at 75 °C for 24 hours with a stirring at 350 rpm. After a typical centrifugal purification method, a chemical yield of size monodispersed polystyrene seed polymer (1 μm un diameter) was 54%. The purified seed polymers were dispersed into water again for the further applications.
9) The water dispersion of the polystyrene seed particles (3.1 X 10^{-2} g/ml) 2.5 ml was treated with a micro emulsion which was prepared from 0.35 ml of dibutyl phthalate, 0.06 g of benzoyl peroxide, 0.09 g of sodium dodecylsulfate, and 25 ml of distilled water by a sonication, and the first step swelling was carried out at room temperature with a stirring at 125 rpm. After the first step swelling was completed, to the dispersion of the swollen particles, was added a dispersion of 2.55 ml of methyl methacrylate, 3.83 ml of ethylene glycol dimethacrylate, and 6.38 ml of cyclohexanol or toluene into 30.6 ml of water including 0.78 g of polyvinylalcohol (dp = 500, saponification value = 86.5 to 89 mol%) as a stabilizer. The swelling was carried out at room temperature for 2 hours with a stirring at 125 rpm. After the second step swelling was finished, polymerization took place at 75 °C under argon atmosphere for 24 hours with slow stirring. The polymerized dispersion was poured into 250 ml of hot methanol and a supernatant was discarded after a sedimentation of particles. The polymer particles were redispersed into methanol and a supernatant was discarded after sedimentation. This procedure was repeated 3 times in methanol, 3 times in tetrahydrofuran, and once in toluene, then polymer particles were filtrated with membrane filter and washed with acetone and dried at room temperature. Chemical yield calculated based on the monomers was better than 90%. Elemental analyses data were C=59.03%, H=7.37% and C=59.30%, H=7.42% for cyclohexanol and toluene, respectively, while the calculated data was C=60.37%, H=7.47%.
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