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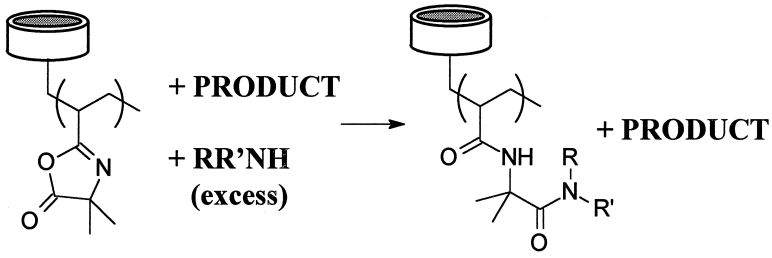
J. Comb. Chem., **2001**, 3 (2), 216-223• DOI: 10.1021/cc000092o • Publication Date (Web): 19 January 2001



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Grafted Macroporous Polymer Monolithic Disks: A New Format of Scavengers for Solution-Phase Combinatorial Chemistry

Jennifer A. Tripp, Frantisek Svec, and Jean M. J. Fréchet*

Department of Chemistry, University of California, Berkeley, California 94720-1460

Received October 13, 2000

Polyethylene encased porous poly(chloromethylstyrene-*co*-divinylbenzene) disks have been prepared by polymerization in a cylindrical glass mold and cut to a disk format. Following attachment of a free radical azo initiator 4,4′-azobis(4-cyanovaleric acid) to available functionalities at the surface of the pores, the polymerization of 2-vinyl-4,4-dimethylazlactone was initiated from the surface. To avoid an undesirable increase in flow resistance and to improve the yield of grafting, divinylbenzene was added to the polymerization mixture in order to form a layer of swellable reactive polymer gel within the pores. The use of these disks as scavenging filters to remove various amines from solutions in flow-through operations was demonstrated by effective removal of amines in a very short period of time from their solutions in a variety of solvents, even including alcohols and water.

Introduction

Much of the early work in combinatorial chemistry has typically been associated with solid-phase supported reactions, which is the approach pioneered by Merrifield almost 40 years ago.[1] However, solution-phase chemistry appears to be preferred in many of the current combinatorial approaches because the number of available reactions is virtually unlimited.[2] The difficulties associated with the tedious purification of solution-phase libraries of compounds have been alleviated somewhat through the use of resin-supported scavengers,[3] specific ion-exchangers,[4] and reactive quenching reagents[5] based on the concept of complementary molecular reactivity and molecular recognition.[6] These materials selectively remove one or more components from the reaction mixture, leaving a purified product in the solution phase. This greatly simplifies the otherwise time-consuming purification steps typical of solution-phase syntheses.

Today, all commercial scavenger resins are available only in the bead format. The spherical particles are popular for a variety of reasons, including the long tradition and vast experience with beads in the field of solid-phase chemistry, their commercial availability, simple preparation using suspension polymerization, good mechanical stability, and the wide range of available chemistries. Size polydispersity, slow diffusion in and out of pores containing reactive sites, and handling difficulties are well-known drawbacks that make beads less than ideal supports in some situations, including automated synthesis. Therefore, a few attempts to prepare polymer gel supports in macroscopic shapes other than beads have been reported recently.[7]

Almost a decade ago, we introduced macroporous materials in the entirely new format of molded porous polymer monoliths.[8] These materials, prepared in unstirred molds, have porous properties very different from those typical of macroporous or gel beads.[9] The majority of pores within these monoliths are large and well-suited for flow-through applications.[9,10] Pore sizes within the monolithic materials can be controlled over a wide range by varying the polymerization conditions used for their preparation.[11] To date, monoliths have been most often used as separation media in various chromatographic modes, supports for catalysts, in solid-phase extraction, and for the fabrication of thermally controlled valve- or gate-like devices.[12]

In contrast, applications using monoliths as solid phases in organic synthesis have been examined less extensively though their flow-through properties could make them ideal for some applications. However, the incorporation of flow-through pores comes at a price as only a small internal surface area is available for reactions within the pores of the monolith. This small surface area limits the number of available reactive functionalities since, in these nonswelling, highly cross-linked macroporous systems, only those groups that are exposed at the pore surface are accessible. Steric hindrance might be another reason for the lower intrinsic reactivity of this class of materials. One way to alleviate this problem would be to prepare monoliths with large surface areas. Indeed, monoliths with specific surface areas in the range of several hundred square meters per gram have been demonstrated.[13] However, this increase in surface area is accompanied by a concurrent rapid decrease in the permeability to liquids, the property that is most crucial for flow-through applications.

Yet another approach to increase the density of functional groups on surfaces is grafting, a technique that is widely used for the manufacture of supports for combinatorial chemistry such as the TentaGel and ArgoGel beads.[14] However, except for the terminal group, the grafted polyoxyethylene chains in these supports do not possess any other reactive functionality and serve largely to modulate the polarity and swelling of these supports. In contrast, the grafting of functionalized monomers enables attachment of a higher number of reactive groups and leads to an increase

10.1021/cc000092o CCC: $20.00
Published on Web 01/19/2001

in loading.[15,16] For example, we have used grafting processes to introduce multiple branches in polymers and dendrimers, or to introduce novel functionalities into monolithic macroporous media.[15] Similarly, Czarnik reported the grafting of styrenic monomers to fluoropolymer MicroTubes,[16b,c] while Hodges recently used a "living" free radical polymerization process to prepare his "designer" scavenging resins. In this approach, the benzylic chloride groups of a chloromethylated Merrifield gel resin were partly displaced by the sodium salt of 2,2,6,6-tetramethylpiperidyl-1-oxy (TEMPO), and this functionality was then used as a reactive site for the graft polymerization of monomers such as 4-bromostyrene and 3-isopropenyl-α,α-dimethylbenzyl isocyanate.[16d]

In our own work, the pore surface of an insoluble macroporous chloromethylstyrene copolymer was first functionalized with 4,4′-azobis(4-cyanovaleric) acid, and this moiety was then used to initiate free radical polymerization of an added functional monomer.[7b] This approach enables a substantial multiplication of the functionalities emanating from the reaction sites located on the internal surface of the monolith while not overly restricting flow through the pores. To demonstrate the utility of these grafted materials as auxiliaries for combinatorial chemistry, we have developed a technique we call "reactive filtration".[7b] This involves preparing monolithic disks with grafted chains of reactive monomer through which a reaction mixture is pushed as would be done through a filter. The monolith previously modified with suitable reactive groups is able to remove the undesired excess reagents from solution while leaving the pure product unaffected.

Results and Discussion

Preparation of Porous Monolith. Porous polymer monoliths can be prepared in a mold of virtually any shape and size, which enables the facile production of a variety of macroscopic objects. A typical procedure involves mixing a reactive monomer, a cross-linking monomer, a porogen, and an initiator and introducing them into the mold. The mixture is then heated to effect free radical polymerization. In contrast to techniques used for the preparation of beads, typically suspension polymerization in an aqueous continuous phase, the major advantage of the "molding" procedure is that no suspending medium is needed and the polymerization starts from a single liquid phase. Therefore, monoliths can be easily prepared from polar, water-soluble monomers and even monomers that would react with water.

The pores within these monolithic materials fulfill a double role: they must allow flow with a low resistance and provide sufficient surface area for subsequent chemical modification. While very large pores would be beneficial for the former requirement, the latter profits from the presence of a large number of small pores. Therefore, the porous structure of the monolith must be carefully optimized. The porosity can be easily controlled over a wide range by changing variables such as the percentage of cross-linker in the monomer mixture, the polymerization temperature, and the nature of the porogenic solvents. Clearly, changes in the composition of the monomer mixture are accompanied by changes in the chemistry of the monolith, and therefore this approach is not desirable. Control of the porous properties of the monolith through the composition of porogenic mixture is therefore the simplest tool that was selected for the optimization of our "generic" monolith.[10] The pore size distribution profile of the monoliths used in this project determined by mercury intrusion porosimetry is shown in Figure 1. The mean pore diameter is 1.0 μm. Pores of this size enable flow at low back pressure and, simultaneously, possess a surface area of approximately 8.5 m^2/g, sufficient for the desired grafting.

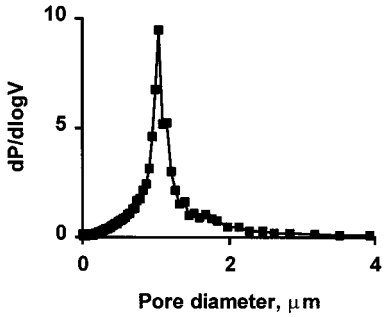


Figure 1. Pore size distribution of poly(chloromethylstyrene-*co*-divinylbenzene) monolith measured by mercury intrusion porosimetry. Polymerization conditions: chloromethylstyrene, 5.76 g; divinylbenzene, 8.64 g (80% grade); toluene, 6.30 g; 1-dodecanol, 15.3 g; and AIBN, 0.144 g (1 wt % with respect to monomers); 70 °C, 20 h.

Since the monolithic structure is completely permeable in all directions, a tight seal is required about the periphery of the cylindrical monolith, enabling flow only in the axial direction while preventing leakage through the sides. This is easily achieved with chromatographic columns in which the monolith completely fills the volume of the cylindrical column from wall to wall. Since the scavenger resins are designed to be disposable, a disk format that could be used in a two-piece cartridge was selected. Since all disks may not fit exactly within the cavity of the cartridge, the risk of side leakage had to be eliminated. The mold design shown in Figure 2a includes a glass test tube with a tightly fitting inner lining of shrinkable polyethylene tubing. This mold is filled with the deaerated polymerization mixture and sealed with a stopper and plastic tape. The polymerization is then carried out at a temperature of 70 °C for 20 h. After the liquid polymerization mixture has solidified, the glass tube is removed or broken, and then the shrinkable polyethylene-lined monolith is heated to a temperature of 120 °C for a few seconds to effect shrinkage and therefore tightly encase the cylindrical monolith. The sheathed cylindrical structure is then sliced into 5 mm thick disks with an impermeable sidewall (Figure 2b). Although the monoliths are sufficiently mechanically stable to be easily handled, the polyethylene rings also serve to reinforce the disks and prevent fraying of their edges. An additional benefit is that the flat face of the ring enables the disk to be firmly sealed between the bottom and top face of the cartridge without exercising excessive force on the porous polymer monolith.

Grafting from the Surface of the Monolith. Given the relative inertness of the monoliths, several grafting techniques were explored in the early stages of this study. For example, a method we used earlier for the development of thermally actuated gates and valves[12f] involved the attachment of allyl

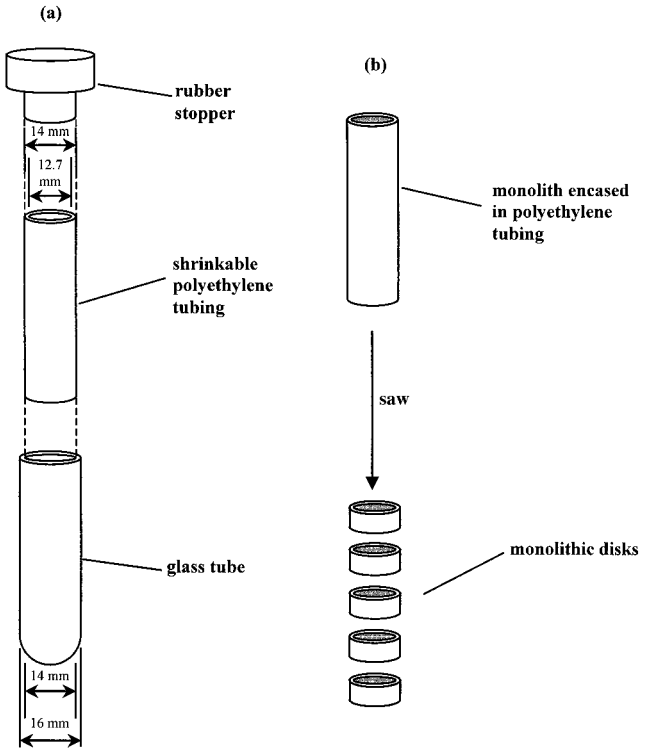


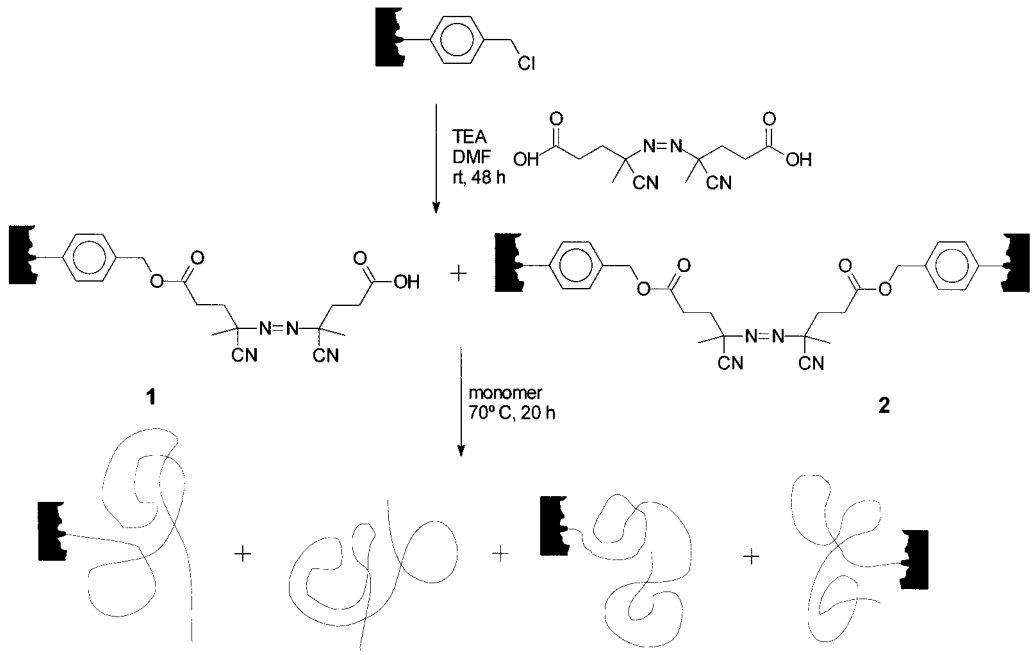
Figure 2. Schematics of the preparation of macroporous disks.

groups to the internal surface of a monolith, followed by polymerization of a solution of monomer and free radical initiator within the pores to effect grafting through incorporation of the surface double bonds. This method, even when modified for the incorporation of acrylic groups on the surface, did not afford materials with a capacity sufficient for use in scavenging applications. We therefore developed a method that relies on the attachment of an azo initiator to the surface of a poly(chloromethylstyrene-*co*-divinylbenzene) (CMS-DVB) monolith. In this approach, shown in Scheme 1, 4,4′-azobis(4-cyanovaleric acid) (ACVA), a symmetrical azo initiator containing two carboxylic acid groups, is attached via the benzyl chloride functionalities of the monolith by nucleophilic displacement of the chloride, forming ester bonds. The pores are then filled with a monomer solution, and the system is heated to initiate polymerization of a functional monomer from the polymer-bound initiating sites. Although our reaction scheme does not allow control of the attachment of the azo initiator through one or both of its reactive ends,[17] the latter is preferred. Doubly bound initiator moieties afford more efficient grafting as propagation can occur from both sites of the initiator thereby maximizing the efficiency of grafting of the functional monomer. In contrast, any singly bound initiator would initiate growth of both a surface-bound chain and a chain in solution. While the soluble polymer can later be washed from the pores and therefore does not pose a problem, the efficiency of grafting is lowered.

A variety of monomers have been tested in this graft polymerization reaction including 2-vinyl-4,4-dimethylazlactone (VAZ),[18] 2-aminoethyl methacrylate (AEMA), 2,3-epoxypropyl methacrylate, 4-acetoxystyrene, and chloromethylstyrene. The grafting can be detected using IR spectroscopy and, for some monomers, also determined quantitatively by elemental analysis. For example, when a solution containing 15% AEMA and 3% divinylbenzene cross-linker is polymerized from the surface of the initiator-functionalized monolithic disk, the nitrogen content in the product is 1.3%, translating into a capacity of 1 mmol/g of polymer-bound amine functionalities.

Capacity and Permeability. The propagation in solution resulting from the presence of the singly bound initiator (**1**) leads to the loss of monomer and results in disks with a lower loading of the required functionalities. This can be avoided by the addition of a small amount of cross-linking monomer. The addition of a cross-linker leads to the formation of a gel that incorporates not only the "truly grafted" chains, but also the chains that grow in the solution, thus leading to better

Scheme 1



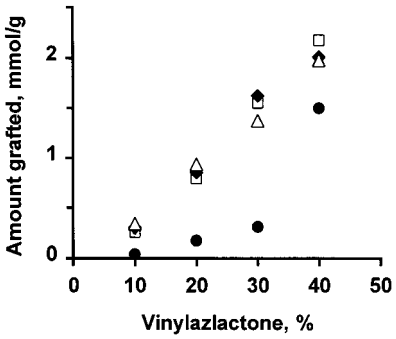


Figure 3. Effect of concentration of 2-vinyl-4,4-dimethylazlactone in toluene solution on extent of grafting at various degrees of cross-linking with divinylbenzene. Grafting conditions: 70 °C, 20 h. ● − 0; △ − 1; ◆ − 2; □ − 4.5% DVB.

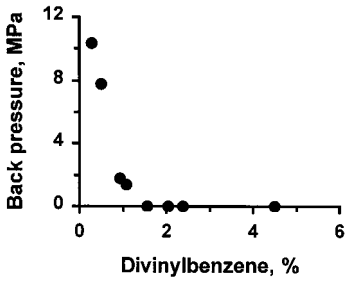


Figure 4. Effect of cross-linking of the polymer layer on resistance of grafted monolithic disks to flow of tetrahydrofuran at a flow rate of 1 mL/min.

utilization of monomer and affording monoliths with a higher loading capacity.

Figure 3 shows the effect of adding divinylbenzene (DVB) on the content of VAZ grafted to the monolith as determined from elemental analysis for nitrogen. The amount of grafted VAZ units increases rapidly upon addition of up to 1% DVB (with respect to the functional monomer) to the polymerization mixture and reaches the value calculated for complete incorporation of all of the monomers added to the pores of the monolith. Therefore, no further increase in the extent of grafting can be expected at concentrations of DVB higher than 1%. Indeed, the curve shown in Figure 3 illustrates that the grafting does not change with the addition of cross-linking monomer in amounts greater than 1%. If one assumes that all added monomers are indeed incorporated, higher degrees of grafting would be achieved by simply increasing the concentration of VAZ in solution. Indeed, Figure 3 documents that the grafting is a linear function of the VAZ concentration. Clearly, the grafting maximum would be reached when the pores are completely filled with neat monomers. A simple calculation reveals that the amount of grafted polymer at this point would be 4.3 mmol/g. However, this value only has a theoretical significance since a monolith with completely filled pores would be impermeable to liquids.

The addition of divinylbenzene also has a considerable effect on the flow resistance of the monolith. Figure 4 illustrates that the flow resistance decreases with increasing percentage of cross-linker in the polymerization mixture while keeping the overall extent of grafting constant. A more cross-linked layer of the grafted polymer swells less and therefore does not block the pores, allowing for flow-through.

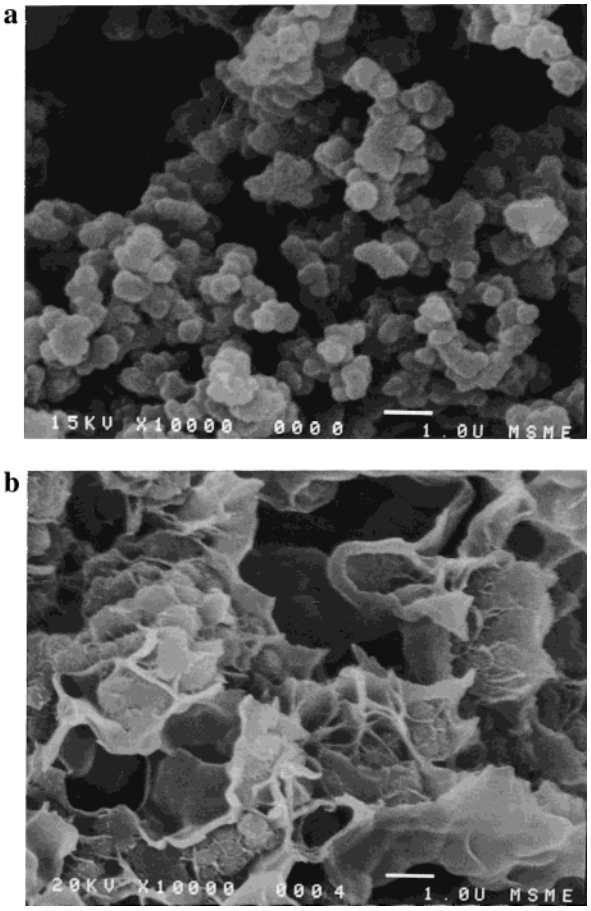


Figure 5. Scanning electron micrographs of the original monolith (a) and monolith grafted using a solution of 50% 2-vinyl-4,4-dimethylazlactone and 1% divinylbenzene in toluene for 20 h at 70 °C (b).

In contrast, the less cross-linked gel swells to a higher extent and fills the pores, thus making them less permeable and more resistant to flow.

Figure 5 shows scanning electron micrographs of the internal surface morphology of both an original monolith and one heavily grafted using a solution of 50% VAZ and 1% DVB. While the pores are well defined within the original monolith, the globular structure is clearly obscured upon grafting polymer along the surface of the pores. After grafting, the microglobules are largely covered with sheets and strands of the secondary polymer. The monolith shown in Figure 5b contains 2.7 mmol/g of azlactone functionalities. Since the SEM technique requires that the specimens be completely dry, some pores in the micrograph of the grafted monolith appear to remain open. However, this highly loaded monolith is essentially impermeable once swollen in a solvent.

Monolithic Scavengers. Monolithic disks grafted with VAZ (**3**) were used as electrophilic scavengers that react with nucleophiles such as amines according to the equation shown in Scheme 2, forming a structure containing two amide links (**4**). This reaction can readily be monitored in the IR spectrum as shown in Figure 6. After reaction with an amine, the azlactone carbonyl peak at 1820 cm^{-1} disappears while a large amide peak is seen at 1648 cm^{-1}. The peak at 1740 cm^{-1} represents the ester linking the grafted polymer to the

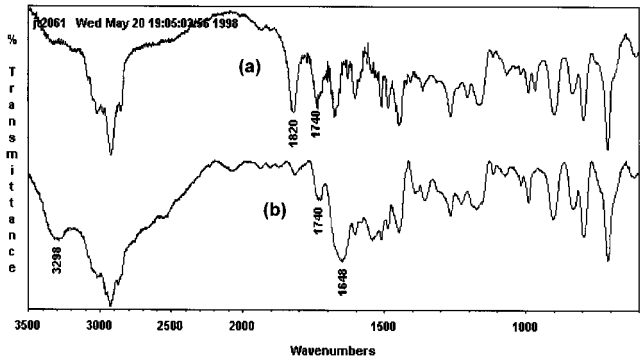


Figure 6. IR spectra of monolith grafted with 2-vinyl-4,4-dimethylazlactone monolith before (a) and after (b) reaction with butylamine.

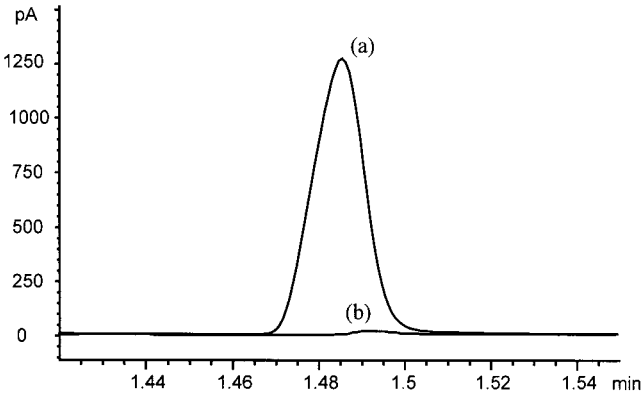
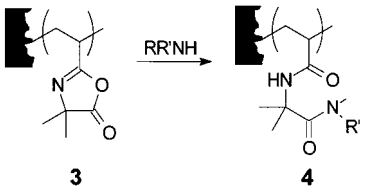


Figure 7. Gas chromatographic analysis of benzylamine solution in tetrahydrofuran (a) and of the same solution after passing through the monolithic scavenging disk (b). Reaction conditions: 8.7 μL (0.08 mmol) of benzylamine; monolithic disk grafted using a toluene solution of 20% 2-vinyl-4,4-dimethylazlactone and 2% divinylbenzene; residence time 24 min.

Scheme 2



CSM-DVB backbone, and this peak remains essentially unchanged.

The advantage of using monoliths in place of beads is that solutions can be pumped *through* the material. This convective flow affords much faster mass transport of reagents to the reactive sites than the slow diffusion process that must occur through the stagnant pool of solvent located within the diffusive pores of typical beads. To achieve flow through the monolith, the scavenging reactions were carried out with grafted monolithic disks encased in the custom-made holder described previously. The amine solution was pumped through the cartridge using a syringe pump, and the amine content of the solution was determined by GC both at the inlet and outlet of the cartridge. Figure 7 shows the large peak seen in the gas chromatogram of a solution of benzylamine in tetrahydrofuran pumped into the cartridge. After this solution passes through the scavenger at a rate of 1 mL/h (a residence time of 24 min), this peak disappears, confirming the virtually complete removal of the amine. The very small peak at a retention time of 1.493 min may be baseline noise or the amine. The shift in retention time would be explained by the fact that in adsorption chromatography more concentrated samples tend to have shorter retention times.[19]

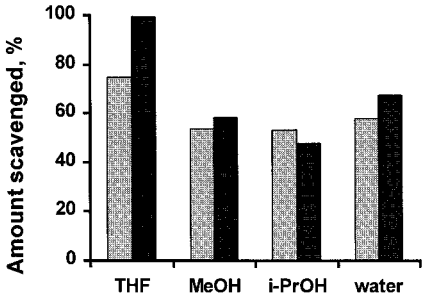


Figure 8. Effect of residence time on scavenging efficiency of macroporous disks for benzylamine in various solvents. Benzylamine solutions: 8.7 μL (0.08 mmol) in 1.5 mL of solvent. Disks 5 mm thick and 14 mm in diameter grafted using a toluene solution containing 20% 2-vinyl-4,4-dimethylazlactone and 2% divinylbenzene. Residence times: 8.0 min (light gray) and 24 min (dark gray).

Table 1. Scavenging Efficiencies of Amines in Model Reactions[a]

amine	solvent	amount scavenged, %
benzylamine	tetrahydrofuran	74.7
phenethylamine	tetrahydrofuran	76.9
butylamine	dichloromethane	78.0
diethylamine	dichloromethane	90.1
3,5-dimethylaniline	tetrahydrofuran	47.6

[a] Conditions. Reaction mixture: 0.2 mmol of *t*-butylisocyanate, 0.3 mmol of amine, 1.5 mL of solvent; porous disc 5 × 13 mm diameter, grafted with 20% VDMAL and 2% DVB; flow rate 3 mL/h, residence time 8 min.

In a standard implementation using commercially available scavenging beads, the beads are added to a solution and usually left in contact with the solution for several hours or overnight. Once the reaction is complete, the beads that still contain some of the desired compound within their pores or swollen matrix are removed. Recovery of the desired compound from the bead requires washing in a process that is again controlled by diffusion. In contrast, in our implementation the solution containing an excess of a reagent is pumped *through* the monolith. Therefore, this compound is in contact with the reactive surface only as long as the solution resides within the monolith. This residence time is a function of the disk pore volume, capacity, and flow rate. The effect of residence time on scavenging has already been demonstrated in our preliminary report.[15]

In addition to the residence time, the rate of the scavenging depends also on other reaction conditions such as the nature of the solvent, the concentration of scavenged moieties, and the temperature. For example, Figure 8 shows the effect of solvent on scavenging efficiency for solutions of benzylamine. In tetrahydrofuran the reaction rate is rather high, and 75% of the amine is scavenged with a residence time of only 8 min (Table 1). The issue of solvents in which the scavenging can take place is rather important. Commercially available nucleophile scavengers typically contain isocyanate groups. Therefore, they are not suitable for reaction with compounds dissolved in alcohols or water since the solvent

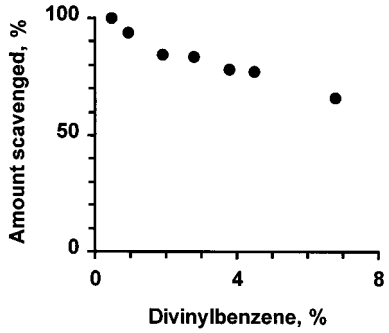


Figure 9. Effect of cross-linking density of grafted gel on scavenging efficiency of macroporous disks for benzylamine in various solvents. Grafting conditions: 20% 2-vinyl-4,4-dimethylazlactone and divinylbenzene in toluene, 70 °C, 20 h.

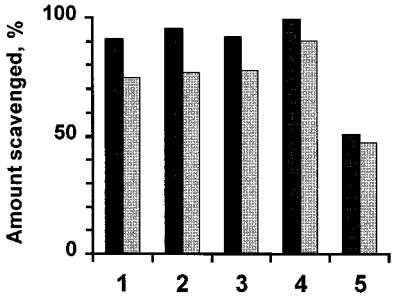


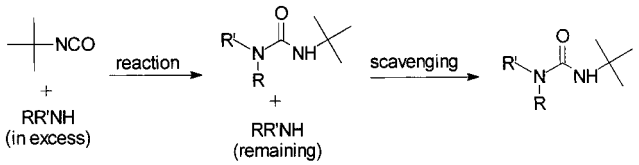
Figure 10. Effect of cross-linking density of grafted gel on scavenging efficiency of five different amines. 1 − benzylamine in tetrahydrofuran; 2 − phenethylamine in tetrahydrofuran; 3 − butylamine in dichloromethane; 4 − diethylamine in dichloromethane; 5 − 3,5-dimethylaniline in tetrahydrofuran. Grafting conditions: 20% vinylazlactone with 1% (dark gray) or 2% (light gray) divinylbenzene in toluene, 70 °C, 20 h.

itself would rapidly deactivate the resin. In contrast, the reaction of azlactone functionalities with alcohols and water is significantly slower than that with amines, and their scavenging can be achieved from alcohol and even aqueous solutions. Figure 8 shows the results of scavenging in tetrahydrofuran, methanol, 2-propanol, and water at two different residence times controlled by the flow rate through a disk grafted with 20% VAZ and 2% DVB. For example, 55% of the benzylamine present in the methanol solution was scavenged at a residence time of 8 min (flow rate of 3 mL/h). An extension of residence time to 24 min does not lead to a significant increase in this value since the competing reaction with alcohol also quenches the azlactone functionalities. To remove a higher amount of amine from the alcohol solution, a larger amount of azlactone functionalities must be utilized. For example, using two standard disks together in the cartridge increases the amount of benzylamine scavenged in methanol from 55% to 76% at the same flow rate of 3.0 mL/h. Complete removal of unreacted amine can be achieved by using additional disks stacked in the cartridge or by increasing the capacity of the disks by grafting a more concentrated solution of reactive monomer.

The cross-linking density of the grafted gel also has a large effect on the scavenging efficiency of the disks. Solutions of benzylamine in tetrahydrofuran were scavenged using disks containing 20% VAZ and various amounts of DVB. As shown in Figure 9, a decrease in the amount of DVB added to the grafting solution leads to an increase in scavenging efficiency. Evidently, the less cross-linked the polymer, the higher the swelling of the gel layer, and the better the accessibility of groups for reaction with the amine in solution. However, the lower cross-linking and higher swellability also lead to an increase in flow resistance. Therefore, an optimum in DVB percentage must be struck to achieve the proper balance between reactivity and flow properties. In practice we selected 1% DVB for use in most of the scavenging experiments.

The utility of monolithic scavengers in solution-phase synthesis is demonstrated in a short array of products prepared by reaction of five different amines with *tert*-butyl isocyanate as shown in Scheme 3. An excess of amine was used to drive the reaction to completion, and then the entire reaction mixture was pumped through the monolith disk grafted with VAZ to scavenge the excess amine. The residence time was held constant at 8.0 min in all of these

Scheme 3



experiments in order to assess the differences between the reactivity of individual amines. The extent of each reaction was quantified again by comparing the GC peak areas for each amine before and after scavenging. Figure 10 shows the percentages of amines scavenged by VAZ-grafted monoliths containing 1% and 2% DVB. As expected, the extent of reaction relates to the nucleophilicity of the amine. Diethylamine is a better nucleophile and, therefore, is scavenged more efficiently than the aliphatic primary amines such as benzylamine, while 3,5-dimethylaniline, the poorest nucleophile in the array, is removed from the mixture to the lowest degree and a longer residence time would be required to scavenge it completely. Both tetrahydrofuran and dichloromethane were used as solvents.

Determination of the residence time required to scavenge more than 99% of the amine again showed that these materials react very quickly. Solutions of different amines were pumped through monoliths containing 20% VAZ and 2% DVB at different flow rates, and the residence time necessary for complete reaction was noted. For primary amines, such as benzylamine and phenethylamine, a residence time of 20 min resulted in virtually complete removal of these amines from solution. For secondary amines, such as diethylamine, a mere 8 min were necessary for complete scavenging. Although a complete reaction could not be obtained for poorly nucleophilic substituted anilines such as 3,5-dimethylaniline, 66% of this amine was scavenged after 48 min residence time at room temperature. Even this value compares favorably with commercial PS-isocyanate beads, which scavenge only 16% of aniline after 1 h reaction under comparable conditions.

Conclusion

Reactive resins in the new format of macroscopic disks obtained from a porous polymer monolith containing chains of reactive polymer grafted to the surface of its pores are a

useful alternative to the typically used scavenging beads. These disks that act as filters to remove the excess of undesired reagents from a solution have shown their utility in "reactive filtration," a technique that complements typical methods of solution-phase combinatorial synthesis. Although we only demonstrated the removal of excess amines from reaction mixtures using disks containing azlactone functionalities, our approach is more general and can be easily extended to a number of materials with a variety of grafted chemistries. Owing to the rapid mass transfer accelerated by its flow-through characteristics, the reactive filtration media require only a short residence time, thus significantly decreasing the time required for work-up processes, an important factor in high throughput synthetic schemes.

Experimental Section

Materials. Chloromethylstyrene (CMS) is a mixture of 3- and 4-isomers and was purchased from Dow Chemical. 2-Vinyl-4,4-dimethylazlactone (VAZ) was obtained as a gift from the 3M Corporation. 4,4′-Azobis(4-cyanovaleric acid) was purchased from Aldrich and purified by repeated washing with diethyl ether. Divinylbenzene (Aldrich, 80% and 55% grade, respectively) was a mixture of isomers containing ethylvinylbenzenes as the major impurities.

Instrumentation. IR spectra were taken on a Mattson Genesis II FTIR spectrometer using the total reflectance mode. Porous properties of the polymers were measured using a Micromeritics Autopore 9420 mercury intrusion porosimeter. Surface area measurements were done on a Micromeritics ASAP 2010 BET adsorptimeter using nitrogen. Flow resistance was measured on a Waters HPLC system controlled by Millennium 2010 Chromatography Manager software using tetrahydrofuran as the solvent. Gas chromatography was carried out using a HP 6890 series GC system equipped with an autoinjector and 30 m HP-5 column. The data were acquired and processed with HP GC ChemStation software.

Preparation of Poly(chloromethylstyrene-*co*-divinylbenzene) Monoliths. The monoliths were prepared in molds consisting of a 14 mm i.d. glass tube with its inside wall lined by a shrinkable polyethylene tubing and sealed at one end (Figure 2). Azobisisobutyronitrile (0.12 g, 1 wt % with respect to monomers) was dissolved in chloromethylstyrene (4.8 g), divinylbenzene (80% grade, 7.2 g), toluene (5.25 g), and 1-dodecanol (12.75 g). The mixture was purged with nitrogen for 10 min, and the open end of the mold was sealed using a rubber septum secured with wire and electrical tape. The polymerization was allowed to proceed in a thermostated bath for 20 h at 70 °C. The glass tube was then carefully crushed, and the monolith, tightly embraced by the polyethylene tubing, was removed and sliced using a table saw into 5 mm thick disks. These disks were extracted with tetrahydrofuran for 24 h in a Soxhlet apparatus.

Attachment of 4,4′-Azobis(4-cyanovaleric acid) to Monolith Surface. To a solution of 3.33 g of 4,4′-azobis(4-cyanovaleric acid) and 2.22 g of triethylamine in 6.66 mL of *N*,*N*-dimethylformamide were added several monolithic poly(chloromethylstyrene-*co*-divinylbenzene) disks. The reaction was carried out without stirring at room temperature for 48 h. The modified disks were then washed with diethyl ether in a Soxhlet extractor for 24 h. IR: 1740 cm^{-1} (C═O). Elemental analysis for nitrogen after heating to remove the diazo groups: N = 0.69%.

Grafting 2-Vinyl-4,4-dimethylazlactone to Monolithic Disks Functionalized with Azobis(cyanovaleric acid). The monoliths functionalized with free-radical initiator were placed in a glass vial, and a volume of a toluene solution containing various percentages of 2-vinyl-4,4-dimethylazlactone and divinylbenzene sufficient to completely cover the solid was added. The content was purged with nitrogen for 10 min, and the flask was sealed and heated in a bath to 70 °C for 20 h. The soluble polymer was removed from the grafted disks by extraction with tetrahydrofuran in a Soxhlet apparatus for 24 h. Any polymer gel on the outside surface of the monolith was removed using a razor blade. IR: 1820 cm^{-1} (azlactone C═O).

Scavenging Amines Using Vinylazlactone-Grafted Disks. The monolithic disk was placed into a custom-made stainless steel holder and attached to a syringe pump (KD Scientific model 101). In a typical scavenging experiment, the monolith was first washed with the desired solvent, and then the solution containing compounds to be scavenged was pumped through the monolith at a specific flow rate. After the scavenging was completed, the monolith was washed again with the solvent. The difference in composition of the solutions that was determined before and after scavenging by means of gas chromatography was used to estimate the amounts of scavenged amines.

Acknowledgment. Support of this research by a grant of the National Institute of General Medical Sciences, National Institutes of Health (GM-48364), is gratefully acknowledged.

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