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Separation of the menthol enantiomers on the sorbent based on supramolecular network structure

Gus'kov V.Yu., Sidelnikov A.V., Sukhareva D.A., Gainullina Yu.Yu., Kudasheva F.K., Maistrenko V.N.

Bashkir State University, Ufa

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In this paper, the possibility of the analytical separation of the menthol enantiomers on chiral supramolecular structures of uracil and melamine with chirality induced by the mechanical agitation was studied by gas chromatography and impedance spectroscopy. It is found that the structure of uracil and melamine placed on an inert support has showed the ability of menthol enantiomer separation in mode of gas chromatography. Application of impedance spectrometry with processing of obtained data by the method of the main components has allowed to reveal the difference in the signals between the optical isomer of menthol.

Keywords: enantiomer, chiral supramolecular structure, uracil, melamine, gas chromatography, impedance spectroscopy

Разделение энантиомеров ментола на сорбентах на основе супрамолекулярных сетчатых структур

Гуськов В.Ю., Сидельников А.В., Сухарева Д.А., Гайнуллина Ю.Ю., Кудашева Ф.Х., Майстренко В.Н.

Федеральное государственное бюджетное образовательное учреждение высшего профессионального образования Башкирский государственный университет, Уфа

Создание новых подходов к разделению энантиомеров остаётся одной из важных задач аналитической химии, по причине оптической активности широкого круга лекарств и биологически активных соединений. В этой связи представляет интерес использование сорбентов на основе супрамолекулярных структур с индуцированной хиральностью. Методом сканирующей туннельной микроскопии было установлено, что ахиральные соединения способны структурироваться в супрамолекулярные ансамбли, в которых имеются гомохиральные домены. При наличии внешнего воздействия возможно индуцировать в таких структурах преимущественное наличие одного из двух типов доменов. В качестве такого внешнего источника могут выступать поляризованный свет, добавление оптически активного соединения, ультразвуковые и даже звуковые волны, а также ламинарный поток жидкости (например, вращение мешалки). Поэтому представляет интерес использование поверхностей с нанесёнными супраструктурами ахиральных соединений с индуцированной хиральностью для разделения энантиомеров. В работе методом газовой хроматографии и импедансной спектроскопии изучена возможность разделения энантиомеров ментола на адсорбентах и поверхностях, покрытых слоем супрамолекулярных структур урацила и меламина в режиме направленного потока частиц.

Для газохроматографического изучения урацил и меламин наносились на инертный носитель при интенсивном размешивании. Полученный образец наполняли в хроматографическую колонку и изучали удерживаемые объёмы D- и L-ментола при различных температурах. В случае импедансной спектрометрии модифицированный инертный носитель наносили на электрод и снимали спектры импеданса в условиях статической сорбции. Полученные при этом данные далее обрабатывали хемометрически с использованием метода главных компонент.

В результате исследования установлено, что ментолы способны разделяться на инертном носителе, модифицированном как урацилом, так и меламином, в условиях хроматографического эксперимента в широком диапазоне температур. Методом импедансной спектрометрии установлено, что адсорбция энантиомеров ментола протекает с различной скоростью: D-ментола за 10 минут, а L-ментола – за 24 минуты.

Ключевые слова: энантиомеры, хиральные супрамолекулярные структуры, урацил, меламин, газовая хроматография, импедансная спектрометрия

Introduction

The development of new approaches to the separation of enantiomers remains one of the most important problems of analytical chemistry, because there is a wide variety of drugs and bioactive compounds with the optical activity. The first methods of analysis of enantiomers were gas chromatographic separation on the chiral amino acid derivatives, implemented by Gil-Av and separation in mode of ligand chromatography proposed by Davankov. To date, the development of new surfaces capable of chiral recognition is relevant to the fields of analytical chemistry, such as chemical and biological sensors [2-4], as well as gas and liquid chromatography [5-7].

The ability to directly research of the surface of different types of supramolecular structures at the molecular level has came with the progress of visualisation the surface of solids (scanning tunneling microscopy, atomic force microscopy). It is possible to establish the presence on the surface of different supramolecular assemblies of chiral domains, formed due to the formation of mirror asymmetrical superstructures [8-10]. So the possibility of the use of the such structures in analytical chemistry for the separation of enantiomers is a topical issue in modern chemistry.

If the superstructure formation in the solution is observed of the molecules normal Brownian motion takes place in the absence of directed flow of particles solution. If the normal Brownian movements of molecules in solution is observed during the formation of the superstructure (i.e., the solution is not stirred or stirred intensively), there is no directed beam of particles in the solution. This leads to the fact that the amount of R- and S-chiral domains is identical and the overall surface is a racemate. If the directional flow of the particles are intentionally produced in the solution (laminar flow of liquid or accurate mixing), the superstructure can be macroscopically chiral [11].

In this paper, the separating possibility of the enantiomers of menthol on adsorbents and surfaces covered with a layer of supramolecular structures of uracil and melamine in mode of the directional flow of the particles has studied by gas chromatography and impedance spectroscopy.

Experimental

Uracil (Avilon, Moscow, Russia) and melamine (Agropromservice, Moscow, Russia) previously purified by recrystallization were used as monomers for the formation of superstructures. Inert support Inerton NAW (Chemapol, Prague, Czech Repablik) and porous polymer adsorbent Dowex L-285 were chosen as the initial adsorbent. Application was carried out in dilute aqueous solutions on automatic magnetic stir bar Dragon MS-H280-Pro (DragonLabs, China) at a temperature of 30±0.5°C. The directional flow of particles is created accurate stirring of solution at rate 500 rev/min. Amount of an applied modifier was 10% of the mass of the initial support.

Chromatographic research was conducted on a gas chromatograph GC-1000 Chromos (Himanalitservis, Dzerzhinsk, Russia) and CVET-500M, equipped with a flame ionization detector, on a packed column with length equal 1 m and an internal diameter of 3 mm. The rate of carrier gas (nitrogen) was 10-20 ml/min. Column oven temperature ranged from 70 to 140°C, the temperature of the evaporator and the detector was 200°C. Samples modified by uracil conditioned at 130°C; cyanuric acid - at 140°C. Optically pure D- and L-menthol (Sigma-Aldrich, USA) were used.

Values of the specific retention volume were calculated from the experimental data. Selectivity factor α was calculated as the ratio of the specific retention volume of enantiomers:

$$\alpha = \frac{V_g^R}{V_g^S}, \tag{1}$$

where index R represents an enantiomer with a high content; S - smaller.

Research of impedancemetric behavior of enantiomers on electrodes modified sorbents was conducted using a three-electrode cell. At this stage of the research electrodes made of stainless steel are used as impedancemetric sensors.

Frequency range of alternating current is 500 kHz to 50 Hz. Direct current potential is 0.00 mV. Concentration of enantiomers is $1.00*10^{-4}$ g/l. The solvent is distilled water. Impedance spectra were recorded continuously under static sorption of menthol (+ and -) of the aqueous solution for 140 minutes at a rate 1 spectrum per minute. Previously sorbent was kept in water for 140 minutes, with simultaneous fixing of the impedance spectra of blank experiment.

The principal components method was used as the base of multivariate signal processing method. This method allows you to split the matrix of experimental data into two parts - informative and noise. Each spectrum of data can be presented in a multidimensional space as a potential single point, after which it is projected on a first principal component, which is built along the maximum data changes. Then, the follow principal component, which should be orthogonal to all other principal components and lie in the direction of the next larger changes in the data, is constructed. Thus, there is the data compression: a plurality of impedance values is a set of generalized coordinates x, y, z, etc. (PC1, PC2, PC3) depending on the number of selected principal components. The number of principal components required for data modeling, was selected according to the schedule of the explained dispersion. The principal component analysis transforms multivariate data into a new coordinate system - the system of principal component the beginning of which is at the center of the field of data, and the direction of the principal component is determined by hidden regularity typical of the experimental data. Similarities and differences between the experimental data is established by mutual location points in the subspace of the principal components, called score plot. You can also monitor changes in the system water / enantiomer / sorbent / sensor under enantiomers sorption from aqueous solutions.

As a preliminary preparation of the data autoscaling was carried out - raw data was centered and normalized. Normalization of data was performed by dividing each element of the data matrix by S_{dev} of the corresponding column.

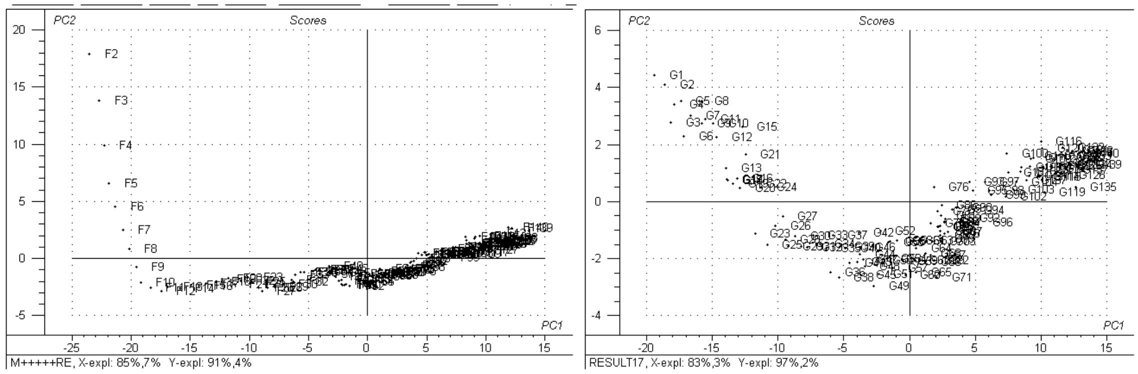
For the impedancemetric determination of enantioselectivity sorbent was previously kept in water for 140 minutes, with simultaneous fixing of the impedance spectra of blank experiment. In both cases, the sorbent 5% after 10-15 minutes break in curve was observed, and then the system gradually moves to the equilibrium state with a small displacement state. After holding the sorbent in water and equilibration aliquot of 2 mL of water over the sorbent was removed and the same volume of menthol solution was placed in a cell, and the solution was stirred, spectra were recorded for 140 minutes (a rate 1 spectrum per minute).

Results and Discussion

Values of the specific retention volumes and factor of selectivity on inert support modified by uracil and melamine obtained in gas chromatography are shown in Table 1. As it follows from the data, a significant difference in the values of the specific retention volume of enantiomers was observed in a wide range of temperatures. The maximum value was observed on the uracil at 70°C. For melamine greatest factor of selectivity was at 80°C. At 95°C retention volumes varied within the error. At temperatures above 100°C the pentane solvent peak superimposed on the peak of the analyte, which made it impossible to analyze.

Table 1. The values of the specific retention volumes and the factor of selectivity of D- and L-menthol on an inert support Inerton NAW, modified by uracil and melamine

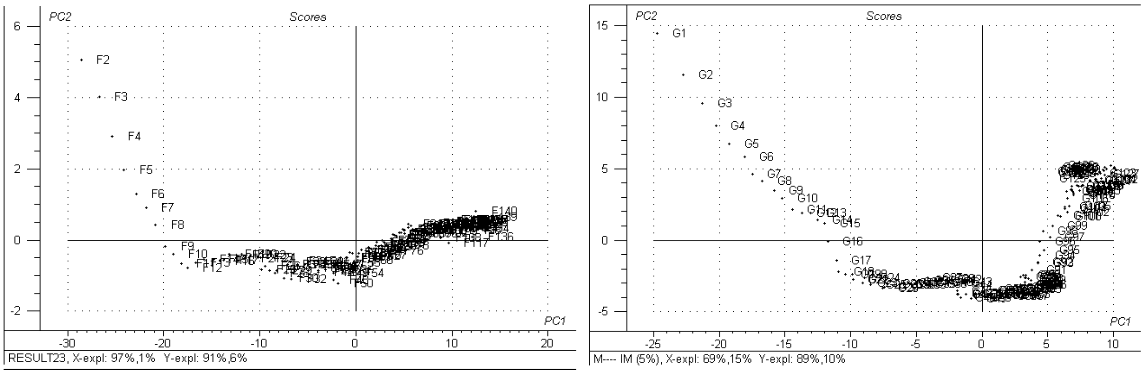
T, °C	uracil			melamine		
	$V^\circ_{g(T)}$		α	$V^\circ_{g(T)}$		α
	D	L		D	L	
50	15.2±0.2	29±1	1.94±0.09	118.2±0.9	119.0±0.8	1.01±0.01
55	10.1±0.3	21±2	2.04±0.26	39±1	43±1	1.11±0.07
60	15.3±0.2	24±1	1.55±0.11	46±1	27.7±0.9	1.66±0.10
65	11.0±0.1	12.0±0.2	1.09±0.03	20.7±0.6	19.5±0.4	1.06±0.05
70	8.1±0.6	19.0±0.1	2.35±0.21	12.7±0.2	17.3±0.3	1.36±0.05
75	13.1±0.5	19.4±0.3	1.48±0.07	10.5±0.5	11.9±0.9	1.13±0.14
80	13.3±0.2	16.6±0.9	1.25±0.08	12.0±0.5	22.0±0.5	1.83±0.11
85	14±2	23.3±0.6	1.66±0.25	4.3±0.3	5.5±0.2	1.28±0.13
90	20.2±0.7	28.5±0.1	1.41±0.11	2.7±0.2	3.0±0.2	1.11±0.14
95	8.9±0.3	8.7±0.4	1.02±0.09	2.8±0.1	2.7±0.2	1.04±0.13



a) b)

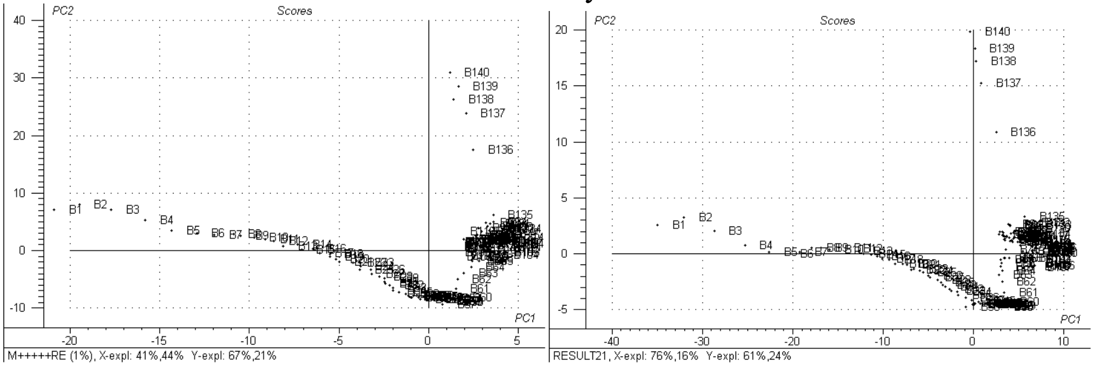
Fig. 1. Kinetic curves of accounts of the real impedance component at the sorption of enantiomers a) Menthol (+) and b) Menthol (-) on the sorbent Dowex L-285 modified by 5% uracil

The results of PCA-modeling of the kinetic data are presented in Fig. 1-3. It was found that for the enantiomers of menthol difference in the time of establishing equilibrium of sorption processes and in the number of stages of sorption is observed. Thus, the kinetic curves of the real component of the impedance (fig. 1) which characterizes the activity of menthol in solution shows that menthol (+) is characterized by five equilibrium states. The time of transition from the first to the second kinetic sorption degree is about 10 minutes.



a) b)

Fig. 2. Kinetic curves of accounts of the imaginary impedance component at the sorption of enantiomers a) Menthol (+) and b) Menthol (-) on the sorbent DowexL285 modified by uracil 5%



a) b)

Fig. 3. Kinetic curves accounts of the real (a) and imaginary (b) impedance component at the sorption of menthol (+) on the sorbent DowexL285 modified by 1% uracil

For menthol (-) according to the impedance break in curve was not observed. Kinetic data of the imaginary component of impedance, characterizing the sorption processes at the electrode surface (Fig. 2) show that the end time of the first stage of the process for the sorption of menthol (+) is 10 minutes and for menthol (-) 24 minutes. This can indicate different rate of sorption process of optically active compounds on modified sorbent.

Conclusion

Thus, in a results it found that supramolecular structure of melamine and uracil are capable of separating enantiomers of menthol at a temperature below 95°C. Approach to the study of the kinetics of sorption processes using methods impedanse spectroscopy and chemometrics (CIM) is proposed and tested. Opportunity in the real condiction and in the on-line mode to obtain kinetic curves of sorption of enantiomers and study the nature of the sorption processes are the advantages of this method. It was established, that the difference in time of achievement of the equilibrium state of the optically active isomers on sorbents synthesized in the performance of the project.

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Гуськов Владимир Юрьевич – к.х.н., доцент кафедры аналитической химии БашГУ, Уфа

Сидельников Артём Викторович – к.х.н., доцент кафедры аналитической химии БашГУ, Уфа

Сухарева Дарья Александровна – аспирант кафедры аналитической химии БашГУ, Уфа

Гайнуллина Юлия Юрьевна – к.х.н., ассистент кафедры аналитической химии БашГУ, Уфа

Кудашева Флорида Хусаиновна – д.х.н., профессор кафедры аналитической химии БашГУ, Уфа

Майстренко Валерий Николаевич – д.х.н., профессор, заведующий кафедрой аналитической химии БашГУ, Уфа

Gus'kov Vladimir Yu. – PhD, Associated Professor of Analytical chemistry chair, BSU, Ufa

Sidel'nikov Artem V. - PhD, Associated Professor of Analytical chemistry chair, BSU, Ufa

Suhareva Darya A. – post-graduate student of Analytical chemistry chair, BSU, Ufa

Gainullina Yulia Yu. - PhD, Assistant Professor of Analytical chemistry chair, BSU, Ufa

Kudasheva Florida H. - PhD, Professor with honors of Analytical chemistry chair, BSU, Ufa

Maistrenko Valery N. - PhD, The Head of Analytical chemistry chair, BSU, Ufa