SHORT COMMUNICATIONS

Aldol Reaction of Silyl Enol Ether with Benzaldehyde in Water-Methanol Solvents Using Fluoroalkyl End-Capped Polymer Gels as Reaction Media

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Recently, there has been great interest in the use of water in organic synthesis as reaction media from the viewpoint of economical and environmentally benign solvents.¹ However, water cannot function as a reaction medium since a variety of organic compounds are insoluble in water. Additionally, water is likely to decompose or deactivate numerous reactive substrates, reagents and catalysts. Therefore, it is deeply desirable to develop novel organic reaction systems which can use water as a solvent for a wide range of organic transformation. In fact, there have been reports on surfactant-aided water-stable Lewis acids such as scandium trifluoromethanesulfonate (scandium triflate, $\text{Sc}(\text{OTf})_3$) or Brønsted acid-catalyzed reactions in water² and organic reactions in water catalyzed using amphiphilic resin-supported complexes.³ On the other hand, much attention has been focused on fluororous techniques for a potentially new environmentally efficient, green chemical, and industrial process for the synthesis of important global organic chemicals.⁴ Therefore, it is very important to apply fluoroalkyl derivatives into aqueous organic reaction systems. Hitherto, we reported that fluoroalkyl end-capped 2-acrylamido-2-methylpropanesulfonic acid (betaine-type) polymers [$\text{R}_\text{F}-(\text{AMPS})_n-\text{R}_\text{F}$; R_F = fluoroalkyl groups] can cause a gelation derived from the synergistic interaction of the aggregation of end-capped fluoroalkyl segments and the ionic interactions of the betaine segments in water under non-crosslinked conditions.⁵ Thus, it is strongly expected that our fluorinated AMPS polymer gels can be applied to organic reaction systems in water. In particular, the utility of hydro-

gelling polymer catalysts is of great interest because of their ease of workup and of separation of products and catalysts, from the environmental point of view. In the course of our comprehensive investigations to develop new fluorinated synthetic reaction systems in aqueous media, we have found that $\text{R}_\text{F}-(\text{AMPS})_n-\text{R}_\text{F}$ polymers can form gels to harden a $\text{Sc}(\text{OTf})_3$ water-methanol solution and these fluorinated hydro-gelling polymers are applied to a new reaction medium for aldol reaction of silyl enol ether with benzaldehyde, and the results are described herein.

A series of fluoroalkyl end-capped 2-acrylamido-2-methylpropanesulfonic acid polymers [$\text{R}_\text{F}-(\text{AMPS})_n-\text{R}_\text{F}$; R_F = $\text{CF}(\text{CF}_3)\text{OC}_3\text{F}_7$, $\text{CF}(\text{CF}_3)\text{OCF}_2\text{CF}(\text{CF}_3)\text{OC}_3\text{F}_7$, $\text{CF}(\text{CF}_3)\text{OC}_6\text{F}_{13}$, perfluoro-1,3-dimethyl-2,5-dioxacyclopentyl group] were prepared by the reactions of the corresponding fluoroalkanoyl peroxides with 2-acrylamido-2-methylpropanesulfonic acid (AMPS) according to our previously reported method.⁵ Preparation of the $\text{R}_\text{F}-(\text{AMPS})_n-\text{R}_\text{F}$ [R_F = $\text{CF}(\text{CF}_3)\text{OC}_3\text{F}_7$] hydrogel containing $\text{Sc}(\text{OTf})_3$ is as follows: $\text{Sc}(\text{OTf})_3$ (0.2 mmol) was dissolved in a methanol–water [1:1 (vol.)] solution (1 mL) at room temperature, and to this solution was added $\text{R}_\text{F}-(\text{AMPS})_n-\text{R}_\text{F}$ polymer (100 mg). The mixture was treated under ultrasonic conditions at 30 °C until this polymer can form the gel. In contrast, the corresponding non-fluorinated AMPS polymer [$-(\text{AMPS})_n-$] was not able to form the gel under similar conditions.

To the resulting fluorinated gel were added 1-phenyl-1-(trimethylsilyloxy)ethylene (1.2 mmol) and

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Table I. Relationship between the product yield and the minimum concentration ($C_{\min}$) of R_F -(AMPS) $_n$ - R_F necessary for gelation in water-methanol [1 : 1 (vol.)] at 30 °C

R_F in R_F -(AMPS) $_n$ - R_F	$C_{\min}$ (g dm $^{-3}$)	Product (Yield/%) ^a
$R_F = \text{F}_3\text{C}-\text{O}-\text{CF}_2-\text{CF}_3$	263	4
$R_F = \text{CF}(\text{CF}_3)\text{OCF}_2\text{CF}(\text{CF}_3)\text{OC}_3\text{F}_7$	48	17
$R_F = \text{CF}(\text{CF}_3)\text{OC}_6\text{F}_{13}$	52	20
$R_F = \text{CF}(\text{CF}_3)\text{OC}_3\text{F}_7$	114	42

^aIsolated yield based on PhCHO. **Scheme 1.**

benzaldehyde (0.4 mmol) successively at room temperature. The mixture was shaken (380 rpm) for 2 h at room temperature. Chloroform was added to the mixture, and the mixture containing chloroform was centrifuged for 30 min. The chloroform layer was easily separated from the fluorinated gel by simple filtration, and the obtained chloroform layer was washed with water. The organic layer was dried and concentrated under reduced pressure. The residue was purified by gel-permeation chromatography to afford the desired product.

Several examples of aldol reactions with some fluoroalkyl end-capped AMPS polymer gels containing $\text{Sc}(\text{OTf})_3$ under similar conditions are shown in Scheme 1 and Table I.

As shown in Scheme 1 and Table I, the reactions proceeded smoothly to afford the aldol adduct in the aqueous fluorinated polymer gel media containing $\text{Sc}(\text{OTf})_3$, although the fluorinated polymer gelling medium possessing no $\text{Sc}(\text{OTf})_3$ could not afford the aldol adduct. Interestingly, the highest yield of the adduct was obtained in the case of the fluorinated polymer gel possessing the moderate $C_{\min}$ value ($R_F = \text{CF}(\text{CF}_3)\text{OC}_3\text{F}_7$, $C_{\min} = 114$ g dm $^{-3}$). This finding suggests that the fluorinated polymer gel possessing the moderate $C_{\min}$ value could provide the sterically suitable gel network for our present aldol reaction.

In particular interest, it has been demonstrated that the fluorinated polymer gel containing $\text{Sc}(\text{OTf})_3$ was recovered quantitatively by simple filtration, and could be reused. The catalytic activity of the recovered fluorinated gel did not decrease even after four uses (see Scheme 2). However, the isolated yields (70–82%) of the aldol product are in general not so high. This would result from the heterogeneous reaction system and the weak extractability of the product from the fluorinated gels by chloroform.

^aRecovered fluorinated gel was used successively (Use 2, 3, and 4).^bIsolated yield based on the PhCHO consumption.^cIsolated yield based on PhCHO.**Scheme 2.**

In summary, we have developed a novel fluorinated hydro-gelling medium for the aldol reaction. Especially, this fluorinated gelling system is expected to be applicable to numerous catalytic reactions in aqueous media. Further studies for fluorinated gelling system possessing a good reactive media are in progress.

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