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Synthesis of cationic poly[N-isopropylacrylamide] microgel latexes using a thiol-containing monomer, vinylbenzylisothiouronium chloride

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SUMMARY : Monodisperse thermosensitive latex particles have been prepared by radical-initiated precipitation polymerization of N-isopropylacrylamide (NIPAM), N,N-methylenebisacrylamide (MBA), and using 2,2'-Azobis(2-amidinopropane) chloride (V50) as an initiator and vinylbenzylisothiouronium chloride (VBIC) as a thiol-containing monomer. The final latexes were characterized with respect to monomer conversion, polymer composition, particle size and size distribution. Particular attention was paid to the effect of VBIC concentration on the synthesis and colloidal properties of the resulting latexes.

Introduction

A recent review showed the paramount importance of polymers containing N-isopropylacrylamide (NIPAM)1). Pelton et al.[2)] described the first synthesis of monodisperse NIPAM particles through a precipitation polymerization process. Such polymer particles exhibit a Cloud Point Temperature (CPT) at 32°C, being hydrophilic and electrosterically stabilized below 32°C, and hydrophobic and electrostatically stabilized above 32°C. A crosslinking agent introduced during polymerization enabled particle cohesion to be maintained when cooled down to the CPT.

Poly[NIPAM] based latexes have been shown to exhibit many versatile applications, such as in the diagnostics field[3)]. Introduction of a functional and cationic monomer, such as 2-aminoethymethacrylate hydrochloride[4)], at the particle surface appeared suitable for increasing the electrostatic stabilization and for creating reactive groups for covalent binding with biomolecules[5)].

In this work, the polymerization of N-isopropylacrylamide and a protected thiol monomer, vinylbenzylisothiouronium chloride (VBIC), is described. The influence of the comonomer on the kinetics of precipitation polymerization and on the particle characteristics are examined.

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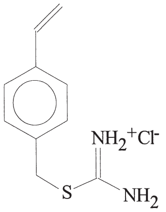
Experimental Section

Preparation and characterization of latexes

The vinylbenzylisothiouronium chloride (VBIC) monomer was prepared according to Yamaguchi's method6).



(structure of VBIC monomer)

Polymerization was carried out at 70°C in a 250 ml reactor using batch polymerization of N-isopropylacrylamide (NIPAM), N,N-methylenebisacrylamide (MBA), vinylbenzylisothiouronium chloride (VBIC) and 2,2'-azobis(2-amidinopropane) chloride (V50) as an initiator. NIPAM conversion was determined by gas chromatography using dimethylformamide as an internal standard4). The yield of particles and the water soluble polymer (WSP) were gravimetrically determined. The molecular weight (M_w) of the recovered WSP was measured using static light scattering. The CPT of both microgel particles and the water soluble polymer was determined by measuring the optical density variation versus temperature.

Results and Discussion

Influence of VBIC monomer concentration.

The effect of VBIC concentration (from 0 to 0.48 mmoles/L) on the precipitation polymerization of NIPAM was examined at constant initiator and crosslinking agent concentrations and at a 70°C polymerization temperature according to the recipe given in table 1.

Table 1 : recipe used for the preparation of microgel particles,

Reagent	Quantity (mmoles/L)
NIPAM	190
MBA	1.2
V50	12
VBIC	0 to 0.48

The influence of functional monomer (VBIC) on NIPAM conversion was first studied and the results obtained are reported in Figure 1, in which NIPAM conversion is plotted against the reaction time. As can be observed, NIPAM conversion was nearly completed within less than 10 minutes reflecting the high NIPAM propagation rate similar to that of any acrylamide derivatives. The presence of VBIC in the polymerization recipe has no influence on the initial polymerization rate, however a high amount of VBIC monomer leads to a decrease in the latent period between the addition of initiator and the start of polymerization.

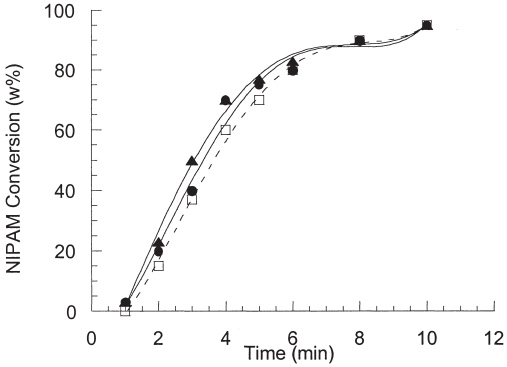


Figure 1 : NIPAM conversion versus time for three VBIC concentrations(□) 0, (▲) 0.09 and (●) 0.48 mmoles/L.

The influence of VBIC on particle yield was also examined as reported in Figure 2. For VBIC concentrations lower than 0.09 mmole/L, no drastic effect was observed, whereas, for higher concentrations, the particle yield was found to be dramatically decreased by the added VBIC amount. This behavior can be attributed to the high water solubility of the cationic monomer which causes an increase in the precursor concentration and higher water soluble polymer. A similar trend was observed when using aminoethylmethacrylate hydrochloride[4)] (AEM)/NIPAM/BMA/V50.

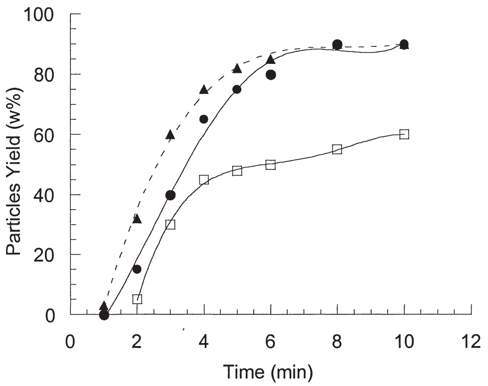


Figure 2 : Particle yield versus time for three VBIC concentrations; (●) 0, (▲) 0.096 and (□) 0.48 mmoles/L.

The influence of VBIC on the particle size versus polymerization time was examined and is illustrated in Figure 3, reporting the QELS particle size at 20°C versus time curves. It is clearly demonstrated that the particle size rapidly reaches a plateau value within a few minutes, reflecting the rapid and short nucleation step leading to the formation of a constant particle number early in the conversion process. The results obtained are in good agreement with those reported by Kamijo et al.[7)] in the case of NIPAM/MBA/KPS and also by Duracher et al.[8)] for N-isopropylmethacrylamide(NIPMAM)/MBA/KPS.

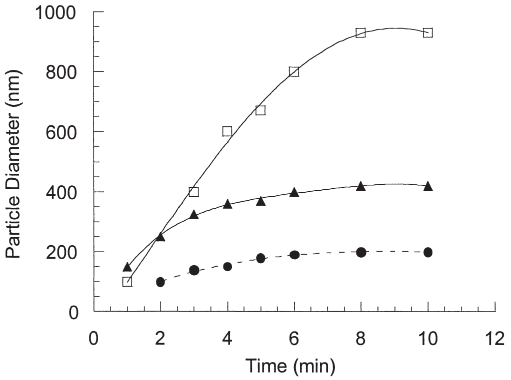


Figure 3 : QELS particle diameter in 10^{-3} M NaCl solution as a function of polymerization time (min) (□) 0, (▲) 0.096 and (●) 0.48 mmoles/L.

For comparison, final particle sizes measured using QELS (at 20°C and 50°C) or using TEM versus VBIC monomer concentration are reported in Figure 4. As shown in Figure 3, particle size was found to be VBIC concentration dependent. In fact, the final particle size decreases on increasing the VBIC amount in the polymerization recipe. This behavior can be attributed to the drastic effect of VBIC on the rate of the formation of precursors, providing a larger number of polymerization loci by a coagulation-like mechanism. Concerning size distribution, all prepared latexes appear to be quite monodisperse irrespective of VBIC concentration in the investigated range (results not shown).

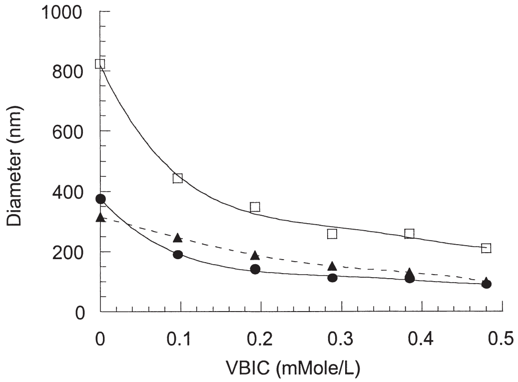


Figure 4 : Particle size versus VBIC concentration; (□) QELS at 20°C, (▲) QELS at 50°C and (●) TEM.

In order to obtain a better insight onto the effect of VBIC on the polymerization of NIPAM, the results on the swelling ratio (SR); volume at 20°C divided by the volume at 50°C and the water soluble polymer amount (WSP; w/w %) are collected in Table 2 for all prepared latexes.

As expected, the WSP was found to increase on increasing the amount of the VBIC. This indicates that the functional monomer plays a major role in the formation of the water soluble oligomer. In addition, the molecular weight of the formed water soluble polymer (for free VBIC, $\overline{M_w}$ ~67800 g/mole and $\overline{M_w}$ ~31600 g/mole for 0.19 mmoles/L of VBIC) was reduced when the amount of VBIC was increased, corroborating the above mentioned assumption. The swelling ratio (SR) significantly increases on increasing the initial VBIC concentration (within the experimental errors range). This can be attributed to the effect of VBIC on the incorporated amount of MBA in the final particle, since the swelling ratio was principally related to the crosslink density in the formed particles.

Table 2 : Swelling ratio, water soluble polymer amount and CPT (for microgel and WSP) as a function of VBIC monomer concentration used in the polymerization recipe.

VBIC amount (mmoles/L)	Swelling Ratio (SR)	WSP (w/w%)	CPT Particle	CPT WSP
0	18	4.9	31.6	35.7
0.0962	5.7	6.4	32.3	36.9
0.1924	6.2	6.6	ND	
0.2884	4.9	4.7	ND	
0.3844	7.8	8.3	ND	
0.480	9.5	14.2	ND	

ND: not determined

Material balance of isothiouronium salt.

Three methods were investigated in order to determine the concentration of the incorporated amount of the functional monomer on the microgel particles or in the water soluble polymer: a radioactive method using. ^{14}C-labeled iodoacetamide[9)] and a colorimetric method based on Ellmann's reagent[10)], allowing indirect quantification, and H^1-NMR technique were investigated. No thiol groups were detected on the microgel particle surface or in the water soluble polymer regardless of the analytical method. Such a result suggests that VBIC would act as a transfer agent. According to the VBIC chemical structure, three sites of transfer can be envisioned (see Figure 5) : i) hydrogen beside thiol takes away and methylbenzyl radical reacted with a monomer or an oligomer, ii) reaction of the amidine function and monomer with thiol, iii) thioamidine leaving an dissolving in the medium. As thiol groups were not detected, even in the water soluble polymers or in the continuous medium, the transfer reaction probably caused amidine groups to leave. Therefore, it is postulated that the thiol function would be principally incorporated inside the polymer microgel.

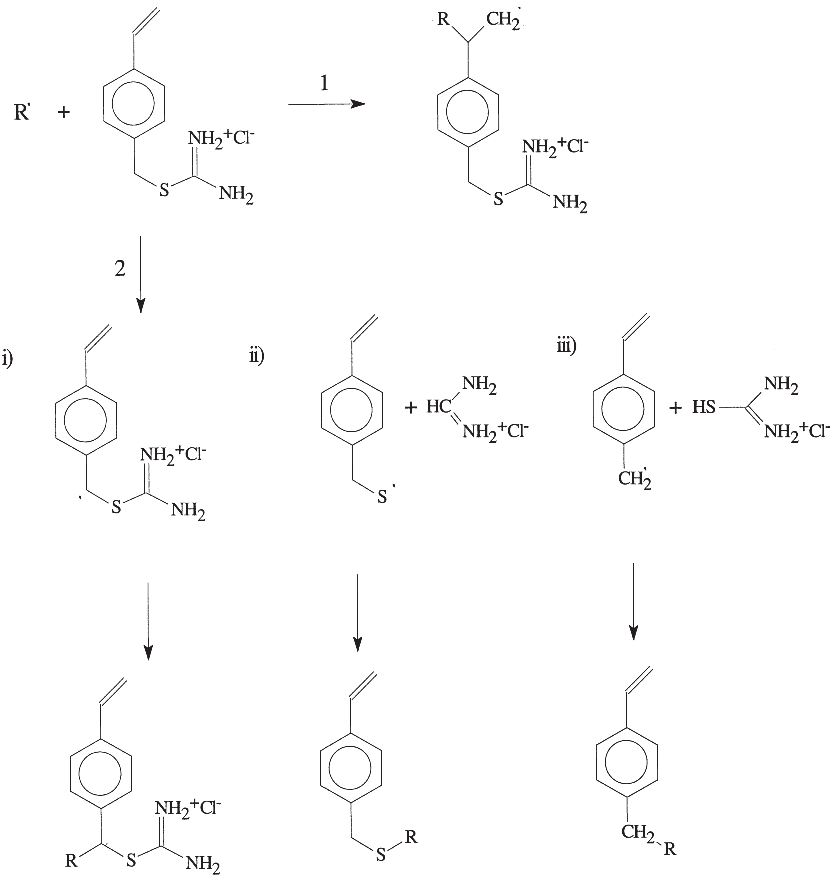


Figure 5 : Polymerization with VBIC; (1) without transfer reaction, (2) with transfer reaction. R is an oligomer, a monomer or a precursor.

Cloud Point Temperature

The CPT's for the prepared latexes and their corresponding water soluble polymers were measured and the results obtained are reported in table 2. As expected, using VBIC does not affect the CPT (32°C) of the final particles, whereas, the recovered water soluble polymers are found to exhibit higher CPT's (36-37°C) compared to free poly(NIPAM) polymer in solution (CPT~32°C). The difference in the CPT in the case of water soluble polymers can be attributed to both the decrease in molecular weight and the presence of cationic chain ends originating from the initiator.

Conclusions

Precipitation polymerization of NIPAM in the presence of VBIC was found to occur very rapidly. Raising the VBIC concentration causes the water soluble polymers to increase whereas particle size decreases, which explains the dramatic effect of the cationic monomer on the particle formation. The CPT of the recovered particles was found to be unchanged (~32°C), contrary to the case of the recovered water soluble polymers (~37°C). The higher CPT of WSP than that of poly(NIPAM) was probably caused by the low molecular weight of the WSP. In addition, the molecular weight ($\overline{M_w}$) of the measured WSP revealed a decrease in $\overline{M_w}$ upon increasing the VBIC amount.

The incorporated amount of thiol-containing monomer was too low to be detectable by any quantitative method, which suggests that, it acted as strong transfer agent in radical polymerization although the thiol function was under protected form.

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