

Urea-based polymethacrylamide purification

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ABSTRACT

A purification procedure of polymethacrylamide (PMAM) based on the urea feature of being a powerful H-bond breaker is proposed here. Polymethacrylamide was synthesized in water and the final product presents itself as an insoluble gel what is an obstacle to purification. This physical gel, kept together by numerous interchain H-bonds between amide groups in the polymer, is dismantled by a urea solution (4 mol.L⁻¹) making the polymer soluble. Methanol is then used to precipitate the polymer, keeping urea, water and methacrylamide in the methanolic phase.

FTIR, TGA, GPC and HPLC were used to characterize the final product and to prove the efficiency and convenience of this method. The procedure proposed here has presented a good recovery of the polymer and can be considered more convenient, less time-consuming and efficient than others such as dialysis.

Keywords: Physical Gel, Polymethacrylamide, Polymer Purification, Urea.

1. INTRODUCTION

Hydrogels are gaining attention due to their use as contaminant removers, bioimplants and other contemporary applications [1-2]. The forces that hold the hydrogel together can be non-covalent, such as hydrogen bonding, in this case the material is called a physical hydrogel [2]. Covalent hydrogels, on the other hand, present crosslinks considered not reversible, so that, once formed, the gel becomes insoluble in any solvent [2].

Polymethacrylamide is a polymer that forms hydrogels kept together by H-bonds between amide groups. Copolymers of polymethacrylamide have been used in many fields, such as water decontamination [3]. Some polymethacrylamide derivatives present low toxicity and have been proposed to be used *in vivo* [4]. On the other hand, their monomers, methacrylamide included, are quite toxic [5].

Agents like LiCl and urea, at high concentrations, are able to create repulsive interactions or to break the intermolecular H-bonds, disassembling the gel [6]. Urea is a particularly interesting agent because it is non-toxic and non-expansive, used for decades as a protein denaturant [7]. In order to generate pure hydrogels, avoiding monomer contamination, purification is crucial. In this work, a new method based on solubilization/precipitation of polymethacrylamide using concentrated urea solutions is proposed and its viability is presented. Purification is crucial to pure gel production. Similar approaches can be useful for other polymers prone to form hydrogen bonding-linked physical hydrogels.

2. MATERIALS AND METHODS

2.1 Polymethacrylamide synthesis

Polymethacrylamide (PMAM) was synthesized from methacrylamide (Sigma-Aldrich, 98%) by free radical polymerization. Sulfate persulfate (P.A., Merck) was used as initiator. Three different ratios of monomer/initiator were used, generating three different materials (see table 1). The reactions were performed in water (80% m/m) at 70 °C for 1 hour under argon atmosphere.

2.2 PMAm purification

After one hour of polymerization, the content in the flask (hydrogel and liquid) was mixed with a 4 mol.L⁻¹ urea (P.A., Vetec) solution in a proportion of 1:5 (m/v) and stirred for 24 h until complete dissolution. The solution was then poured slowly in methanol (P.A., Quimis) also under stirring, up to the ratio of 2:1 (solution:methanol). The product is then vacuum filtered using a quantitative paper filter (Whatman No 1440125) and washed several times with methanol at room temperature. The polymer is then dried at 50 °C under air.

Urea solution has the function of break down the gel and make the polymer soluble in aqueous solution. In the urea solution, the polymer chains become soluble and the water-based gel is dismantled, what allows the next steps of the procedure proposed. After solubilization, polymethacrylamide is precipitated in methanol as mentioned. All other components are either soluble (urea) or miscible (water) in the alcoholic phase.

2.3. Characterization

A Prestige 21, Shimadzu, Fourier transform infrared (FTIR) spectrometer was used to collect the spectra of the material in KBr pellets from 4500 to 500 cm⁻¹. 64 scanning were taken.

The thermogravimetric analysis (TGA) was performed in Netzsche model STA449F3 equipment. Approximately 10 mg of the sample was used and analyzed under nitrogen flux (100 ml.min⁻¹). The heating rate was set to 10 °C.min⁻¹ and the thermograms were taken from 30 to 550 °C.

Gel permeation chromatography (GPC) was carried out with a Phenomenex PolySep – SEC GFC P5000 e P3000 (300 x 7.8 mm) columns with range for exclusion size between 3-400 kDa and Phenomenex, PolySep – SEC GFC P (35 x 7.8 mm) pre-column at 35 °C, using a refractive index detector RID-10A – SHIMADZU. The eluent was phosphate buffer (50 mmol.L⁻¹, pH = 7), sodium azide 0.05 %m/v and potassium nitrate 0.05 %m/v in water. Flow rate was kept at 0.5 min.mL⁻¹. Sample solutions were prepared with the eluent solution and 15 µL were injected.

High performance liquid chromatography (HPLC) used a Bio Rad Aminex HPX-87H (300 x 7.8 mm) column at 45 °C and a refractive index detector Waters 410. The eluent was H₂SO₄ 0.01 eq.L⁻¹ in water and the flow rate 0.6 mL.min⁻¹. Sample solutions were prepared in magnesium perchlorate aqueous solution (0.45 mol.L⁻¹), a good solvent for polymethacrylamide, methacrylamide and urea [6]. The injection volume was 20 µL.

3. RESULTS AND DISCUSSIONS

3.1 Recover efficiency

Even after the whole cycle of purification and taken into account that the polymerization was stopped after only one hour (conversion is less than 100 %), the global yields range from 60 to 74% for all the batches (table 1), suggesting a low level of losses during the purification procedure.

Table 1: Average molar mass, polydispersity and yield to polymers in different monomer/initiator ratios in the procedure.

RATIO [M]/[I]	Mn (g.mol ⁻¹)*	Mw (g.mol ⁻¹)*	PDI	YIELD (%)**
200:1	63196	92997	1.47	60.4
244:1	60954	84126	1.38	73.6
158:1	51144	71143	1.39	64.4

* By GPC, relative to polymethylmethacrylate molar mass standards.

** Global yield after one cycle of purification.

3.2 Characterization

The FTIR spectrum of a representative sample of the three polymer batches after purification can be seen in Figure 1.

The broad band centered at 3440 cm⁻¹ with a shoulder at 3200 cm⁻¹ is associated with the stretching of the N-H bond of primary amide functional groups. A signal in 2990 cm⁻¹ can be associated with the C-H stretching of the methyl group. A characteristic signal in 1655 cm⁻¹ is due to the stretching of C=O of the amide carbonyl group. The signals at 1477 and 1384 cm⁻¹ refer to C-N stretching and C-H bending groups,

respectively [8]. FTIR confirms that the three batches of materials with different monomer:initiator ratios are chemically equivalent (data not shown).

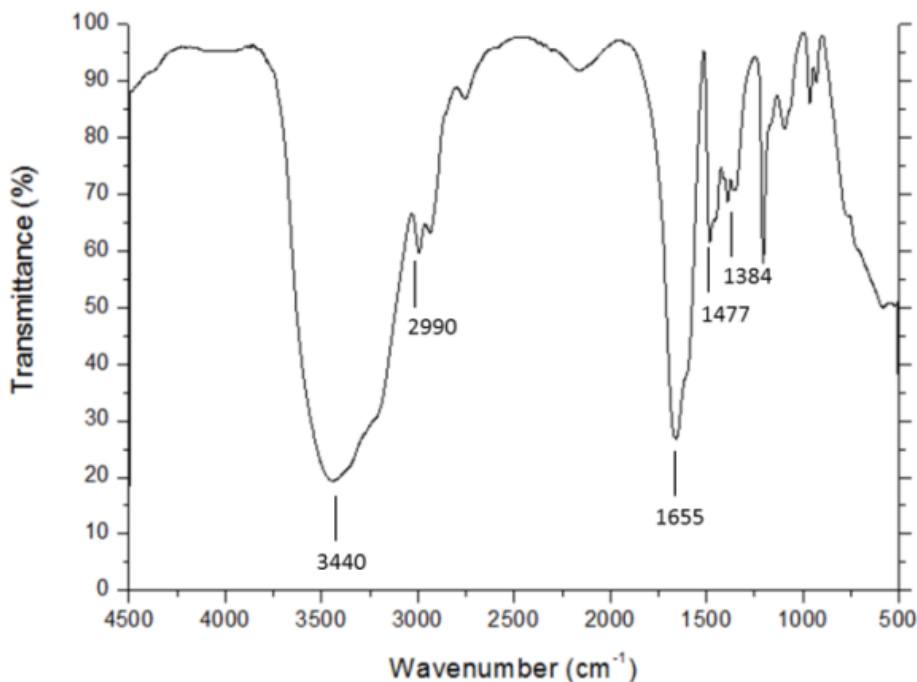


Figure 1: FTIR spectrum of PMAm (1:200 monomer/initiator ratio).

FTIR is sometimes a good tool to check for contamination of a polymeric product. Unfortunately, literature indicates that the FTIR spectrum of urea [9] is very similar to the spectrum of PMAm. Therefore, FTIR by itself cannot be considered an ideal technique to check the absence of urea in the PMAm material.

Thermogravimetry was other technique used to confirm the success of the purification method. Comparing the thermograms of urea and purified PMAm (figure 2), different transitions are observed and, most important, the transitions seen on pure-urea thermograms are not observed on the PMAm one.

Urea thermogram presents a thermal event in the range of 158 to 235 °C due to cyanuric acid formation. This acid is a cyclic compound formed by the union of three urea molecules that occurs during this first thermal step [10]. This event is not seen in the purified PMAm thermogram, indicating a low level of urea contamination.

Finally, High Performance Liquid Chromatography (HPLC) was used to furtherly verify the presence (actually the absence) of urea contamination on the final product (PMAm purified). This is quite important since a highly concentrated urea solution (4 mmol.L⁻¹ or 240 g.L⁻¹) is required for polymer previous solubilization. Elution times for urea methacrylamide (standards) and PMAm are summarized on Table 2. The signals are well separated in the chromatogram what is ideal for a good identification of each compound.

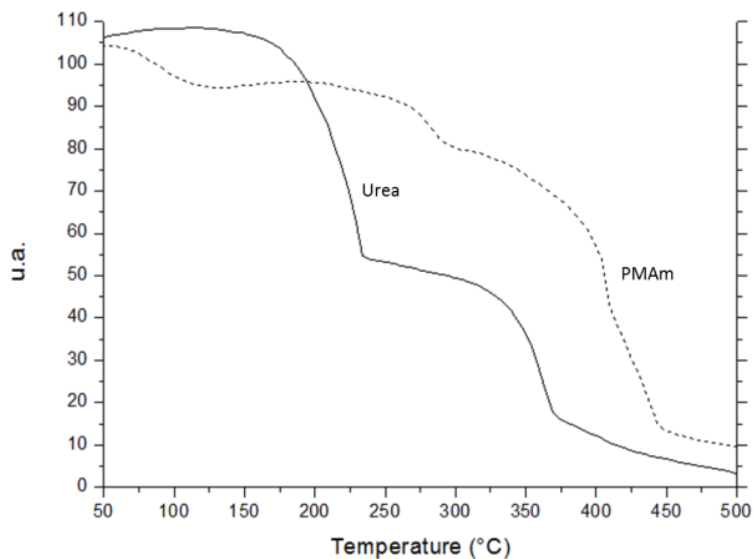


Figure 2: Overlapped thermograms of PMAm and Urea.

Table 2: HPLC elution times in minutes.

Methacrylamide	43.29
Urea	26.05
PMAm*	13.18 - 13.36

* From figure 3, before and after purification.

In figure 3, in the chromatogram of the sample before purification, a signal around 13 min is attributed to PMAm, but the major signal on the chromatogram is due to methacrylamide (around 43 min). The presence of the monomer is expected, since conversion did not reach 100%. On the other hand, after purification (one cycle only) the signal attributed to the monomer decreases almost to zero and the most pronounced signal is due to PMAm polymer. HPLC strongly suggests that the procedure is very efficient (being uncomplicated at the same time) because it indicates that urea is not coprecipitated with the polymer and the amount of residual monomers after the purification procedure is negligible.

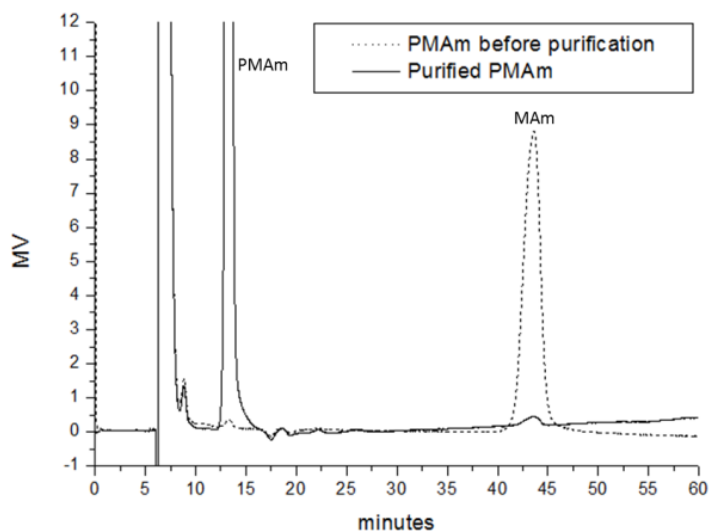


Figure 3: HPLC Chromatograms of the PMAm materials: before purification (raw product mix) and after one cycle of the procedure proposed.

4. CONCLUSION

The polymethacrylamide purification method presented here turned out to be a practical and efficient procedure. The global yield of the whole procedure shows values between 60,4-73,6 %. Very low contamination of urea and methacrylamide on the purified product was detected according to FTIR, TGA, GPC and HPLC analyses.

Based on that, the procedure can be recommended as an alternative to PMAm purification, replacing other methods such as dialysis.

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