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Retention prediction for polymer additives in reversed-phase liquid chromatography

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ABSTRACT

A retention prediction approach for polymer additives has been investigated. The relationship between retention and hydrophobicity can be useful in predicting the retention of polymer additives in reversed-phase liquid chromatography. Peak identification is possible using both a retention matching process based on this prediction scheme and an ultraviolet spectral matching process with a photo-diode array, multi-wavelength ultraviolet detection system.

INTRODUCTION

The selection of satisfactory separation conditions is still a major problem in liquid chromatography (LC). At present, trial-and-error experiments are usually performed to find the best optimal separation conditions, but this approach is a very difficult, tedious and time-consuming task. A recent improvement proposed by Berridge [1,2] and Snyder and co-workers [3–5] involved systematic computer techniques which are gradually becoming more popular although still in the developmental stage. A unique computer technique which we have proposed is the retention prediction approach [6–10]. Retention predicted by this concept can be useful in the optimization of procedures to obtain faster analysis times and better separations [7,10].

In order to predict the retention of solutes, a clear understanding of the retention mechanism is required. Consideration of the basis of the retention mechanism of reversed-phase LC makes it possible to predict a component's physicochemical parameters such as surface area, partition coefficient between two immiscible phases and aqueous solubility which might correlate with retention. In practice, such correlations between retention and physicochemical parameters exist and some of these parameters have been determined based on these relationships. This is the basic idea of the approach termed QSRR (quantitative structure–retention relationships) [11,12]. QSSR can be useful in predicting retention in reversed-phase LC, based on the premise that relationships exist between the physicochemical parameters representing the molecular properties of the solute such as structure, shape and/or electronic state, etc., and its retention, if such parameters are available. Using log P (the partition coefficient between 1-octanol and water proposed by Hansch and Leo [13]),

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Baker and co-workers [14–16] and Smith [17,18] have also attempted to predict retention index in LC.

The basic concept of retention prediction can be described as

$$k' = \mathrm{f}(Pi) \tag{1}$$

where k' is the capacity factor of a solute and Pi is a physicochemical parameter of the solute. To generalize the retention description in eqn. (1) for n different chromatographic conditions such as mobile phase compositions, temperature or pH of the mobile phase, the following n equations should be obtained by the same procedures with multiple regression analysis. In this instance, we assume two parameters are the most dominant for the retention:

$$\begin{array}{ll} X = X_1 & \log k' = a_1 P_1 + b_1 P_1 + c_1 \\ X = X_2 & \log k' = a_2 P_2 + b_2 P_2 + c_2 \\ \vdots & \qquad\qquad\quad \vdots \\ X = X_n & \log k' = a_n P_n + b_n P_n + c_n \end{array} \tag{2}$$

where X is the experimental condition, a and b are coefficients corresponding to the descriptors P_1 and P_2, respectively, c is the intercept, and n is the number of experimental conditions examined.

If a, b and c can be expressed as functions of X, namely, if X–a, X—b and X–c are highly correlated, the following three equations can be obtained from the multiple regression analyses:

$$a = \mathrm{f}_1\,(X) \tag{3}$$

$$b = \mathrm{f}_2\,(X) \tag{4}$$

$$c = \mathrm{f}_3\,(X) \tag{5}$$

and then

$$\log k' = \mathrm{f}_1\,(X)\,P_1 + \mathrm{f}_2(X)P_2 + \mathrm{f}_3(X) \tag{6}$$

should be obtained by several experiments. This equation means that, if X, P_1 and P_2 are given, the logarithm of the capacity factor, $\log k'$, can be determined for any chromatographic condition. This is the basic concept of our retention prediction approach. Predicted k' can then be useful in optimizing the separation conditions in which the conditions (X in this case) will be optimized by the calculation [7,10].

In this paper, the retention prediction approach for polymer additives is described as an extention of our work in this field. The analysis (determination and identification) of polymer additives is one of the most important practical analytical problems because of the number of additives existing in commercially available polymer materials, the quantities and species of which are very important in the quality control of polymer products.

EXPERIMENTAL

The LC system used consisted of a Jasco 880-PU pump (Tokyo, Japan), Rheodyne 7125 20-μl loop injector (Cotati, CA, USA) and a Jasco MULTI-320 photodiode array multiwavelength UV detector. The column for the separation of polymer additives was a Capcell Pak C_{18} (250 mm × 4.6 mm I.D., Shiseido, Yokohama, Japan) with mobile phases consisting of methanol and water. The flow-rate of the mobile phase was 1 ml/min and the column temperature was maintained at 40°C in a Jasco TU-100 column oven. The column dead volume was determined by the sodium nitrite peak.

Data handling, retention prediction and identification by the UV spectral matching process were performed with a NEC 9801 Series 16-bit microcomputer.

The polymer additives used in this work can be separated into two groups, Irganox and Tinuvin. Structures of which are shown in Fig. 1.

RESULTS AND DISCUSSION

The first step towards retention prediction for polymer additives is to establish which descriptor can best describe retention. Basic consideration of the retention mechanism of reversed-phase LC suggests that hydrophobicity should be the dominant physicochemical parameter in describing retention [11], as many authors have reported the possibility of retention prediction using log P in reversed-phase LC [14–18]. Although there are a number of methods proposed by Hansch and Leo [13] and Rekker [19] for calculating the hydrophobicity of these polymer additives, the values determined in the laboratory provide better accuracy for retention prediction. Therefore, we have attempted to determine the hydrophobicity of the additives using a common LC method [20–22]. In order to determine hydrophobicity, we used alkylbenzenes as the standard because alkylbenzenes have phenyl rings and alkyl chains, as do the polymer additives. Of course this selection is not completely appropriate for the accurate determination of the hydrophobicity of polymer additives because the compounds have polar substituents such as $-OH$ or hetero atoms in their structures and the structural similarities between the additives and alkylbenzenes are restricted. However, it is also true that finding the best standard compound groups suitable for additives which have a variety of structures is difficult. Alkylbenzenes are simple and convenient for this purpose. Using methods described in the literature [20–22], the log P values for the polymer additives obtained with this LC system are summarized in Table I. These values will change if a different LC system is used for the determination and thus it is very important to note that the log P values in Table I are not universally applicable.

In order to obtain a retention prediction equation, we divided the standard additives into two groups, Irganox and Tinuvin, because of their greatly differing structures.

Four of the additives selected as standards were injected into the LC system with mobile phase compositions of methanol–water in the ratios 95:5, 90:10, 88:12 and 85:15. The measured capacity factors are listed in Table II. The relationships between log P and log k' were obtained by regression analysis for each data set with different mobile phase compositions, using

$$\log k' = A_x \log P + B \tag{7}$$

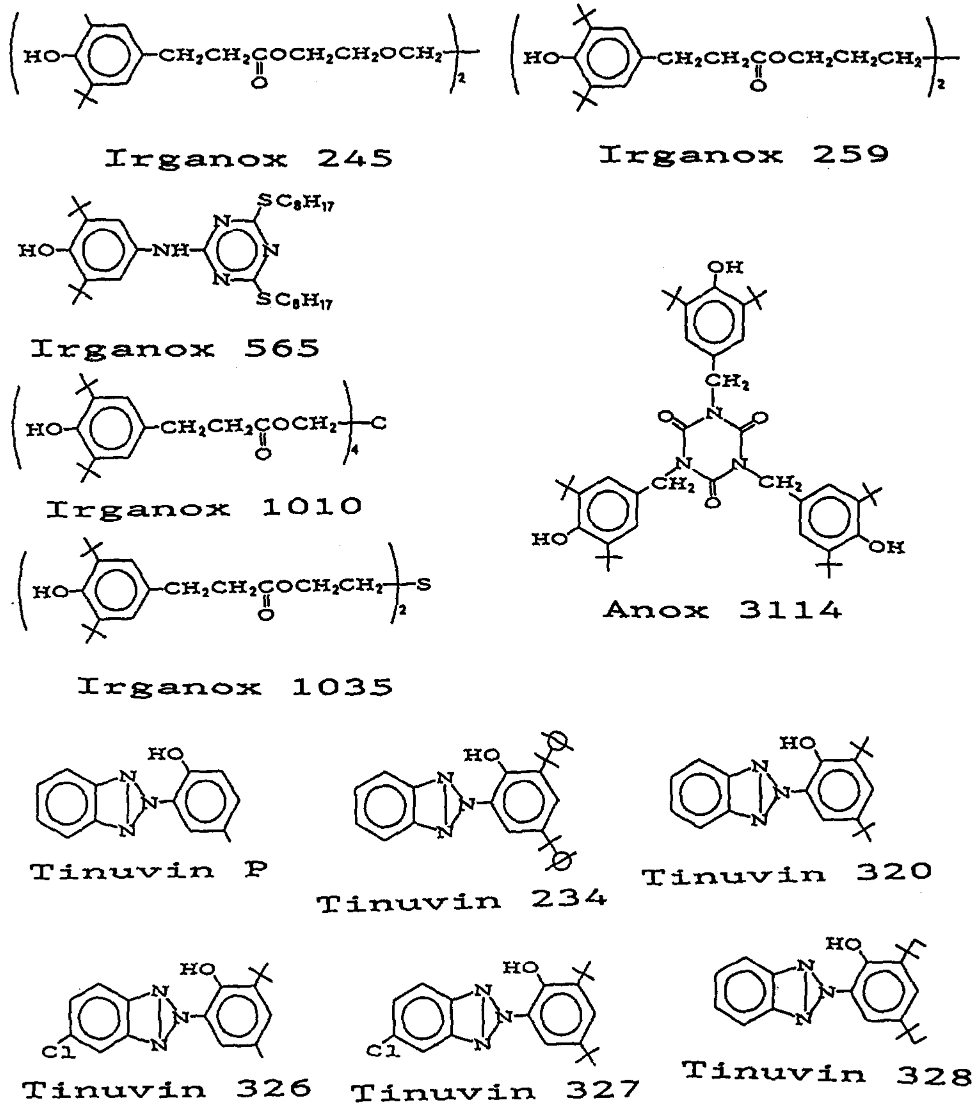

Fig. 1. Structures of the polymer additives used.

The values of A, B and the correltion coefficients are given in Table II.

The relationships between the mobile phase composion X (in this case methanol volume percentage in the mobile phase), and A and B were then subjected to regression analysis to obtain the equations. They are:

$$\text{for Irganox } A = 6.55\,X^2 - 12.2\,X + 5.93 \qquad r = 0.998 \qquad (8)$$

$$B = -48.3\,X^2 + 78.6\,X - 32.5 \qquad r = 0.999 \qquad (9)$$

TABLE I

DETERMINED LOG *P* VALUES OF THE POLYMER ADDITIVES USED

Log *P* values cited here were determined by the LC system used in this work, based on alkylbenzenes as the standard.

Compound	Log *P*
Irganox 245	2.34
Tinuvin P	4.38
Irganox 1035	5.78
Irganox 259	6.47
Anox 3114	7.12
Tinuvin 320	7.46
Tinuvin 234	7.73
Tinuvin 326	7.79
Tinuvin 328	8.34
Tinuvin 327	8.46
Irganox 1010	9.84
Irganox 565	10.1

TABLE II

RETENTION DATA OF SELECTED POLYMER ADDITIVES WITH VARIOUS MOBILE PHASE COMPOSITIONS AND REGRESSION DATA FOR EQN. 7

Compound	Capacity factor			
	Volume fraction of methanol in the mobile phase			
	$X=0.95$	$X=0.90$	$X=0.88$	$X=0.85$
Irganox				
Irganox 245	0.117	0.450	0.624	1.08
Irganox 259	1.22	4.16	6.76	13.9
Anox 3114	1.55	5.93	10.0	22.1
Irganox 565	6.93	28.9	51.2	122
A[a]	0.229	0.233	0.247	0.272
B[a]	−1.44	−0.89	−0.775	−0.605
r[b]	0.999	1.000	1.000	1.000
Tinuvin				
Tinuvin P	0.763	1.35	1.68	2.22
Tinuvin 320	3.24	7.84	11.1	18.5
Tinuvin 328	4.40	11.4	16.7	29.0
Tinuvin 327	4.68	12.2	17.9	31.3
A	0.193	0.234	0.252	0.282
B	−0.961	−0.895	−0.878	−0.888
r	1.000	1.000	1.000	1.000

[a] Regression coefficients for eqn. 7.

[b] Correlation coefficient.

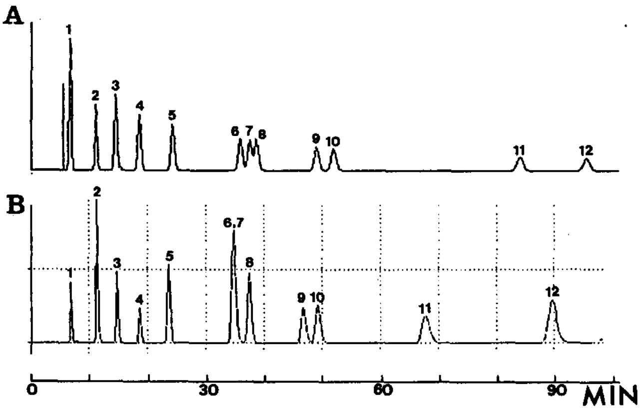

Fig. 2. Comparison of (A) the predicted and (B) the observed (254 nm) chromatograms. Mobile phase: methanol–water (92:8); flow-rate: 1 ml/min; column temperature: 40°C.

$$\text{for Tinuvin } A = 1.46\,X^2 - 3.52\,X + 2.26 \qquad r = 1.000 \qquad (10)$$

$$B = -13.0\,X^2 + 22.6\,X - 10.7 \qquad r = 0.999 \qquad (11)$$

Using these retention descriptions one can predict the retention of various polymer additives at appropriate conditions. The actual trial was performed at $X = 0.92$ and the chromatogram obtained is compared with the predicted chromatogram in Fig. 2, with the retention data compared in Table III. The agreements between the measured and predicted retention times are very good except for peak 11, Irganox 1010. This

TABLE III

COMPARISON OF THE OBSERVED AND THE PREDICTED RETENTION TIMES OF TWELVE POLYMER ADDITIVES

Peak number	Retention time (min)		Relative error [a] (%)
	Observed	Predicted	
1	6.92	7.06	2.0
2	11.1	11.6	4.5
3	14.7	14.9	1.4
4	18.7	18.9	1.1
5	23.5	24.4	3.8
6	34.7	36.4	4.9
7	34.7	37.8	8.9
8	37.5	38.8	3.5
9	46.6	49.3	5.8
10	49.3	52.1	5.7
11	67.7	84.0	24.1
12	89.7	95.5	6.5

[a] Relative error (%) = [(observed − predicted)/observed] × 100.

deviation might arise from the bulkiness of the solute. In this prediction scheme, log *P* was used as the descriptors of equivalent molecular size, shape and three-dimensional structure. As in reversed-phase LC the three-dimensional structure of solutes strongly influences retention.

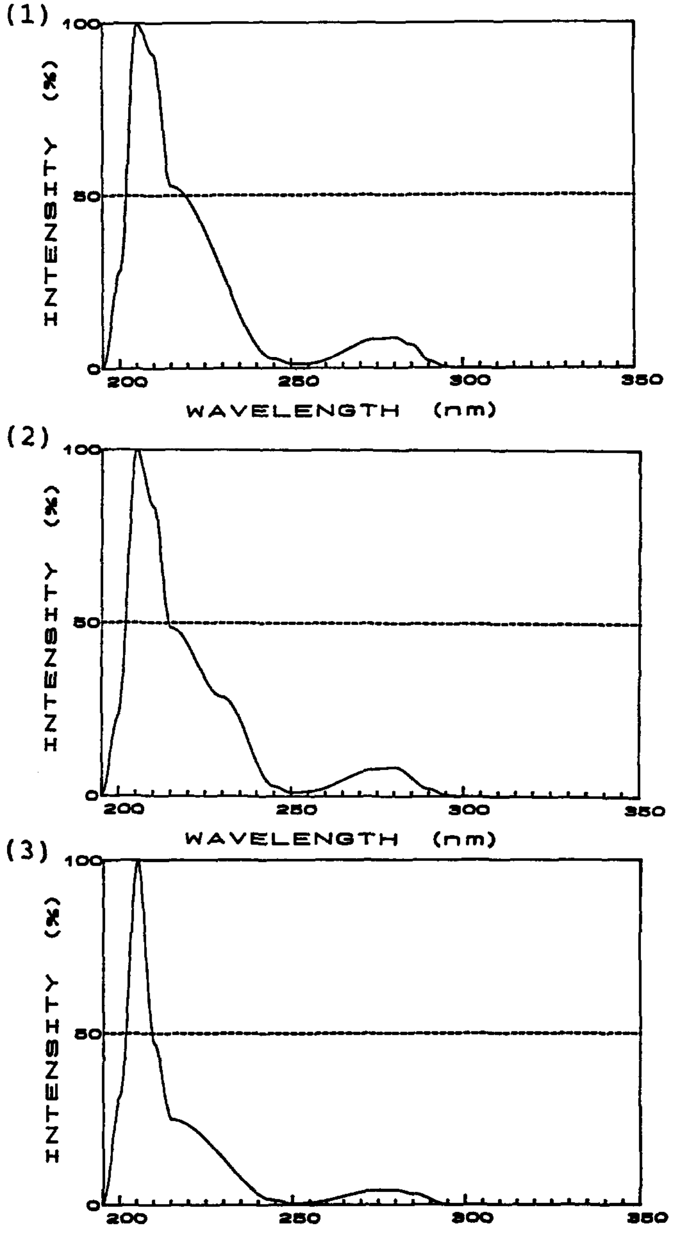

Fig. 3. UV spectra of the observed and the top two candidates found by UV spectral matching. (1) Observed UV spectrum of peak 3. (2) UV spectrum in the spectral data base for Irganox 1035. (3) UV spectrum in the spectral data base for Irganox 259.

TABLE IV

RESULTS OF THE IDENTIFICATION PROCESSES FOR PEAK 3 IN THE CHROMATOGRAM SHOWN IN FIG. 2

Rank	Sample name	Matching rate
UV spectrum matching process		
1	Irganox 1035	1.000
2	Irganox 259	1.000
3	Irganox 1010	0.999
4	Irganox 245	0.999
5	Anox 3114	0.979
6	Tinuvin 234	0.363
7	Irganox 565	0.345
8	Tinuvin 328	0.088
9	Tinuvin 327	0.088
10	Tinuvin P	0.087
Retention matching process		
1	Irganox 1035	0.918

In order to identify the peaks in the chromatogram two approaches can be applied [18–20]: (1) retention match between measured and predicted values or (2) UV spectral match between measured spectra and stored spectra. For the first approach, one can use the retention prediction scheme established in our laboratory and for the second approach, one can use the diode-array detection system where the UV spectra of polymer additives are stored.

As an example of this identification scheme, we attempted the identification of peaks 3 and 12 in the chromatogram shown in Fig. 2. The results are summarized in Tables IV and V and Fig. 3. In the identification process for peak 3, identification by UV spectral match, as shown in Table IV, is difficult because at least five candidates

TABLE V

RESULTS OF THE IDENTIFICATION PROCESSES FOR PEAK 12 IN THE CHROMATOGRAM SHOWN IN FIG. 2

Rank	Sample name	Matching rate
UV spectrum matching process		
1	Irganox 565	1.000
2	Irganox 1010	0.372
3	Irganox 245	0.359
4	Irganox 259	0.352
5	Irganox 1035	0.351
6	Anox 3114	0.302
7	Tinuvin 327	0.080
8	Tinuvin 326	0.068
9	Tinuvin 320	0.067
10	Tinuvin 328	0.062
Retention matching process		
1	Irganox 1010	0.779
2	Irganox 565	0.766

TABLE VI

RESULTS OF PEAK IDENTIFICATION FOR THE CHROMATOGRAM IN FIG. 2

Peak No.	Correlation coefficient		Identified polymer additives
	UV spectrum matching	Retention matching	
1	1.000	0.468	Irganox 245
2	1.000	0.718	Tinuvin P
3	1.000	0.918	Irganox 1035
4	1.000	0.945	Irganox 259
5	1.000	0.843	Anox 3114
6	0.988	0.796	Tinuvin 320
7	0.979	0.633	Tinuvin 234
8	1.000	0.873	Tinuvin 326
9	1.000	0.783	Tinuvin 328
10	1.000	0.787	Tinuvin 327
11	1.000	0.129	Irganox 1010
12	1.000	0.766	Irganox 565

are listed as possible, because of their similarity, as shown in Fig. 3, where the UV spectra of the top two candidates are illustrated in comparison to the observed UV spectrum. However, using the retention prediction approach, one can identify that this peak is Irganox 1035 as none of the other candidates from the UV spectral matching also matched retention time. For the determination of the peak 12, as shown in Table V, the situation was reversed. By UV spectral matching only one candidate was identified, however, retention matching provided two candidates. The top candidate from both processes, Irganox 565, can thus be identified as peak 12.

Every peak in the chromatogram in Fig. 2 has been retrieved and the final identification results are summarized in Table VI. The identified solutes agree well with the injected components.

In conclusion, the approach described in this paper can open a new dimension in the identification and quantitation of polymer additives by LC. We have shown that identification of compounds is made possible by retention matching based on retention prediction in addition to UV spectral matching. Further studies of other groups of compounds will make this approach of great practical use.

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