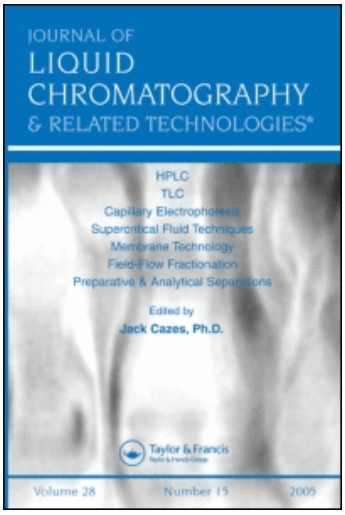

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SIMULTANEOUS DETERMINATION OF POLYAMIDE 6 MONOMERS: AMINO 6 HEXANOIC ACID AND ε-CAPROLACTAM BY RP HPLC

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ABSTRACT

Several analytical methods have been proposed in this literature, to analyse the monomers used in the polymerisation of the NYLON 6. Nevertheless, none of these analytical techniques allows for the simultaneous determination of aminocaproic acid, ε-caprolactam, and their oligomers. Our report describes a simple and rapid reversed phase HPLC for the assay of all these compounds.

This method has been validated in terms of linearity, repeatability, limit of quantification, and limit of detection. Considering its specificity and sensitivity, this method has been applied to the determination of the residual amount of the monomers present within polyamide 6. That is why, we have carried out the desorption kinetic of monomers and oligomers.

INTRODUCTION

Polyamide 6 is obtained by polycondensation of an aliphatic amino acid, which is produced by the hydrolysis of ε-caprolactam. After the polycondensation of this monomer, the polymer obtained is stored under vacuum. In these conditions, although the polymerisation will continue spontaneously, some monomers and oligomers will remain in the material.

Several investigations concerning the toxicity of ε-caprolactam have been described in the literature. According to Parodi et al.,[1] this compound can induce an significant change in the conformation of the DNA coil without inducing true breaks in DNA. Other studies have shown an in vivo mutagenic activity of ε caprolactam, which induces chromosomic modifications in lymphocytes.[2,3] In oral and intraperitoneal administration the ε caprolactam is hepatotoxic. Moreover, the pharmacological activities of aminocaproic acid are well known. It is used as hemostatic and antifibrinolytic and anti-inflammatory agent.[4] That is why, the level of ε caprolactam and aminocaproic acid in a polyamide have to be determined in containers used to store products for human consumption. The level of ε-caprolactam is limited by the French Pharmacopeia to one percent in plastic material (raw material).[5]

It must be emphasised that monomers and their oligomers are bitter products. Several analytical methods have been proposed to analyse these compounds.[6,7] Nevertheless, these techniques do not allow for simultaneous determination of aminocaproic acid, ε-caprolactam, and their oligomers. Because of their difference in toxicity it should be necessary to determine both the aminocaproic acid and its cyclic form (ε-caprolactam). So far, the methods described in the literature only allow for the determination of either one or the other monomer. Moreover, in most cases these works concern the identification of monomers separately and their respective oligomers in polyamide 6, by essentially two methods.

The polarimetric determination was first based on the sulfuric hydrolysis of ε-caprolactam, before the formation of the Schiff base, by reaction with formaldehyde.[8] A gas chromatographic method was used directly, or after, reduction of ε caprolactam and their oligomers. This technique is also selected in the monograph of polyamide 6 in the European Pharmacopeia,[5] for the determination of ε-caprolactam within this plastic material. However, aminocaproic acid is not mentioned. According to the synthesis method of the NYLON 6,[9,10] ε-caprolactam is first hydrolysed into an aliphatic amino acid. This reaction is reversible. Therefore, we suspect that aminocaproic acid undergoes a cyclisation or inversion. This transformation should take place in the detector or injector, since their temperature is fixed at 250°C.

A recent report proposed a planar chromatography method for the simultaneous determination of ε-caprolactam and aminocaproic acid after derivatization with a Ninhydrin Collidin reagent (which reacted on the primary amine selectively).[11] The HPLC method with precolumn dansylation has been described by LAU CAM[12] for the assay of aminocaproic acid in tablet form.

Our report describes a simple and rapid reversed phase HPLC method for the assay of the two monomers used in the polymerisation of polyamide 6; aminocaproic acid and ε-caprolactam.

EXPERIMENTAL

The liquid chromatograph consists of a pump, JASCO PU 880 (Prolabo, Paris,France), and a Rheodyne injection valve equipped with a 20 μL loop (Touzart et Matignon, Vitry, France). The separations were achieved on a Lichrosorb C_{18}, ODS2, 250 x 4.6 mm I.D. column, packed with 5 μm silica (Prolabo, Paris,France) in isocratic elution mode using a Methanol and Phosphate buffer (50 mmoles) (50/50) (v/v) PH = 4. Spectra were collected with a diode array detector (Waters 990) connected to a computer NEC APC4 (Waters, Saint Quentin en Yvelines, France).

Reagents

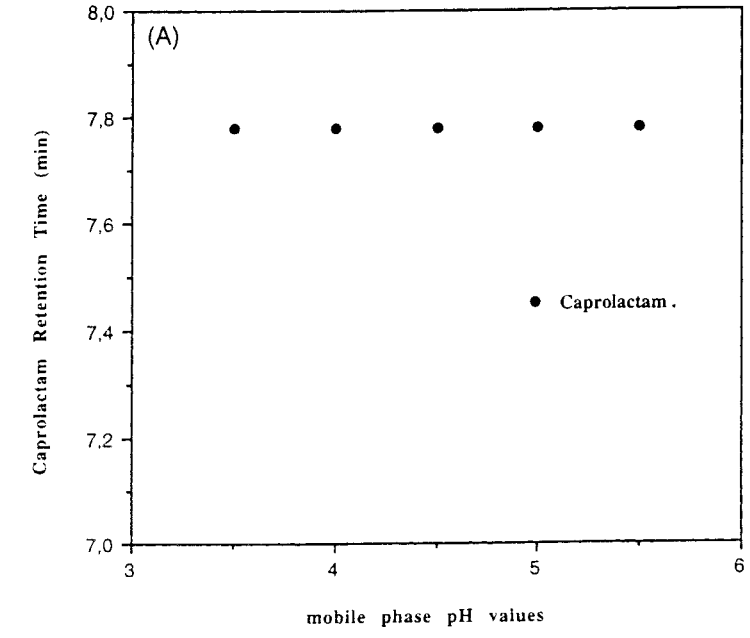
The reagent grade monomers (ε caprolactam and aminocaproic acid) were from Sigma (Saint Quentin Fallavier, France). HPLC grade methanol was provided by Prolabo (Paris, France), while phosphate salt (NaH_2PO_4) and sodium hydroxide were from Merck (Paris, France).

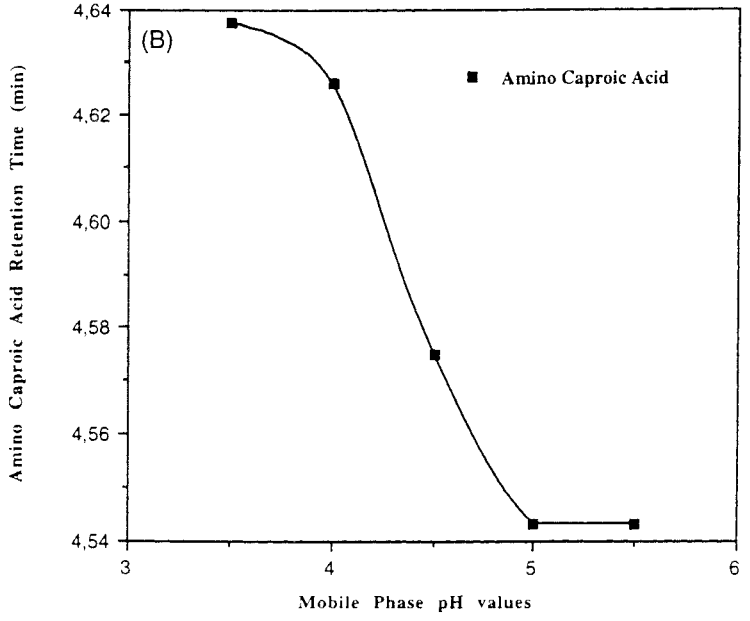
Sample Preparation

Polyamide 6 samples were cut into small shavings 5 mm^2 in area. 500 mg were introduced into a vial. 25 mL of mobile phase was added and the desorption was carried out by mechanical agitation for four hours. The solution obtained was then filtered through a 0.2 μm Millex filter (Millipore, Saint Quentin en Yvelines, France). 20 μL was injected into the chromatograph.

RESULTS AND DISCUSSION

Aminocaproic acid exhibits two ionisation constants (pK_1 = 4.43, pK_2 = 10.75). So, we studied the influence of the pH of mobile phase on the





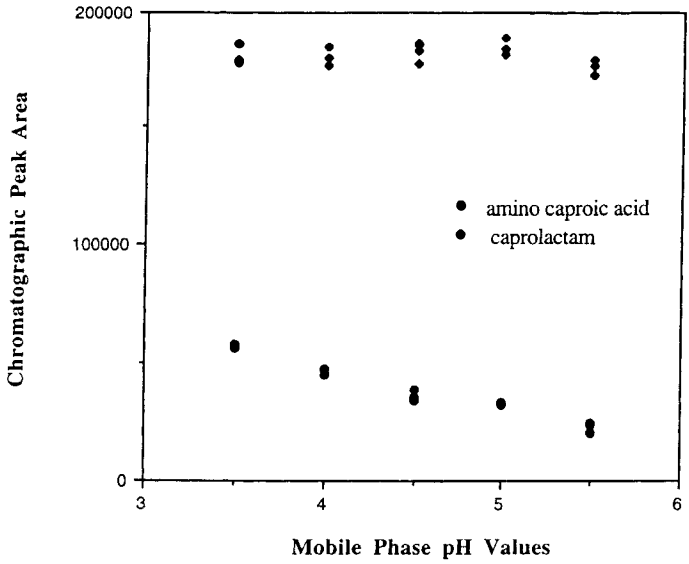


Figure 2. Mobile phase pH effect on the intensity of chromatographic peaks corresponding to ε-caprolactam and aminocaproic acid.

chromatographic behaviour of these compounds. Figure 1 illustrates the influence of the pH of the mobile phase on the retention time (Tr.) of monomers. Figure 1A does not show a significant difference in ε-caprolactam retention time, while that of aminocaproic acid is affected by pH variations. Indeed, we observed a progressive decrease of Tr, when the pH ranged between 3.5 and 5.5 (figure 1B). These pH values influence also the response factor of these compounds.

Figure 2 illustrates the modification of the chromatographic peak intensities calculated for these two monomers, as a function of this same pH range. Aminocaproic acid displays the relatively highest response factor at low pH values. These results are in agreement with the pK_1 value, since the amino groups that characterize the molecule, are totally protonated. Simultaneously, we observed that the intensity of the peak corresponding to ε caprolactam is not significantly modified, with the pH variation. In addition, the ε caprolactam peak shape is also not affected in these conditions.

Figure 1 (left). Mobile phase pH effect on the monomers retention time. A: aminocaproic acid; B: ε-caprolactam.

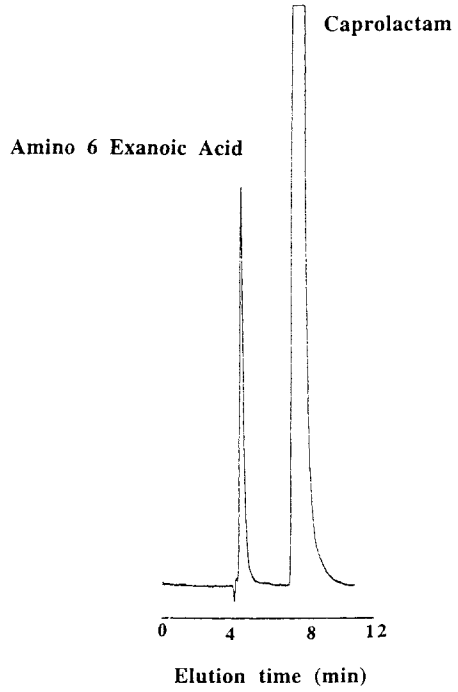


Figure 3. RP-HPLC separation of the synthetic mixture, containing 1000 ppm of ε caprolactam and 250 ppm of amino caproic acid. Chromatographic Conditions: Column: lichrosorb, C 18, ODS II, 5µm, 250 X 4,6 mm ID; Mobile Phase: Methanol; Phosphate buffer (50% / 50%), pH= 4; λ =225 nm.

According to the mobile phase optimisation results, we selected for the continuation of our study, a pH value of 4, because it gives a response comparable to that obtained for 3.5 mobile phase pH value, for which, we obtained a slightly higher values. Finally, at this pH value (pH = 4) silanol activity of the stationary phase is not modified. The detection wavelength of 225 nm was chosen, because the absorbance of polyamide 6 monomers are higher at this wavelength.

Figure 3 shows the RP HPLC separation of the synthetic mixture with a better resolution. This method has been validated in terms of linearity, repeatability, limit of quantification and limit of detection. The calibration curves were calculated using the least squares regression method. The linearity range was determined using the relative standard deviation of the response factor. All results are summarized in Table 1.

Table 1

Validation Quantitative Method of Monomers Present in Polyamid 6

Samples	Linearity Range (ppm)		Regression Curve		RSD%	Detection Limit (n.mole)	Repetability RSD% (n=5)
			Intercept	Slope			
Aminocaproic Acid	200	1000	715.34	64.12	3	2	1.6
Caprolactam	30	1000	4048.60	1038.20	3	50	4.0

Considering its specificity and its sensitivity we applied this method to the simultaneous determination of residual aminocaproic acid and ε-caprolactam. Moreover, the medical grade polyamide 6 is generally washed before use. However, the industrial methods for rinsing this polymer do not allow for the total elimination of the monomers. These compounds persist on plastic material in small quantities. In order to optimise the monomers desorption method, we worked with unwashed polyamide 6 material, because this polymer contains theoretically large quantities of monomers. In addition, we did not have the capability to determine the extraction yield, because the residual amount of these compounds depends on the polymerisation method. So, we have carried out the kinetics of desorption, in order to extract the maximum compounds.

As we suspected, these monomers are present on the polymer surface and can be easily removed from the material after mechanical agitation. In addition this technique leads to the fragmentation of the fibers of Nylon 6 material. The curve obtained reached a plateau approximately after three hours for the ε caprolactam and its oligomers (Figure 4). The chromatogram obtained for this desorption time is shown in Figure 5. Aminocaproic acid is not evidenced in this chromatogram, its residual quantity in this plastic material is probably lower than the detection limit. Indeed we observed only the presence of ε caprolactam and their oligomers.

The residual amount of ε caprolactam was determined in the washed and unwashed plastic material. The results presented in Table 2 show an significant decrease in the quantities of ε caprolactam (about a fifteenth) after industrial washing. In addition, the residual amount found by these analytical conditions are lower than the limit authorized by European Pharmacopeia. Indeed, the ε-caprolactam residual amount within polyamide 6 is fixed at 1%. Therefore, it is important to wash this plastic material before use.

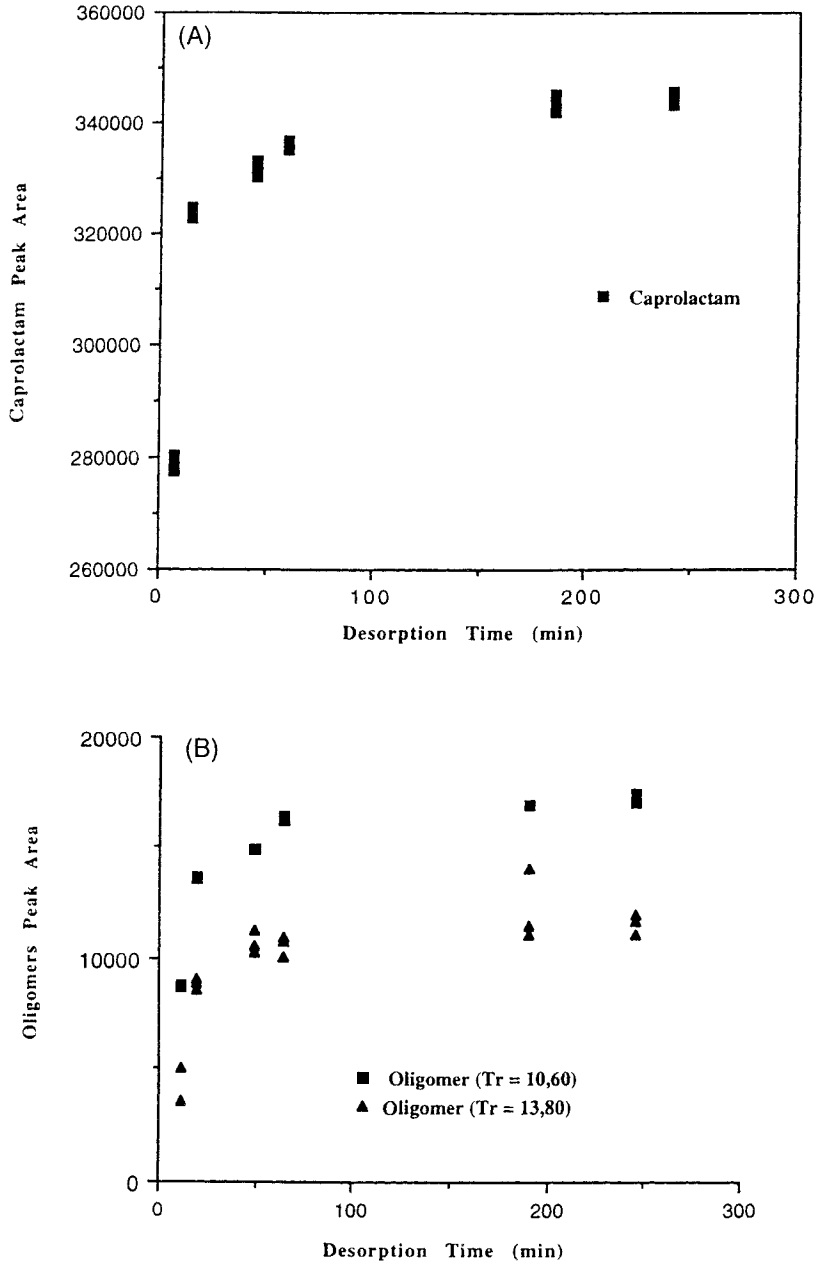


Figure 4. Desorption kinetic of unwashed Nylon 6, in mobile phase. A: Desorption kinetic of ε-caprolactam. B: Desorption kinetic of oligomers.

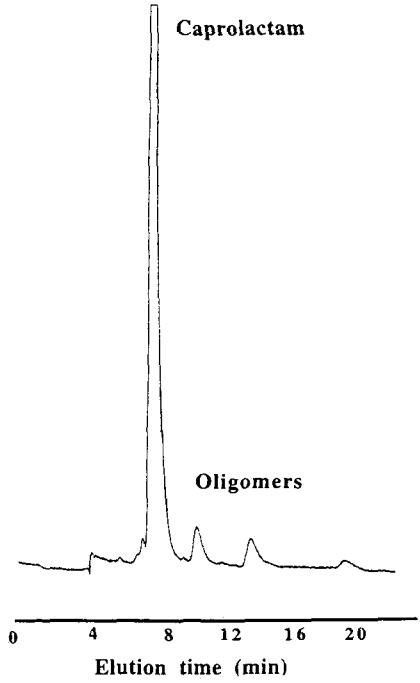


Figure 5. Chromatogram of NYLON 6 desorption solution in mobile phase after 200 minutes. Chromatographic Conditions: Column: lichrosorb, C_{18}, ODS II, 5μm, 250 X 4,6 mm ID; Mobile Phase: Methanol; Phosphate buffer (50% / 50%), pH= 4; λ =225 nm.

Table 2

Determination of ε-Caprolactam in Nylon 6

No. of Desorption	Quantity of ε Carpolactam With Nylon 6	
	Unwashed	Washed
1	2.222	0.150
2	2.110	0.154
3	2.189	0.157
4	2.290	0.147
5	2.516	0.144
Mean	2.267	0.150
RSD%	6.40	3.45

CONCLUSION

Our report proved the suitability of RP HPLC method for identifying the residual monomers and oligomers in polyamide 6 material and to quantify the residual amount of aminocaproïc acid and its cyclic form. This proposed method is a convenient approach to verify the conformation of the various types of polyamide 6 materials. In addition, considering, the toxicity of ε caprolactam and sensitivity of the analytical method, the norm estimated at 1% (residual quantity of ε caprolactam) can be revised, according to the toxicological data concerning this compound.

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