

Research Article

Solvent Effect on the Solid-Surface Fluorescence of Pyrene on Cellulose Diacetate Matrices

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Received 31 January 2018; Accepted 17 May 2018; Published 11 June 2018

Academic Editor: Giulio Cerullo

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The effect of the solvent nature (acetonitrile, ethanol, dimethyl sulfoxide, and dioxane) and its concentration on the fluorescence intensity of pyrene sorbed on the cellulose diacetate (CDA) film from a water-organic solution was studied. Dimethyl sulfoxide and ethanol are shown to be the most effective solvent additives for pyrene solid-surface fluorescence (SSF). The maximum SSF signal of pyrene was found upon sorption of the substance from aqueous media containing 1.2-4.2 vol% DMSO. For the pyrene quantitation the concentration dependence of its SSF intensity at the maximum of the spectrum at $\lambda_{em} = 394$ nm and $\lambda_{exp} = 320$ nm was plotted. The dependence has a linear character in the pyrene concentration range $2 \cdot 10^{-6}$ - $2 \cdot 10^{-8}$ g/L, and the limit of pyrene detection is $2 \cdot 10^{-11}$ g/L. The possibility of determining benzo(a)pyrene using SSF technique with the CDA matrix is proved. The proposed method is promising for use in environmental monitoring of polycyclic aromatic hydrocarbons.

1. Introduction

Solid-surface fluorescence (SSF) is a method of analysis which combines sorption concentration of a substance on a solid matrix followed by its fluorescent analysis in the sorbent phase [1, 2]. This technique provides a significant increase in the sensitivity and selectivity of fluorescence analysis. SSF was applied for determination of organic and inorganic compounds in various media [3-5]. SSF analysis of polycyclic aromatic hydrocarbons (PAH) is of particular interest.

PAH take an important place among environmental pollutants because of their ability to accumulate in the environment, high stability, carcinogenic, and mutagenic activity [6, 7]. PAH are produced in both natural and anthropogenic thermal processes, such as volcanic activity, forest fires, tectonic and hydrothermal manifestations, burning of solid and liquid fuels, pyrolytic waste decomposition, and operation of internal combustion engines; moreover they get to the environment from leakage and spills of petroleum and products thereof [8, 9]. That is why PAH are

found in various environmental media, materials, and food [9, 10].

The list of priority PAH for mandatory control, approved by the US Environmental Protection Agency (EPA), contains 16 compounds [11]. In Russia the most toxic PAH benzo(a)pyrene should be controlled in drinking water, waste water, air, soil, and food. The complexity of PAH analysis in environmental objects is due to their low concentrations and the multicomponent nature of their mixtures; therefore, any analytical methods to be developed should have high selectivity and a low detection limit. As PAH are luminophores with typical quasiline spectra the SSF method is promising for the design of test systems for environmental monitoring.

Various sorbents have been studied as solid-phase matrices for SSF analysis of PAH: silica gel [12], zeolites [13], foamed polyurethane [14], nylon membranes [15], silver nanoparticles [16], and cellulose [17]. Materials based on natural polysaccharides and their derivatives are of the most interest because of their availability, low cost, and biodegradation possibility. The cellulose matrix is one of the most

popular sorbent for SSF [3, 17, 18], but it has some disadvantages, among which there are disposability and the relatively low efficiency of sorption due to the hydrophilic nature of the material.

Materials made from the artificial polysaccharide cellulose diacetate (CDA) have a number of valuable properties, which allow using them as sorbents and membranes for the purification and preconcentration of different substances [19, 20]. Earlier we reported about testing CDA fibers and films as matrices for the SSF of pyrene taken as a model PAH [21, 22]. Both were shown to be good sorbents for pyrene from water-miscellar surfactant media. CDA films were characterized as the preferable matrices for SSF of PAH.

The molding composition for CDA films preparation was optimized; the designed films were compared with commercial filtering CDA membranes by the efficiency of pyrene sorption and SSF [23]. In the range of pyrene concentrations in sorbate 10^{-6} – 10^{-8} M an SSF signal was observed only for the laboratory films. It was concluded that matrices to be used for pyrene SSF should be finely porous (pore sizes within 100–500 nm), smooth, not transparent, and hydrophobic.

In order to get the intensive SSF signal of PAH existing in low concentrations in water media we had to identify the optimal conditions for analyte sorption on the CDA matrices. It is known that a solvent has a great influence on the efficiency of substance sorption and on its luminescence [24–28]. Therefore, the aim of this study was to investigate the effect of the solvent nature and concentration on the sorption and fluorescence of pyrene on a CDA matrix and to estimate the possibility of PAH quantitation in aqueous medium using this method.

2. Materials and Methods

Matrices were made using CDA with the following characteristics: a viscosity-average molecular weight of 77 kDa, an acetylation degree of 55%, and 3% moisture (Technofilter Ltd., Vladimir, Russian Federation). Films were cast under standard conditions by placing a 2 wt. % CDA solution in an acetone : water (95 : 5, acetone of analytical grade) mixture followed by solvent evaporation. The solution was applied onto mirror flat glasses previously degreased with ethanol and acetone, using a glass round spinneret. The solvent removal completeness was judged by no changes in the weight. The film thickness was $45 \pm 5 \mu\text{m}$.

Pyrene (Fluka, Germany) solutions in water-organic media with concentrations $2 \cdot 10^{-4}$ – $2 \cdot 10^{-11}$ g/L (10^{-6} – 10^{-13} M) were used in experiments. Stock pyrene solutions (10^{-2} g/L) were prepared in several solvents: acetonitrile, ethanol (96%), dimethyl sulfoxide (DMSO), and dioxane (the solvents were of analytical grade, LenReaktiv, Saint-Petersburg, Russia) and stored in a dark place to prevent photochemical destruction. Working solutions were obtained therefrom by successive dilution with water.

Standard dichloromethane solution of benzo(a)pyrene with concentration of 1.0 g/L (Supelco, USA) was used. Working solutions with concentrations 10^{-5} g/L ($4 \cdot 10^{-8}$ M) and 10^{-4} g/L ($4 \cdot 10^{-7}$ M) were prepared by successive diluting the

standard solution with ethanol to concentrations of 10^{-2} g/L and then by successive dilution with water.

The sorption of pyrene and benzo(a)pyrene from solutions was performed in dynamic mode. To this purpose, the solutions ($V = 10$ ml) were passed through the matrices three–five times, using a disposable sterile syringe Master UNI “PharmLine Limited” (Cornwall Buildings, Great Britain). The mass of the CDA films was 8.0 ± 2.5 mg. Then the matrices were dried at room temperature until constant weight.

The fluorescence spectra of pyrene and benzo(a)pyrene in a solution and on solid matrices were recorded on a spectrofluorimeter Fluorat-02-Panorama (Lumex, Saint-Petersburg, Russia) with a holder for solid samples. The spectral range for pyrene was 350–420 nm, with the excitation radiation wavelength (λ_{ex}) being 320 nm. The spectral range for benzo(a)pyrene was 380–480 nm, $\lambda_{\text{ex}} = 296$ nm. The fluorescence intensity (I_{Fl}) of pyrene was measured at the second maximum of the spectrum at $\lambda_{\text{em}} = 394$ nm and $\lambda_{\text{ex}} = 320$ nm.

3. Results and Discussion

3.1. Fluorescence of Pyrene and Benzo(a)Pyrene in Water-Ethanol Solutions and on Cellulose Diacetate Matrices. In order to estimate the possibility of determining PAH in aqueous media using SSF on the CDA films we compared the fluorescence of pyrene and benzo(a)pyrene in water-ethanol solutions and in the solid phase of CDA matrix. Pyrene is usually utilized as a model compound in studies on PAH because of its low toxicity [17, 21–23]. Benzo(a)pyrene is known as the most toxic PAH with carcinogenic and mutagenic activities [6]. Analysis of benzo(a)pyrene as an individual compound is relevant for conducting sanitary and hygienic studies in Russia.

A comparative analysis of the fluorescence intensities of pyrene in water-ethanol solutions and in the CDA solid phase after its sorption from these solutions has shown that pyrene at a concentration of 10^{-5} g/L ($5 \cdot 10^{-8}$ M) in solution is not detected (see Figure 1(a)) whereas pyrene sorbed on the CDA film from a similar solution shows an SSF signal.

The higher SSF signals on the CDA matrix were obtained for benzo(a)pyrene sorbed on the CDA film from water-ethanol solutions in comparison with pyrene of similar concentrations (see Figure 1(b)). In water media the fluorescence of benzo(a)pyrene at a concentration of 10^{-5} g/L ($4 \cdot 10^{-8}$ M) was not detected as well.

Since the molar concentration of benzo(a)pyrene in the sorbate was lower and the intensity of SSF higher than those of pyrene we can conclude that benzo(a)pyrene has the better affinity for the surface of the matrix than pyrene. Therefore we may be sure that the results obtained in subsequent experiments with pyrene will also correspond to benzo(a)pyrene.

Consequently, a significant increase in the fluorescence signal of pyrene and benzo(a)pyrene on the CDA films was found in comparison with aqueous solutions that makes SSF technique with the CDA matrix promising for use in environmental monitoring. It is important that the fluorescence intensity of the substances on this matrix remains at the same

TABLE 1: Physical properties* of the solvents used and their toxicity.

Solvent	T [°C]	ρ [g/cm ³]	ϵ_r	$\mu \cdot 10^{30}$, [C·m]	E_T^N	β	α	LD ₅₀ , [mg/kg]
Water	100.0	1.000	78.3	5.9	1.000	-	1.17	-
Ethanol	78.3	0.7893	24.55	5.8	0.654	-	0.83	10300
Acetonitrile	81.6	0.7875	35.94	11.8	0.460	0.31	-	2460
DMSO	189.0	1.1004	46.46	13.5	0.444	0.76	-	20 000
Dioxane	101.3	1.0330	2.21	1.5	0.164	0.37	-	5170

*The values given by Reichardt [24]: T is the boiling temperature, ρ the density, ϵ_r the dielectric constant, μ the dipole moment, E_T^N the empirical parameter of the solvent polarity, β , and α the Kamlet-Taft solvatochromic parameters (β is the hydrogen bond acceptor ability and α the hydrogen bond donation ability).

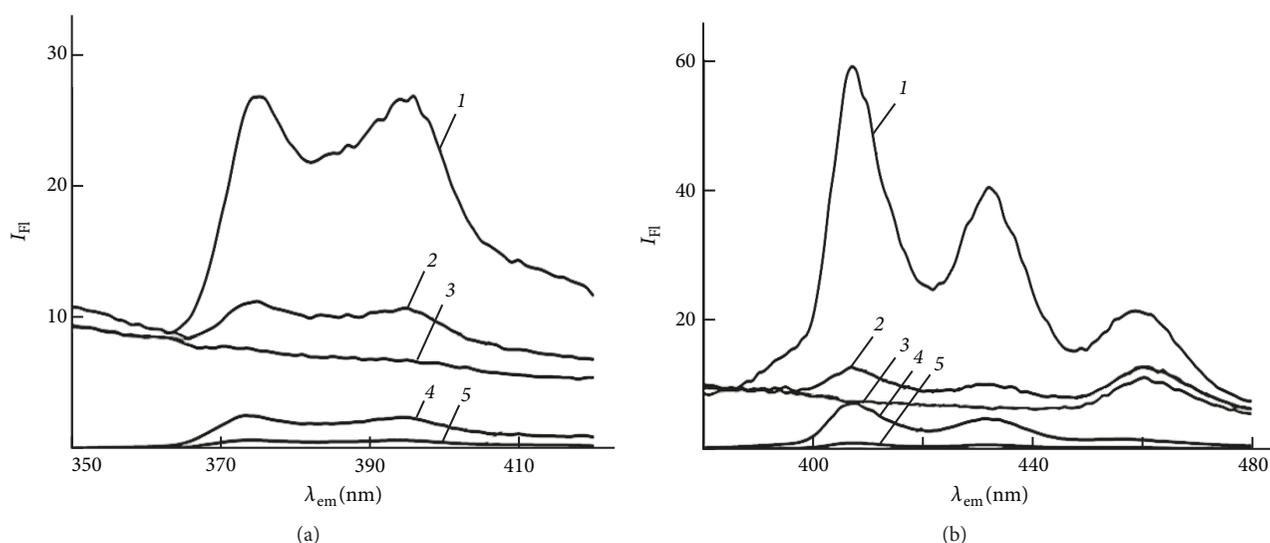


FIGURE 1: Fluorescence spectra of (a) pyrene and (b) benzo(a)pyrene: 1: sorbed onto a CDA matrix from a water-ethanol solution with a concentration of 10^{-4} g/L; 2: sorbed from the solution with a concentration of 10^{-5} g/L; 4: in a water-ethanol solution with a concentration of 10^{-4} g/L; 5: in a water-ethanol solution with a concentration of 10^{-5} g/L; and 3: fluorescence spectra of the CDA matrix. The spectra were obtained using $\lambda_{ex} = 320$ nm for pyrene, $\lambda_{ex} = 296$ nm for benzo(a)pyrene.

level within 2 months, which is convenient for preserving the results of analysis, for example, for their subsequent verification.

3.2. Solvent Effect at the SSF of Pyrene. Pyrene solutions in water-organic media with concentrations of $2 \cdot 10^{-4}$, $2 \cdot 10^{-5}$, and $2 \cdot 10^{-6}$ g/L were used in our experiments. Stock pyrene solutions were prepared in solvents with different physical properties [24] (see Table 1). The solvent concentration in the most concentrated aqueous pyrene solution was 0.2%. The choice of these solvents was due to pyrene and other PAH being soluble in them and their ability to mix with water.

In Figure 2 the SSF intensities of pyrene on the CDA film after sorption from the water-organic solvent systems are compared. It can be seen from the diagram that with a pyrene content of $2 \cdot 10^{-6}$ g/L the solvent has little effect on the SSF intensity. At a pyrene concentration of $2 \cdot 10^{-5}$ g/L, the SSF intensities differ, depending on the solvent nature, and the strongest fluorescence signal was detected in the case of DMSO. At a pyrene concentration of $2 \cdot 10^{-4}$ g/L, the highest SSF signal was detected in the water-ethanol medium.

It follows from the data obtained that when using the organic solvents DMSO and ethanol, high fluorescence intensities of pyrene were observed. Moreover, these solvents are the least toxic (see Table 1) [29], so they are more preferable in analytical practice.

The influence of the solvent concentration (ethanol and DMSO) in the sorbate on the SSF intensity of pyrene was estimated. To this end, pyrene was sorbed from its $2 \cdot 10^{-5}$ g/L aqueous solutions with various solvent contents onto CDA films and the fluorescence spectra of the probe in the solid phase of the matrices were recorded. It has been established that the SSF intensity of pyrene is the highest when the content of the both solvents in the aqueous media is 1.2-4.2 vol% (see Table 2), but the SPL intensity of the pyrene signal in the presence of DMSO is 1.7 times (on the average) higher than that in the case of ethanol.

Pyrene solvation in DMSO apparently leads to more efficient concentrating of the probe on the hydrophobic CDA matrix [22, 23]. Analysis of the reference data presented in Table 1 has shown that DMSO has a higher dielectric constant and a higher dipole moment than ethanol, but judging by the

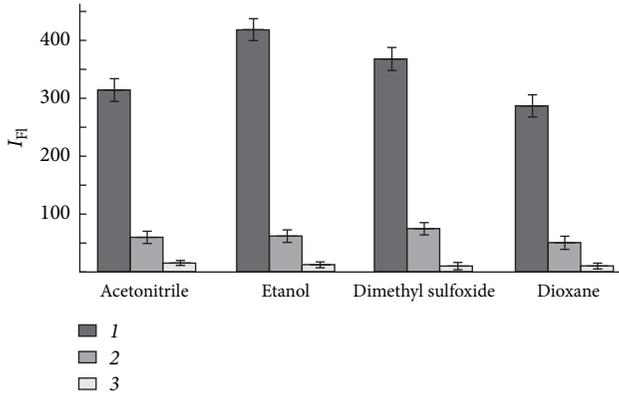


FIGURE 2: The fluorescence intensity (I_{FI}) of pyrene on the CDA matrix when sorbed from aqueous media with concentrations of $2 \cdot 10^{-4}$ g/L (1), $2 \cdot 10^{-5}$ g/L (2), and $2 \cdot 10^{-6}$ g/L (3), containing various organic solvents: acetonitrile, ethanol, dimethyl sulfoxide, and dioxane. I_{FI} is measured at $\lambda_{em} = 394$ nm, $\lambda_{ex} = 320$ nm.

TABLE 2: The fluorescence intensity of pyrene sorbed onto CDA matrices from aqueous media containing the solvent with several concentrations.

Solvent concentration in the sorbate, vol%	I_{fi} of pyrene ($\lambda_{em} = 394$ nm) in the solid phase after sorption from the aqueous medium containing:	
	ethanol	DMSO
0.2	72.3±4.1	80.2±5.0
1.2	121.2±5.5	204.3±7.4
2.2	109.7±6.3	195.4±6.1
4.2	114.4±5.1	188.5±6.6
6.2	104.2±4.1	150.1±7.3
10.0	92.5±3.6	132.2±5.4
15.0	87.0±5.2	126.5±5.3
20.0	83.6±6.3	98.1±6.2

empirical parameter E_T^N , its polarity is much lower than that of ethanol; besides, it is a hydrogen bond acceptor ($\beta = 0.73$), while ethanol is a hydrogen bond donor ($\alpha = 0.86$), i.e., it is a protic solvent. It is known that when solvent mixtures are used, selective solvation of the substance proceeds, i.e., the formation of a shell from the molecules of the preferred solvent near the solute molecule [24]. Pyrene is a hydrophobic (nonpolar) compound, with a planar molecule with electron density distributed throughout it. In aqueous media, DMSO, owing to its chemical structure and physical properties (ϵ_r , μ), is a more effective solvating agent for pyrene than ethanol. In an aqueous solution, the solvation shell made of DMSO molecules has its own micropolarity, which probably affects the processes of pyrene sorption. It is also possible that the hydrogen bond acceptor ability of DMSO due to the S = O group determines the efficiency of concentrating of the probe on the surface of the matrix, since the monomeric units of cellulose diacetate contain hydroxyl groups (hydrogen bond donors). To explain the discovered phenomenon requires additional research. It should be noted that an increased

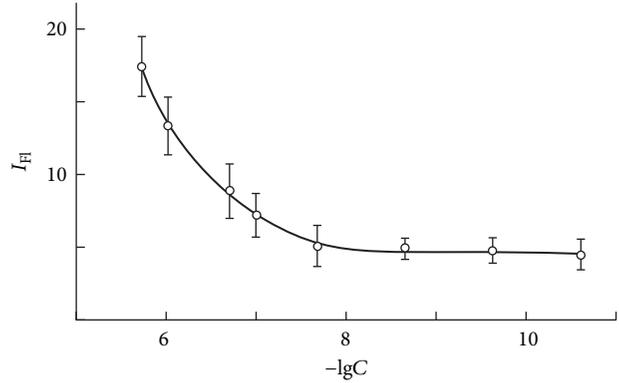


FIGURE 3: Dependence of the fluorescence intensity (I_{FI}) of pyrene on CDA matrices on the logarithm of its concentration ($2 \cdot 10^{-11}$ – $2 \cdot 10^{-6}$ g/L) in the sorbate. I_{FI} is measured at $\lambda_{em} = 394$ nm, $\lambda_{ex} = 320$ nm.

DMSO content in the aqueous medium above 20% leads to a change in the CDA film properties, which negatively affects the results of SSF analysis.

Thus, DMSO manifests itself as the most effective solvent of pyrene during sorption from an aqueous medium onto a CDA film, the optimum range of DMSO concentrations in aqueous media being 1.2–4.2 vol.%.

3.3. Quantitative SSF Analysis of Pyrene in Model Aqueous Solutions. To assess the possibility of quantitative pyrene analysis in aqueous media, we plotted the dependence of the fluorescence intensity of pyrene in the sorbent phase on its concentration in aqueous solutions containing 1.2% of DMSO. The dependence was plotted within the pyrene concentration range $2 \cdot 10^{-11}$ – $2 \cdot 10^{-6}$ g/L. Dynamic sorption of pyrene from solution on the CDA matrices was performed by passing 10 ml of the solution through the sorption column at least five times at a rate of 1 drop/s. The films with PAH were dried, after which SSF spectra of pyrene were recorded. The dependence shown in Figure 3 was plotted from the maximum of the second peak of the pyrene fluorescence spectrum ($\lambda_{em} = 394$ nm and $\lambda_{ex} = 320$ nm).

It can be seen from Figure 3 that the semilogarithmic concentration dependence has a linear character in the range of $2 \cdot 10^{-6}$ – $2 \cdot 10^{-8}$ g/L. When the pyrene concentration in the sorbate is decreased down to $2 \cdot 10^{-11}$ g/L, the SSF signal intensity has very low values and varies little. With further reduction in the pyrene concentration, the signal on the matrix is not detected, i.e., the detection limit of pyrene is $2 \cdot 10^{-11}$ g/l (10^{-13} M).

For the quantitative analysis of pyrene, a calibration graph was plotted in the concentration range $2 \cdot 10^{-6}$ – $2 \cdot 10^{-8}$ g/L (see Figure 4). Table 3 presents the data of the statistical processing of our experimental data.

Thus, we have plotted the dependence of the SSF signal on the pyrene concentration in the sorbate, it has a linear character in the range $2 \cdot 10^{-6}$ – $2 \cdot 10^{-8}$ g/L (pyrene), and the detection sensitivity of the substance was fixed at $2 \cdot 10^{-11}$ g/L, which is below the maximum permissible concentration limit

TABLE 3: Statistical processing of the experiment.

C [g/L]	$-\lg C$	$\bar{X} (I_{FI})$	σ	N	d	p
$2 \cdot 10^{-6}$	5.7	17.47	2.12	10	1.31	0.05
10^{-6}	6.0	13.37	1.97	10	1.22	0.05
$2 \cdot 10^{-7}$	6.7	8.87	1.87	10	1.15	0.05
10^{-7}	7.0	7.17	1.51	10	0.93	0.05
$2 \cdot 10^{-8}$	7.7	5.02	1.43	10	0.89	0.05

Note: C is the concentration of pyrene; \bar{X} (mean) the arithmetic mean of the values of I_{FI} ; σ the standard deviation; N the sample size; d the confidence interval; p the critical level of significance.

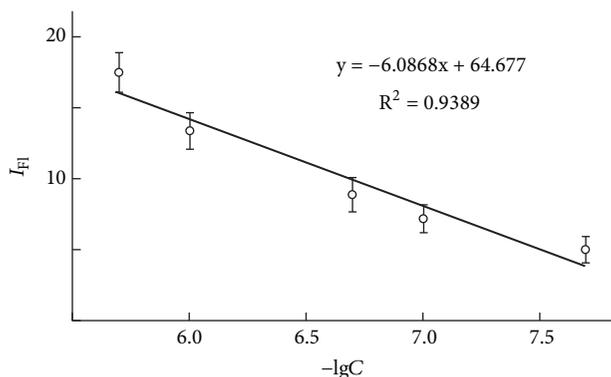


FIGURE 4: Calibration graph of the dependence of the fluorescence intensity (I_{FI}) of pyrene on CDA matrices on the logarithm of its concentration ($2 \cdot 10^{-6}$ - $2 \cdot 10^{-8}$ g/L) in a water-DMSO solution. I_{FI} is measured at $\lambda_{em} = 394$ nm and $\lambda_{ex} = 320$ nm.

of the most toxic PAH (benzo(a)pyrene) in drinking water. Consequently, the application of our CDA matrices and the SSF analysis conditions allows analyzing PAH traces in environmental objects.

4. Conclusions

The possibility of determining PAH in aqueous media using the method of solid-surface fluorescence on the cellulose diacetate films was proved on the example of pyrene and benzo(a)pyrene. A significant increase in the fluorescence signal of the both substances adsorbed on the CDA films from water-ethanol solutions was found in comparison with aqueous solutions. The most SSF intensity was noted for benzo(a)pyrene.

The effect of the solvent nature (acetonitrile, ethanol, dimethyl sulfoxide, and dioxane) and its concentration on the fluorescence intensity of pyrene sorbed on the CDA film from a water-organic solution was studied. It was shown that DMSO and ethanol are the most effective solvent additives for pyrene solid-surface fluorescence. The maximum SSF signal of pyrene was found upon sorption of the substance from aqueous media containing 1.2-4.2 vol% DMSO.

On the basis of comparative analysis of physical properties (dielectric constant, dipole moment, polarity, and hydrogen bond acceptor/donor ability) of ethanol and DMSO it has been concluded that in aqueous media DMSO is a more effective solvating agent for hydrophobic (nonpolar) pyrene

than ethanol. In water-solvent mixture DMSO molecules form a shell around a pyrene molecule. This solvation shell has its own micropolarity, which probably affects the processes of pyrene sorption. The hydrogen bond acceptor ability of DMSO due to the S = O group may determine the efficiency of concentrating of the probe on the surface of the CDA matrix.

A sorption-luminescent method for the determination of pyrene in aqueous media was developed, which involves dynamic sorption of pyrene from aqueous solutions containing 1.2% DMSO per CDA film; recording of SSF spectra in the range of 350–420 nm at $\lambda_{exp} = 320$ nm; determination of the pyrene concentration from the concentration dependence of the SSF intensity at the maximum of the spectrum at $\lambda_{em} = 394$ nm. The dependence has a linear character in the pyrene concentration range $2 \cdot 10^{-6}$ – $2 \cdot 10^{-8}$ g/L, and the limit of pyrene detection is $2 \cdot 10^{-11}$ g/L. SSF technique with the CDA matrix is promising for use in environmental monitoring of PAH traces.

Data Availability

The original spectral data is stored in the Nature & Technosphere Safety Department Laboratory at the Yuri Gagarin Saratov State Technical University, Saratov, Russia, and is available from the authors upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The results of this work were obtained in the framework of the State Task no. 4.1299.2014/K of the Russian Ministry of Education and Science.

References

- [1] J. N. Miller, "Luminescence measurements on surfaces," *Pure & Applied Chemistry*, vol. 57, no. 3, pp. 515–522, 1984.
- [2] R. J. Hurtubise, "Solid-matrix luminescence analysis: photo-physics, physicochemical interactions and applications," *Analytica Chimica Acta*, vol. 351, no. 1–3, pp. 1–22, 1997.

- [3] V. G. Amelin, N. S. Aleshin, O. I. Abramenkova, Y. N. Nikolaev, and I. A. Lomonosov, "Solid-phase fluorometric determination of Al(III), Be(II), and Ga(III) using dynamic preconcentration on reagent cellulose matrix," *Journal of Analytical Chemistry*, vol. 66, no. 8, pp. 709–713, 2011.
- [4] M. C. Talio, M. Alesso, M. Acosta, M. G. Acosta, M. O. Luconi, and L. P. Fernández, "Caffeine monitoring in biological fluids by solid surface fluorescence using membranes modified with nanotubes," *Clinica Chimica Acta*, vol. 425, pp. 42–47, 2013.
- [5] I. I. Parashchenko, T. D. Smirnova, S. N. Shtykov, V. I. Kochubei, and N. N. Zhukova, "Doxycycline-sensitized solid-phase fluorescence of europium on silica in the presence of surfactants," *Journal of Analytical Chemistry*, vol. 68, no. 2, pp. 112–116, 2013.
- [6] B. Mucoz and A. Albores, "DNA damage caused by polycyclic aromatic hydrocarbons: mechanisms and markers," DNA Repair, InTech, Rijeka, Croatia, 2011.
- [7] G. Safo-Adu, F. G. Ofosu, D. Carboo, and Y. SerforArmah, "Health risk assessment of exposure to particulate polycyclic aromatic hydrocarbons at a Tollbooth on a Major Highway," *American Journal of Scientific and Industrial Research*, vol. 5, no. 4, pp. 110–119, 2014.
- [8] Y. Zhang and S. Tao, "Global atmospheric emission inventory of polycyclic aromatic hydrocarbons (PAHs) for 2004," *Atmospheric Environment*, vol. 43, no. 4, pp. 812–819, 2009.
- [9] E. N. Pakpahan, M. H. Isa, and S. R. M. Kutty, "Polycyclic aromatic hydrocarbons in petroleum sludge cake: extraction and origin—a case study," *International Journal of Applied Science and Technology*, vol. 1, no. 5, pp. 201–207, 2011.
- [10] S. Danyi, F. Brose, C. Basseur et al., "Analysis of EU priority polycyclic aromatic hydrocarbons in food supplements using high performance liquid chromatography coupled to an ultraviolet, diode array or fluorescence detector," *Analytica Chimica Acta*, vol. 633, no. 2, pp. 293–299, 2009.
- [11] "United States Environmental Protection Agency, Office of Environmental Information, Emergency Planning and Community Right-to-Know Act – Section 313: Guidance for Reporting Toxic Chemicals: Polycyclic Aromatic Compounds," Washington, DC 20460, p. 25, 2001.
- [12] T. Saitoh, H. Itoh, and M. Hiraide, "Admicelle-enhanced synchronous fluorescence spectrometry for the selective determination of polycyclic aromatic hydrocarbons in water," *Talanta*, vol. 79, no. 2, pp. 177–182, 2009.
- [13] W. B. Wilson, A. A. Costa, H. Wang, A. D. Campiglia, J. A. Dias, and S. C. L. Dias, "Pre-concentration of water samples with BEA zeolite for the direct determination of polycyclic aromatic hydrocarbons with laser-excited time-resolved Shpol'skii spectroscopy," *Microchemical Journal*, vol. 110, pp. 246–255, 2013.
- [14] S. G. Dmitrienko, E. Y. Gurariy, R. E. Nosov, and Y. A. Zolotov, "Solid-phase extraction of polycyclic aromatic hydrocarbons from aqueous samples using polyurethane foams in connection with solid-matrix spectrofluorimetry," *Analytical Letters*, vol. 34, no. 3, pp. 425–438, 2001.
- [15] V. Vásquez, M. E. Báez, M. Bravo, and E. Fuentes, "Determination of heavy polycyclic aromatic hydrocarbons of concern in edible oils via excitation-emission fluorescence spectroscopy on nylon membranes coupled to unfolded partial least-squares/residual bilinearization," *Analytical and Bioanalytical Chemistry*, vol. 405, no. 23, pp. 7497–7507, 2013.
- [16] G. I. Romanovskaya, A. Y. Olenin, and S. Y. Vasil'Eva, "Concentration of polycyclic aromatic hydrocarbons by chemically modified silver nanoparticles," *Russian Journal of Physical Chemistry A*, vol. 85, no. 2, pp. 274–278, 2011.
- [17] O. A. Dyachuk, T. I. Gubina, and G. V. Melnikov, "Adsorption preconcentration in the luminescence determination of polycyclic aromatic hydrocarbons," *Journal of Analytical Chemistry*, vol. 64, no. 1, pp. 7–11, 2009.
- [18] A. H. Ackerman and R. J. Hurtubise, "Methods for coating filter paper for solid-phase microextraction with luminescence detection and characterization of the coated filter paper by infrared spectrometry," *Analytica Chimica Acta*, vol. 474, no. 1–2, pp. 77–89, 2002.
- [19] P. Zugenmaier, "Characterization and physical properties of cellulose acetates," *Macromolecular Symposia*, vol. 208, pp. 81–166, 2004.
- [20] S. Fischer, K. Thümmeler, B. Volkert, K. Hettrich, I. Schmidt, and K. Fischer, "Properties and applications of cellulose acetate," *Macromolecular Symposia*, vol. 262, no. 1, pp. 89–96, 2008.
- [21] S. M. Rogacheva, A. B. Shipovskaya, A. V. Strashko, T. I. Gubina, E. V. Volkova, and A. G. Melnikov, "Polysaccharide fibers as matrices for solid-surface fluorescence," *International Journal of Polymer Science*, vol. 2014, Article ID 183413, 9 pages, 2014.
- [22] A. B. Shipovskaya, T. I. Gubina, A. V. Strashko, and O. N. Malinkina, "Cellulose diacetate films as a solid-phase matrix for fluorescence analysis of pyrene traces in aqueous media," *Cellulose*, vol. 22, no. 2, pp. 1321–1332, 2015.
- [23] S. M. Rogacheva, E. V. Volkova, A. V. Strashko et al., "Preparation of cellulose diacetate membranes for solid-surface fluorescence of polycyclic aromatic hydrocarbons," *Izvestiya Vysshikh Uchebnykh Zavedeniy. Khimiya i Khimicheskaya Tekhnologiya*, vol. 59, no. 12, pp. 80–86, 2016.
- [24] Ch. Reichardt, *Solvents and Solvent Effects in Organic Chemistry*, Wiley-VCH, Weinheim, Germany, 3rd edition, 2003.
- [25] L. T. Zhuravlev and V. V. Potapov, "Density of silanol groups on the surface of silica precipitated from a hydrothermal solution," *Russian Journal of Physical Chemistry A*, vol. 80, no. 7, pp. 1119–1128, 2006.
- [26] P. N. Kolotilov, K. E. Polunin, I. A. Polunina, and A. V. Larin, "Effect of component ratio of binary organic solvent on sorption of phenols by silica," *Colloid Journal*, vol. 72, no. 4, pp. 499–503, 2010.
- [27] M. S. Khakhalina, I. Y. Tikhomirova, and M. V. Puzyk, "Effect of vapors of water and organic solvents on the luminescence of cation-exchange membranes immobilized with cyclometalated Pt(II) complexes," *Optics and Spectroscopy*, vol. 108, no. 5, pp. 703–709, 2010.
- [28] D. Wróbel, I. Hanyz, R. Bartkowiak, and R. M. Ion, "Fluorescence and time-resolved delayed luminescence of porphyrins in organic solvents and polymer matrices," *Journal of Fluorescence*, vol. 8, no. 3, pp. 191–198, 1998.
- [29] "Vrednyye veshchestva v promyshlennosti. Spravochnik dlya khimikov, inzhenerov i vrachey. T. 1. Organicheskiye veshchestva / Pod red. N. V. Lazareva i E. N. Levinoy. L., «Khimiya», 1976. 592 s" (Russian).



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