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Comparison of Matrices for Optimal Analysis of Synthetic Polymers Using MALDI-TOF Mass Spectrometry

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Abstract : Characterization of the various chemical aspects of composite polymers is important for quality control of manufactured polymers. In this study, we compared three suitable matrices (α cyano-4-hydroxycinnamic acid [CHCA], 2,5 dihydroxy benzoic acid [2,5-DHB], and dithranol), to characterize various synthetic polymers by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry. Although the spectra obtained with the CHCA and 2,5-DHB matrices were generally good, in certain samples ghost peaks disappeared only when dithranol was used as the matrix. Furthermore, we examined the use of sodium trifluoroacetate (NaTFA) as an additive to reduce interference by metals and copolymers in the spectra. In conclusion, appropriate selection of a matrix, according to the characteristics of the polymer, and the use of additives to improve sensitivity are important considerations for polymer analysis and development.

Keywords : MALDI-TOF MS, synthetic polymer, CHCA, 2,5-DHB, dithranol

Introduction

Polymers are found almost everywhere in daily life, including packaging materials, automotive parts, medical supplies, and countless other products.[1-9] Synthetic polymers are linkages of hundreds or thousands of individual units, each of which has a small molecular weight, to yield a combined molecular weight ranging from 500 Da to 100 kDa or more. Polymer manufacturers also add antioxidants, dyes, waxes and other materials to improve polymer utility or to aid the manufacturing process.[10-15] To improve the quality of such products, it is important to be able to characterize the various chemical aspects of these composite polymers.

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Synthesized polymers tend to be heterogeneous mixtures of variable-length chains and thus exhibit a molecular weight distribution (MWD), rather than a single molecular weight. The MWD of a polymer is one of the most important factors that determine properties such as its mechanical behavior, melting point, and viscosity. Therefore, the ability to control the MWD of a polymer allows an expanded field of applications for the polymer. To understand the properties of a polymer, a technology capable of precisely analyzing the polymer is required.[16,17]

Commonly used matrices for polymer analysis include α-cyano-4-hydroxycinnamic acid (CHCA), 2,5-dihydroxybenzoic acid (2,5-DHB), dithranol, 2 (4 hydroxyphenylazo) benzoic acid (HABA), and all-trans-retinoic acid. In this study, three different matrices were compared in the analysis of various synthetic polymers using matrix-assisted laser desorption ionization time-of-flight (MALDI-TOF) mass spectrometry.

Experimental

All chemicals used were purchased from Sigma-Aldrich (St. Louis, MO, USA). The following polymers were used (Table 1): polycaprolactone, polyvinylpyrrolidone (PVP), polyethylene (PE), polysaccharide (Dextran), polybutadiene, polyacrylic acid sodium salt, polypropylene glycol (PPG),

Table 1. List of polymer materials (purchased by Sigma-Aldrich, USA).

No.	Name	Mw	Molecular formula	Cas No.	Proposal matrix
B1	Polycaprolactone	~14,000	$(C_6H_{10}O_2)n$	-	Dithranol
B2	PVP (Polyvinylpyrrolidone)	~10,000	$(C_6H_9NO)n$	9003-39-8	CHCA
B3	PE (Polyethylene)	~4,000 (Mn)	$(C_2H_4)n$	9002-88-4	DHB
B4	Polysaccharide (Dextran)	5,000	$(C_6H_{10}O_5)n$	9004-54-0	DHB
B5	Polybutadiene	~5,000 (Mn)	$(C_4H_6)n$	9003-17-2	CHCA
B6	Polyacrylic acid sodium salt	~5,100	$(C_3H_3NaO_2)n$	9003-04-7	CHCA
B7	PPG (Polypropylene glycol)	~4,000 (Mn)	$(C_3H_8O_2)n$	25322-69-4	Dithranol
B8	PEG (Polyethylene glycol)	8,000	$(C_2H_4O)n$	25322-68-3	CHCA
B9	PDMS (Polydimethylsiloxane) +bis(hydroxyakyl) terminated	~5,600 (Mn)	$(C_2H_6OSi)n$	156327-07-0	CHCA
B10	PMMA (Polymethyl methacrylate)	~15,000	$[CH_2C(CH_3)(CO_2CH_3)]n$	9011-14-7	Dithranol

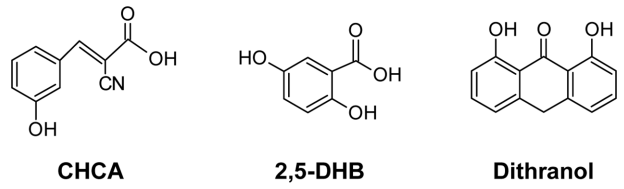

Figure 1. Structural formulas by type of matrix materials used in MALDI analyses.

polyethylene glycol (PEG), bis(hydroxyalkyl) terminated poly(dimethyl-siloxane) (PDMS), and polymethyl methacrylate (PMMA).

The following matrices were used (Figure 1): α Cyano-4-hydroxycinnamic acid (CHCA), 2,5 dihydroxy benzoic acid (2,5-DHB) and 1,8,9 trihydroxy anthracene (dithranol). The solvent used was acetonitrile, and sodium trifluoroacetate (NaTFA) was used as a counter ion source and additive.

The matrix was manually deposited onto the MALDI target from a solution containing 30:70 (*v/v*) acetonitrile and 0.1% TFA in water. The analyte and matrix were mixed in equal volumes and then 1-μL aliquots were spotted on top of the target plate using the dried droplet method.[18]

All experiments were performed on an MALDI-TOF mass spectrometer (UltrafleXtreme, Bruker) and (IDSys, ASTA) equipped with a 337-nm wavelength N_2 laser in positive-ion linear or reflectron mode. The instruments by ASTA was used only for reproducibility verification purposes.

Results and Discussion

Figure 2 shows the MALDI-TOF mass spectra of each of the polymers in three different matrices. The spectra are shown in the same order as their respective polymers in Table 1 (i.e., spectra 1–10 correspond to polymers 1–10 in Table 1) for each matrix. Each polymer exhibited a different spectrum, depending on the matrix.

Comparing matrices, CHCA and 2,5-DHB showed clearly observable peaks evenly for all samples. In samples containing Si, such as B9 (PDMS), the spectra show definite metal interference, which reduced the signal intensity.

An advantage of dithranol over CHCA and 2,5 DHB is demonstrated in Figure 3. An unknown peak ("ghost peak" indicated by a red line) in the spectra of PPG disappeared in dithranol, and a clean peak was confirmed.

Depending on its polarity, the strength of a polymer can be improved by the use of additives. In MALDI-MS, compounds with functional groups that are easily protonated, such as basic amines, are readily detected by their $[M+H]^+$ peaks. Compounds lacking basic functional groups may instead be detected by using a monovalent cation, such as Na^+ or K^+. Detecting compounds by $[M+Na]^+$ or $[M+K]^+$ peaks not only reduces sensitivity but also may cause the m/z values of various adducts to overlap. In this case, additives can promote the formation of certain adducts, thereby improving sensitivity and reducing spectral complexity (Figure 4). In previous studies, fucose,[19] 5-chloro-2-mercaptobenziazole,[20] and sugar[21] have been used as additives to improve sensitivity. The additive chosen should always be appropriate for the analytical spectrum.

Of the 10 polymer samples, B9 (PDMS) was the only sample containing Si, which decreased sensitivity. In the case of B10 (PMMA), which is a copolymer, several polymer signals overlapped, and interference may have occurred in the signal.[22] Figure 4 compares the spectra of these two samples before and after the addition of NaTFA. That improved the sensitivity and centralized the spectral signals.

Besides the choice of matrix and additive, the

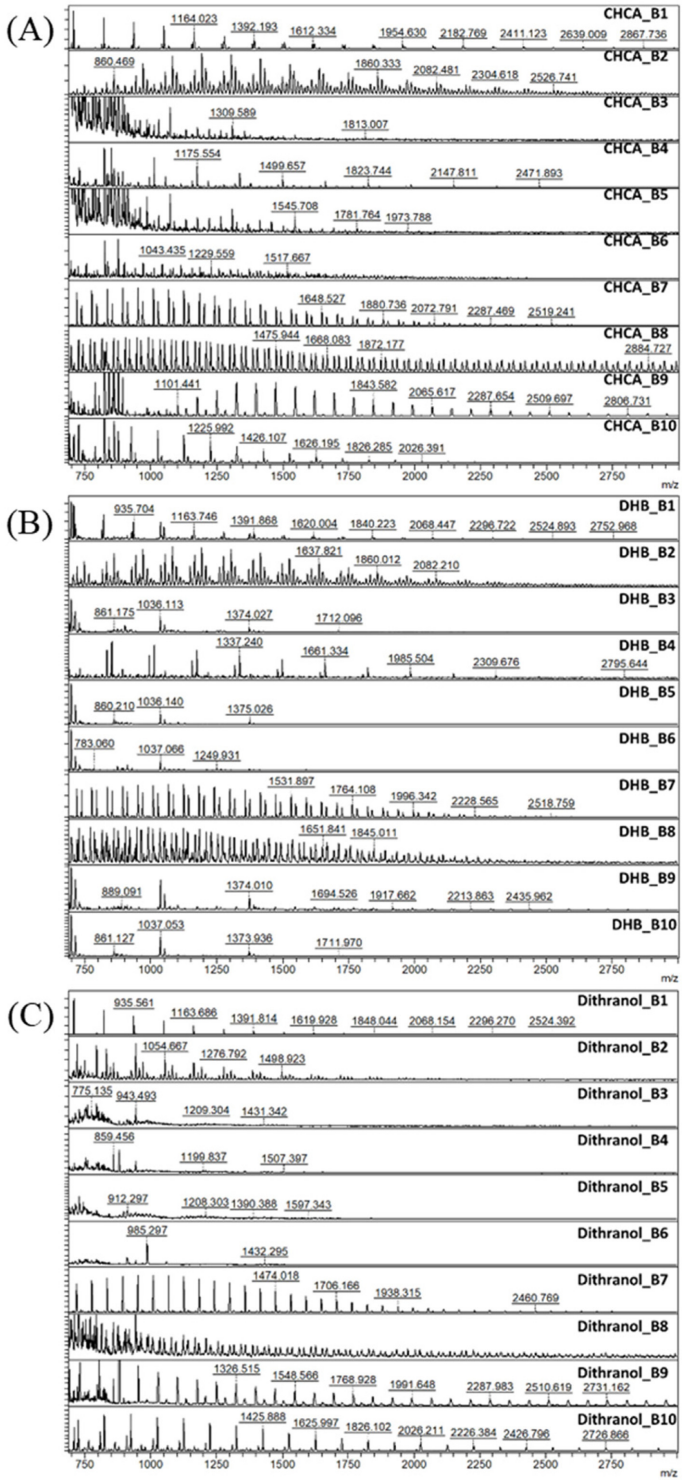

Figure 2. MALDI-TOF mass spectra of polymers in CHCA (A), 2,5-DHB (B), and Dithranol (C) matrices.

appropriate mode of MS must be selected according to the mass range of the sample. The mass spectrometer used in these experiments used a time-of-flight (TOF) method, which is based on the principle that ions receiving equal energy in the acceleration field will accelerate differentially to the detector, with lighter ions reaching the detector

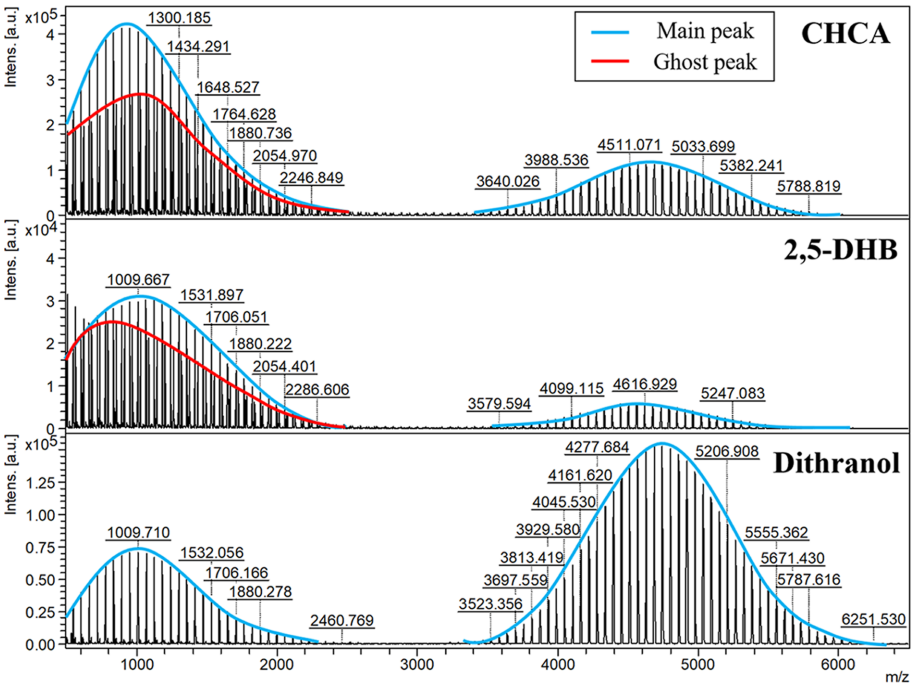

Figure 3. Results of MALDI-TOF MS by matrix type comparison using B7 sample (PPG).

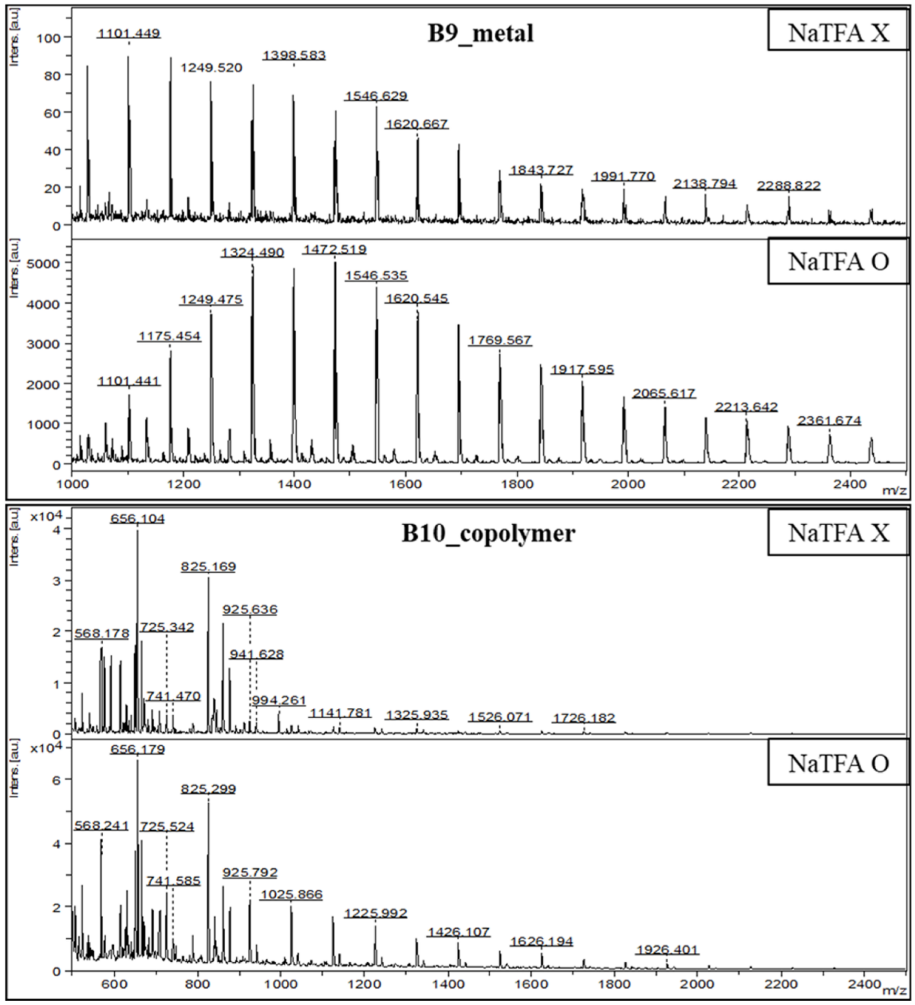

Figure 4. Comparison of MALDI-TOF MS spectra with and without additives according to the characteristics of the sample (B9 and B10).

before heavier ones. The MALDI-TOF MS instrument has a linear mode and a reflectron mode. The linear mode is good for measuring heavy molecules (more than 5000 *m/z*) in linear motion. However, in the reflectron mode, after the flight path is over, it is reflected from the electrostatic ion mirror and travels further away, so it is used when measuring relatively light molecules (less than 5000 *m/z*). Therefore, it is necessary to check the molecular weight range of each sample and measure it in an appropriate mode. So the overall effect is to even out the arrival times at the detector of ions with varying initial velocities, thereby improving the mass resolution. In a previous study,[23] it was confirmed that the linear mode is good for measuring heavy molecules, while the reflectron mode is best for measuring light molecules. Thus, appropriate selection of the detection mode for the MWD of the polymer under study enables more effective utilization of the MS method.

Conclusions

To obtain optimal analytical results, it is important to select appropriate methods of pre-treatment and analysis, according to the properties of the synthetic polymer under consideration. As confirmed in this study, the analyte should be carefully characterized so that an appropriate matrix can be selected that will minimize disturbing factors. In some cases, appropriate additives can be used to improve sensitivity, centralize the signals, and reduce spectral complexity. Finally, it is important to select an appropriate detection mode, according to the expected MWD of the polymer. We hope this study will prove helpful as a resource for polymer scientists using MALDI-TOF MS.

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