



Diffuse reflectance determination of Malachite Green using polyurethane foam as solid support and sodium dodecylsulfate as counter ion

Nicolle F. Robaina, Luis Gustavo T. dos Reis, Ricardo J. Cassella*

Departamento de Química Analítica, Universidade Federal Fluminense, Outeiro de São João Batista s/n, Centro, Niterói/RJ, 24020-141, Brazil

ARTICLE INFO

Article history:

Received 25 February 2011

Received in revised form 5 April 2011

Accepted 23 April 2011

Available online 30 April 2011

Keywords:

Diffuse reflectance

Polyurethane foam

Malachite Green

Water

ABSTRACT

This paper reports the use of polyurethane foam (PUF) as solid support for diffuse reflectance spectrophotometric determination of Malachite Green (MG), a well known cationic dye used as biocide in the aquaculture industry, using sodium dodecylsulfate (SDS) as a counter ion. The method was based on the formation of an ionic-pair between the dye and the anionic surfactant SDS, which was sorbed onto PUF surface, where the diffuse reflectance was measured at 635 nm. Several parameters that could affect the performance of the system were evaluated. As expected, the SDS concentration presented strong influence on the analytical signal because the PUF was able to retain only the ionic-pair. The pH influenced the analytical signal, which was more intense in the acidic/neutral range, while the ionic strength only influenced the kinetic of the MG (as MG–SDS ionic-pair) sorption. The methodology was employed in the determination of MG in river waters and a recovery test was performed to test the accuracy of the procedure. Recovery percentages between 98.7 and 107% were observed when 60 or 80 $\mu\text{g L}^{-1}$ of MG were added to the samples.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

Malachite Green (MG) is a cationic triphenylmethane dye largely employed for coloring silk, wool, jute, leather, cotton, paper and acrylic [1]. Other applications of the MG include its use as a medical disinfectant and as a biocide against infections caused by protozoa and fungi [2–4]. The MG is considered as an efficient fungicide and parasiticide in aquaculture industry because it is readily absorbed by fish organisms and metabolically reduced to the lipophilic leuco-Malachite Green (LMG), which presents a long residence time in edible fish tissues [5]. The use of MG dye in the aquaculture industry is widely disseminated around the world in spite of the fact that the dye is banned in several countries, including United States, where the US Food and Drug Administration (FDA) did not approve its use as a veterinary drug. Even so, the MG is still employed in various countries because of the low cost, high commercial availability and efficiency [6]. The prohibition of the MG in Europe and USA was based on studies that point out the MG and LMG as toxic agents for human cells. Also, it was reported that they can be genotoxic [5,9] and carcinogenic [7,8], being responsible for the possible appearance of liver, renal and hepatic tumors in rodents.

As mentioned previously, MG is still employed in aquacultures worldwide. For this reason, its discharge into natural waters is a

matter of concern as well as the appearance of trace quantities of MG and LMG in edible fishes. In this context, the development of suitable analytical methods for the determination of MG in waters is required. Several analytical techniques have been employed for this purpose. The great majority of the works published in the current literature are related to the use of liquid chromatographic methods for the MG quantification in water and/or fish samples [10–19]. The main problems of these methods are the high cost of the instrumentation, especially when the mass spectrometer is used as detector, the laborious sample preparation procedure and the manipulation of highly toxic solvents. Some other techniques such as electrophoresis [20,21], fluorimetry [22] and voltammetry [23] have also been employed for the MG determination in different kinds of samples.

Specifically for the MG determination, the employment of spectrophotometric methods seems to be a good alternative because of the high absorptivity of the dye in the visible region of the electromagnetic spectrum. Even so, only few works can be found describing the development of spectrophotometric determination of MG [24–27]. Pourreza and Elhami [24] developed a spectrophotometric method for the MG determination in waters after separation of the analyte by cloud-point extraction with Triton X-100. The MG was measured directly in the extracts, diluted in ethanol, exploring the maximum absorbance observed at 630 nm. An et al. [25] also used a cloud-point extraction procedure for the spectrophotometric determination of MG (and Crystal violet) in waters. Differently of Pourreza and Elhami, the authors

* Corresponding author. Tel.: +55 21 2629 2222; fax: +55 21 2629 2143.

E-mail address: cassella@vm.uff.br (R.J. Cassella).

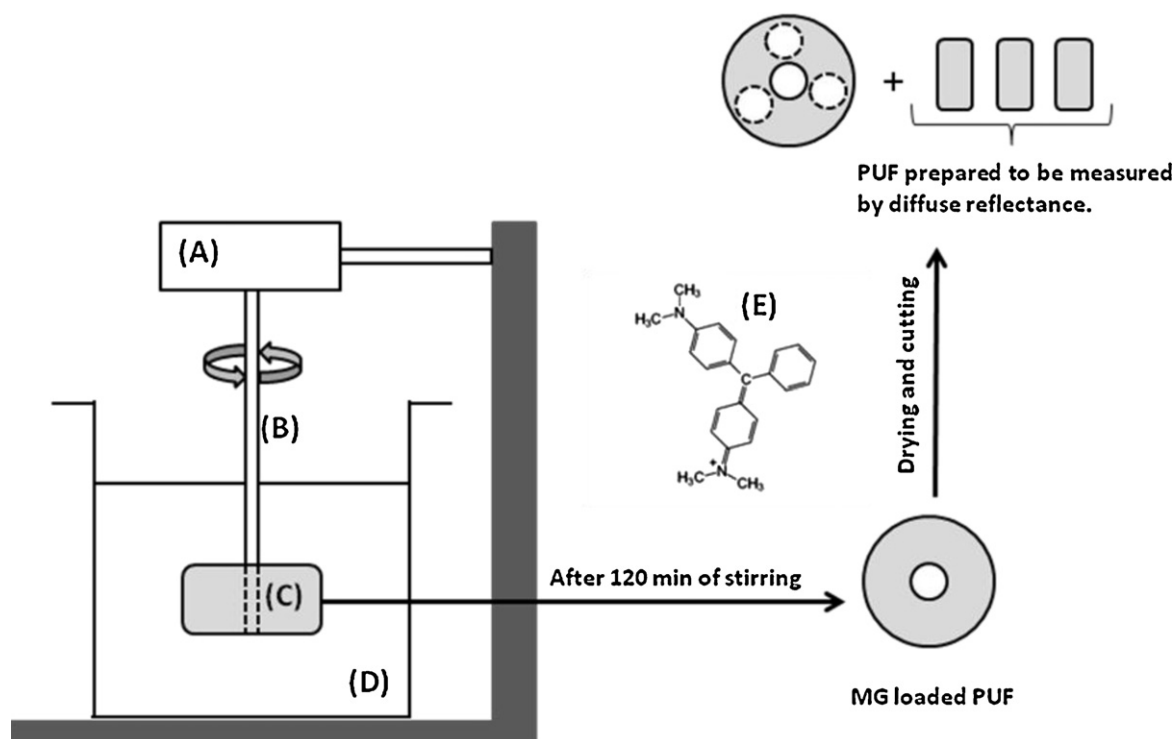


Fig. 1. Scheme of the manifold and whole procedure employed in this work for the MG determination by diffuse reflectance. (A) Overhead stirrer, (B) overhead stirrer arm, (C) PUF cylinder (200 ± 10 mg), (D) solution (200 mL, sample or standard) containing MG and SDS and (E) MG structure.

employed Triton X-114 as surfactant and applied a multivariate calibration strategy based on the partial least-squares regression (PLS) to resolve the spectral interference of one dye on other.

Afkhami et al. [26] and Farhadi et al. [27] employed similar strategies for the preconcentration of MG before its spectrophotometric determination. In both cases, the MG was adsorbed onto solid-phases in a form of an ionic-pair with sodium dodecylsulfate (SDS). Afkhami et al. [26] used maghemite ($\gamma\text{-Fe}_2\text{O}_3$) nanoparticles modified with SDS as adsorbent, while Farhadi et al. [27] employed SDS-coated alumina for this task. The main drawback of these two works was the use of considerable amounts of toxic organic solvents to promote MG elution before its spectrophotometric measurement.

The main goal of this work was to propose a novel method for the MG determination in river waters based on the measurement of the MG sorbed onto polyurethane foam (PUF), a very low cost sorbent successfully used for the adsorption of several organic substances [28–30], by diffuse reflectance in the visible region. The SDS was used as a counter ion in order to form, with the dye, an ionic-pair of low solubility in water and make possible the sorption of the analyte onto the solid-phase. This approach was already proposed in other works [31–35], but never explored for MG determination.

2. Experimental

2.1. Apparatus

The diffuse reflectance measurements of the PUF loaded with MG were performed with a Varian Cary 5000 spectrophotometer (Mulgrave, Australia) equipped with the accessory for diffuse reflectance. The spectra were recorded in the range of 500–750 nm with a nominal resolution of 1 nm and the measurements were realized at 635 nm, which corresponds to the wavelength where maximum absorption was observed for the MG sorbed onto PUF.

An Ika RW 20 DZM (Staufen, Germany) overhead stirrer was employed for the stirring of PUF with MG–SDS solutions. It was equipped with a stirrer arm made of stainless steel furnished by the own manufacturer. Cylinders of PUF were adjusted to this stirrer arm in order to extract the MG from the solutions containing the dye and SDS (Fig. 1).

2.2. Reagents and solutions

All reagents used in this work were of analytical grade and employed without any additional treatment. The solutions were always prepared with ultrapure water purified in a Simplicity Milli-Q System (Millipore, Bedford, USA).

A 100 mg L^{-1} MG stock solution was prepared by dissolving 55.3 mg of the reagent (chloride form), provided by Vetec (Rio de Janeiro, Brazil), in approximately 100 mL of water. After the total dissolution of the solid, the mixture was transferred to a 500 mL volumetric flask and the volume was made up to the mark with water. This solution was stable for two weeks, at least. The MG solutions used during the experimental work were prepared daily by adequate dilution of the stock solution with water.

A $1.00 \times 10^{-3} \text{ mol L}^{-1}$ SDS stock solution was prepared by dissolving 0.144 g of SDS (Vetec, Rio de Janeiro, Brazil) in approximately 100 mL of purified water. Then, the mixture was transferred to a 500 mL volumetric flask and the volume was made up to the mark with purified water. The SDS solutions used during the experimental work were prepared daily by adequate dilution of the stock solutions with water.

Open-cell polyether type PUF with 0.020 g cm^{-3} density (3 M, Brazil) was used throughout the experimental work. In order to use the PUF in the sorption experiments, cylinders with 3 cm diameter and 1.5 cm height were cut with a leather cutter. A hole of 0.5 cm diameter was cut in the center of the cylinder (also with a leather cutter) in order to allow its adaptation to the overhead stirrer arm. The PUF cylinders always weighed 200 ± 10 mg.

2.3. General procedure

For the PUF loading with the analyte, the PUF cylinder was adapted to the arm of the overhead stirrer and soaked (Fig. 1) in a solution prepared by mixing 180 mL of the sample (or standard solution of MG) with 20 mL of the $1.00 \times 10^{-4} \text{ mol L}^{-1}$ SDS solution, in a 250 mL beaker. The cylinder was stirred for 120 min and, after elapsed this time, it was removed from the arm of the overhead stirrer and dried between two sheets of filter paper. Then, three small cylinders of 0.5 cm diameter and 1.5 cm height were cut out from the PUF loaded with the MG (in fact, MG–SDS ionic-pair) and used to record the diffuse reflectance spectra. The small cylinders were directly adjusted, one by one, to the accessory for diffuse reflectance of the spectrophotometer and the spectrum was recorded in the range of 500–750 nm. The obtained spectra were treated in order to eliminate the baseline displacement due to the scattered radiation. For this purpose, the diffuse reflectance signal at 750 nm was subtracted of the signals obtained in each wavelength. The $\log 1/R$ at 635 nm was used as quantitative variable and all experiments were carried out at the laboratory ambient temperature ($24 \pm 1^\circ \text{C}$), except otherwise mentioned. A scheme of the general procedure can be seen in Fig 1.

2.4. Reference method

In the reference method, the MG was extracted from sample by PUF using the same procedure adopted in the general procedure. Nevertheless, after the MG extraction from the sample, the MG was eluted of the foam cylinder by using 20 mL of acetonitrile. Then, the volume was completed to 25 mL, in a volumetric flask, and the absorbance of the extract at 635 nm was measured. In this case, the analytical curves were constructed using MG solutions prepared in acetonitrile.

3. Results and discussion

As mentioned previously, the main goal of this work was to develop a method for MG determination in waters based on the diffuse reflectance measurement of MG sorbed onto PUF using SDS as a counter ion. Some parameters that could affect the performance of the system such as the SDS concentration, pH, ionic strength and stirring speed were studied using the univariate approach.

3.1. Effect of the SDS concentration

The first parameter evaluated in this work was the effect of the SDS concentration on the diffuse reflectance signal of the MG. This test was performed considering that the retention of the MG by the PUF depends on the formation of an ionic-pair with the anionic SDS, because the sorption of cationic dyes by the PUF, without the formation of the ionic-pair, was shown to be negligible [36–38]. The experiment was performed keeping the concentration of the dye constant at 1.0 mg L^{-1} , the stirring speed at 200 rpm and varying the concentration of the anionic surfactant in the range of 0 – $1.75 \times 10^{-4} \text{ mol L}^{-1}$. The stirring time was always 150 min. As it can be seen in Fig. 2, the analytical signal increased with the increase of the SDS concentration up to $5.00 \times 10^{-5} \text{ mol L}^{-1}$. For concentrations of SDS higher than $5.00 \times 10^{-5} \text{ mol L}^{-1}$, the analytical signal remained almost constant, evidencing that the MG was quantitatively converted into the ionic-pair and adsorbed onto PUF. Based on these data, the SDS concentration was established at $1.00 \times 10^{-4} \text{ mol L}^{-1}$ for the method in order to ensure that the MG could be quantitatively transferred to the PUF surface and that maximum sensitivity could be attained for the method.

The effect of the SDS concentration can be explained by analyzing the equilibrium established between MG and MG–SDS

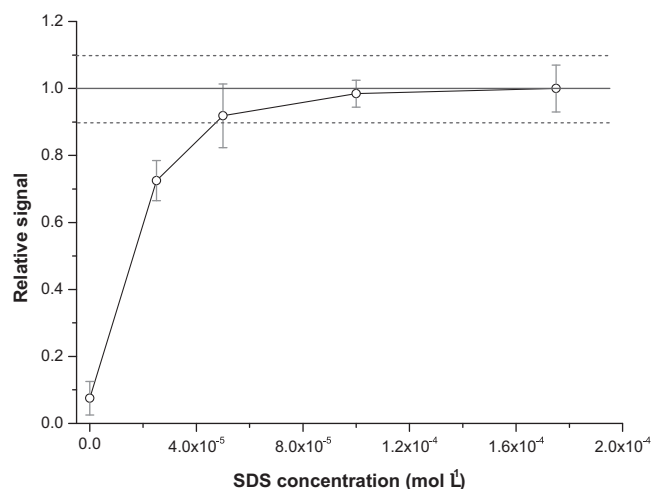


Fig. 2. Effect of the SDS concentration on the relative signal of MG adsorbed onto PUF. The stirring time was 150 min, the pH of the solution was not adjusted and the MG concentration was 1.0 mg L^{-1} .

(ionic-pair) in the aqueous solution. At low SDS concentration, the displacement of the equilibrium in the direction of the ionic-pair formation is not favored. As the ionic-pair presents higher affinity by the PUF in relation to the cationic dye, low retention was observed, resulting in a low signal of diffuse reflectance. When the SDS concentration was increased, the formation of the MG–SDS ionic-pair was enhanced, resulting in the increase of the retention of the ionic-pair and in the diffuse reflectance signal.

3.2. Effect of the pH

In general, the pH of the medium presents remarkable influence on the adsorption of organic molecules onto solid-phases. This occurs because the pH of the medium can affect the distribution of the chemical species in solution and/or modify the characteristics of the adsorbent surface [39]. In this case, the pH of the extraction solution can modify the structure of the PUF surface, by protonating the N–H groups of the urethane units and/or the unprotonated nitrogen atom of the MG molecule. In this context, the effect of the pH on the diffuse reflectance signal was studied because it could have noticeable effect on the sorption of MG onto PUF.

The effect of the pH was investigated by varying the pH of the MG solution in the range of 2.0–11.8 using suitable buffer systems with a total concentration of 0.010 mol L^{-1} . To adjust the solution in pH 2.0, a phosphoric acid buffer solution was used, while for the pH 4.0 and 6.0, the acetate buffer solution was employed. The phosphate buffer solution was used to keep the pH at 8.0 and a boric acid buffer solution was employed for the adjustment at 10.0 and 11.8.

The SDS concentration was fixed at $1.00 \times 10^{-4} \text{ mol L}^{-1}$, the stirring time was 150 min and the speed of the overhead stirrer was set at 200 rpm. As it can be seen in Fig. 3, the diffuse reflectance signal did not vary significantly in the pH range of 2.0–8.0. This behavior can be explained by the fact that both the PUF surface and the MG structure were not protonated even in more acidic conditions (pH approximately 2.0). As result, no variation in the sorption efficiency of the dye by the PUF was noted and no variation in the diffuse reflectance signal was observed. However, in more basic solutions (pH higher than 8.0), the analytical signal decreased continuously with the increase of the pH. This phenomenon can be credited to the conversion of the MG into the colorless leuco-dye form as result of the attack of the hydroxyl ions to the central carbon atom [40]. The same experiment was carried out with an unbuffered solution. In this case, the diffuse reflectance was approximately the same of

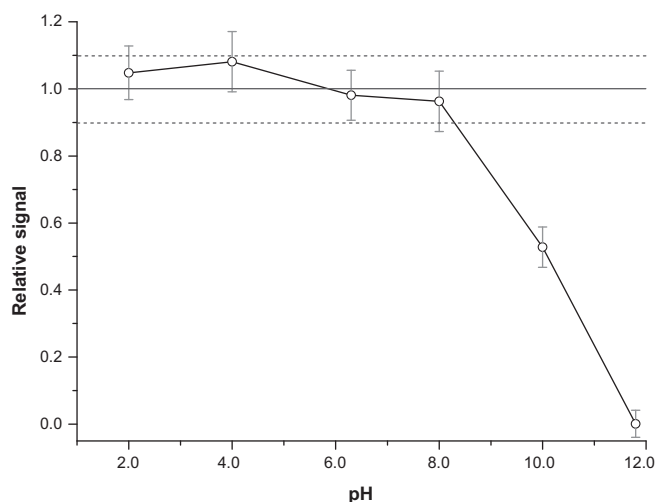


Fig. 3. Effect of the pH on the relative signal of MG adsorbed onto PUF. The stirring time was 150 min, the SDS concentration was $1.00 \times 10^{-4} \text{ mol L}^{-1}$ and the MG concentration was 1.0 mg L^{-1} .

those observed in the range of 2.0–8.0, probably because the pH of this solution was around 4.5–5.0 and did not vary significantly during the sorption step. Once the samples (river waters) presented pH in the range of 4.5–5.5, it was decided to perform the adsorption of MG with no pH adjustment.

3.3. Effect of the ionic strength and stirring time

Another important parameter to be evaluated is the ionic strength. Natural waters can have variable ionic strength, depending on their origin. Although river waters, in general, present low ionic strength, the influence of this variable on the diffuse reflectance signal of the MG sorbed onto PUF was studied.

The influence of the ionic strength was investigated by varying the NaCl concentration in the range of 0 (without NaCl addition)– 2.0 mol L^{-1} . As in other experiments, the SDS concentration was fixed at $1.00 \times 10^{-4} \text{ mol L}^{-1}$ and the overhead stirrer speed was set at 200 rpm. The effect of the ionic strength was tested for different stirring times in the range of 15–180 min. As it can be seen in Fig. 4, the ionic strength has no significant influence on the diffuse reflectance signal of the MG, especially if longer stirring times

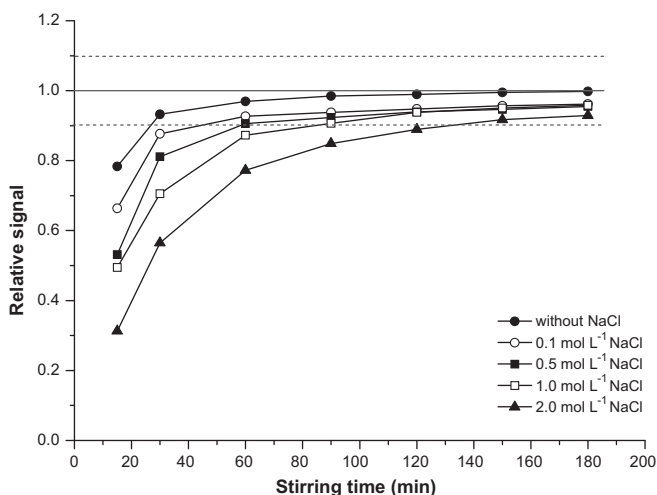


Fig. 4. Effect of the ionic strength and the stirring time on the relative signal of MG adsorbed onto PUF. The SDS concentration was $1.00 \times 10^{-4} \text{ mol L}^{-1}$ and the MG concentration was 1.0 mg L^{-1} . The pH of the solution was not adjusted.

are used. This behavior evidences that the ionic strength, in fact, influences mainly the kinetic of the MG sorption onto PUF. So, in order to ensure that the maximum diffuse reflectance signal could be achieved, even for samples with high content of dissolved salts, the stirring time of 120 min was set for the method.

3.4. Effect of stirring speed

After studying the effect of the ionic strength, which is affected by the stirring time, the influence of the stirring speed was evaluated. In this case, it was expected that increasing the stirring speed, the contact between the sorbent (PUF) and the MG–SDS ionic-pair could be enhanced, thus accelerating the sorption process. However, it was not observed any significant difference between the relative signals obtained in the range of 200–500 rpm of stirring speed. Therefore, the stirring speed of 200 rpm was maintained for the method.

4. Interference study

Generally, a wide range of cations and anions can be present in natural waters like river waters. In order to evaluate the effect of possible interferent species on the developed method, the most frequently cations and anions found in river waters were chosen. The group of cations was composed of Ca(II), Mg(II), Na(I) and K(I), as the major ions, and Fe(III), Zn(II), Cu(II) and Mn(II) as the minor ions. For the study of possible interferent anions, chloride and nitrate were selected. No interference (variation of $\pm 10\%$ of the signal) was observed when Ca(II) and Mg(II) were found in concentrations up to 10 mg L^{-1} . Na(I) and K(I) did not cause interference in concentrations up to 1000 mg L^{-1} . Nevertheless, some interference was observed when the minor ions (Fe(III), Zn(II), Cu(II) and Mn(II)) were present in the solutions, probably due to their complexation with MG, which difficults the formation of the ionic-pair (MG–SDS). These cations only can be present in concentrations up to 1 mg L^{-1} . For the anions, no interference was verified when they were added in concentrations up to 1000 mg L^{-1} (maximum tested). It is important to remark that the concentration of MG in the experiments was 0.25 mg L^{-1} .

5. Analytical features and application of the method

At the optimized conditions, a linear relationship was observed between the MG concentration (in the range of $50\text{--}250 \text{ } \mu\text{g L}^{-1}$) and the $\log 1/R$ measured at 635 nm (Fig. 5). This linear relationship can be represented by the following equation: $\log 1/R = 6.48 \times 10^{-4} [\text{MG} (\text{ } \mu\text{g L}^{-1})] + 0.0067$, $r^2 = 0.9911$. The limit of detection (3σ criterion), estimated from the standard deviation of 5 independent measurements of the blank, was $2.2 \text{ } \mu\text{g L}^{-1}$. The limit of quantification (10σ criterion), also estimated from the standard deviation of 5 independent measurements of the blank, was $7.3 \text{ } \mu\text{g L}^{-1}$. The RSD, calculated as the standard deviation of 5 independent measurements of the $50 \text{ } \mu\text{g L}^{-1}$ MG standard solution was 8.5%.

The applicability of the proposed methodology was tested through the determination of MG in three samples of river waters. Also, in order to evaluate the accuracy of the procedure, the samples were spiked with known concentrations of MG (60 and $80 \text{ } \mu\text{g L}^{-1}$) and analyzed by the procedure proposed in this work and by the spectrophotometric method described in Section 2.4, taken as reference method. The polyurethane foams loaded with MG were prepared using the optimized conditions (180 mL of sample or standard solution of MG + 20 mL of SDS stock solution, without adjustment of pH and, stirring time of 120 min and speed stirring of 200 rpm) and measured by diffuse reflectance at 635 nm . The obtained results are shown in Table 1. As it can be seen, the con-

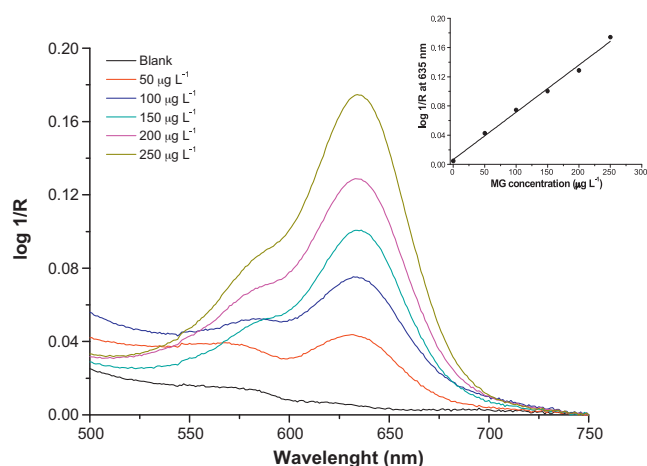


Fig. 5. Spectra of the MG standards used to prepare a typical analytical curve. The inner figure represents the analytical curve built up with the data of log 1/R measured at 635 nm.

Table 1

Application of the proposed methodology for the analysis of river waters and recovery tests. The results are expressed as mean value \pm standard deviation ($n=3$).

Sample	MG added ($\mu\text{g L}^{-1}$)	MG proposed method ($\mu\text{g L}^{-1}$)	Recovery (%)	MG reference method ($\mu\text{g L}^{-1}$)
A	0	<LOQ	98.7	<LOQ
	60	59.2 ± 4.6		60.3 ± 0.8
B	0	<LOQ	107	<LOQ
	60	64.2 ± 4.5		65.0 ± 0.5
C	0	<LOQ	101	<LOQ
	80	80.8 ± 7.1		78.8 ± 1.2

centration of MG in the samples was always below the limit of quantification. The recovery rates observed in the analysis of spiked samples were in the range of 98.7–107%, showing that the methodology presents suitable accuracy to be applied in the determination of trace concentrations of MG in river waters. Also, it is important to mention that there was no statistical difference (95% confidence level, Student-t test) between the MG concentrations found in the spiked samples by the proposed method and the MG concentrations found by the reference method.

6. Conclusions

This work demonstrated that the polyurethane foam (PUF) can act as a proper solid support for the sorption of Malachite Green (MG) when it is associated with sodium dodecylsulfate (SDS), forming an ionic-pair. The sorption of MG onto PUF surface was employed for the diffuse reflectance measurements of MG after its extraction from samples of river water, making possible the development of a novel analytical method for the MG determination.

In the development of the methodology, the concentration of SDS added to the medium was the most important variable to be studied because it showed strong influence on the diffuse reflectance signal. Surprisingly, the pH of the extraction medium did not present remarkable effect on the method, except in the range of 8–11.8, in which the MG is converted into the colorless leuco-MG form, causing a strong decrease of the analytical signal. Best results were verified when the waters samples were analyzed

without any pH adjustment. The ionic strength of the medium seems to influence only the kinetics of the MG extraction by the PUF.

The proposed methodology was successfully applied in the analysis of spiked samples of river water, being observed recovery percentages in the range of 98.7–107% when 60 or 80 $\mu\text{g L}^{-1}$ of MG was added to the samples.

Acknowledgments

The authors are grateful to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Fundação Carlos Chagas Filho de Apoio à Pesquisa do Estado do Rio de Janeiro (FAPERJ) and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for providing grants, scholarships and financial supports.

References

- [1] S.J. Culp, F.A. Beland, J. Am. Colloid Toxicol. 15 (1996) 219.
- [2] G.L. Hoffman, F.P. Meyer, Parasites of Freshwater Fishes, TFH Publications, Neptune, New Jersey, 1974.
- [3] D.J. Alderman, R.S. Clifton-Hadley, J. Fish Dis. 16 (1993) 297.
- [4] R.A. Schnick, Prog. Fish Cult. 50 (1988) 190.
- [5] A.A.M. Stolk, T. Zuidema, M.W.F. Nielsen, Trends Anal. Chem. 26 (2007) 967.
- [6] S. Lee, J. Choi, L. Chen, B. Park, J.B. Kyong, G.H. Seong, J. Choo, Y. Lee, K.-H. Shin, E.K. Lee, S.-W. Joo, K.H. Lee, Anal. Chim. Acta 590 (2007) 139.
- [7] B. Bose, L. Motiwale, K.V.K. Rao, Cancer Lett. 230 (2005) 260.
- [8] A. Stamatou, C. Nebbia, I. De Angelis, A.G. Albo, M. Carletti, C. Rebecchi, F. Zampaglioni, M. Dacasto, Toxicol. In Vitro 19 (2005) 853.
- [9] 96/23/EC Council Directive of 29 April 1996, Brussels, Off. J. Eur. Commun. L125 (1996) 10.
- [10] K. Mitrowska, A. Posyniak, J. Zmudzki, J. Chromatogr. A 1089 (2005) 187.
- [11] K. Halme, E. Lindfors, K. Peltonen, J. Chromatogr. B 845 (2007) 74.
- [12] D. Arroyo, M.C. Ortiz, L.A. Sarabia, F. Palacios, J. Chromatogr. A 1187 (2008) 1.
- [13] A.A. Bergwerff, P. Scherpenisse, J. Chromatogr. B 788 (2003) 351.
- [14] K.C. Lee, J.L. Wu, Z. Cai, J. Chromatogr. B 843 (2006) 247.
- [15] P. Scherpenisse, A.A. Bergwerff, Anal. Chim. Acta 529 (2005) 173.
- [16] W.C. Andersen, S.B. Turnipseed, J.E. Roybal, J. Agric. Food Chem. 54 (2006) 4517.
- [17] M.D. Hernando, M. Mezcu, J.M. Suárez-Barcena, A.R. Fernández-Alba, Anal. Chim. Acta 562 (2006) 176.
- [18] X. Wu, G. Zhang, Y. Wu, X. Hou, Z. Yuan, J. Chromatogr. A 1172 (2007) 121.
- [19] C. Long, Z. Mai, B. Zhu, X. Zou, Y. Gao, X. Huang, J. Chromatogr. A 1203 (2008) 21.
- [20] C.-H. Tsai, J.-D. Lin, C.-H. Lin, Talanta 72 (2007) 368.
- [21] X.B. Luo, X. Jiang, X.M. Tu, S.L. Luo, L.S. Yan, B. Chen, Electrophoresis 31 (2010) 688.
- [22] D. Cheng, B. Li, Talanta 78 (2009) 949.
- [23] H. Yi, W. Qu, W. Huang, Microchim. Acta 160 (2008) 291.
- [24] N. Pourreza, S. Elhami, Anal. Chim. Acta 596 (2007) 62.
- [25] L. An, J. Deng, L. Zhou, H. Li, F. Chen, H. Wang, Y. Liu, J. Hazard. Mater. 175 (2010) 883.
- [26] A. Afkhami, R. Moosavi, T. Madrakian, Talanta 82 (2010) 785.
- [27] K. Farhadi, R. Maleki, N.M. Nezhad, N. Samadi, Spectrosc. Lett. 43 (2010) 101.
- [28] R.J. Cassella, S. Garrigues, R.E. Santelli, M. de la Guardia, Analyst 125 (2000) 257.
- [29] L. Schumack, A. Chow, Talanta 34 (1987) 957.
- [30] M.S. El-Shahawi, S.M. Al-Daheri, Anal. Chim. Acta 320 (1996) 277.
- [31] S.G. Dmitrienko, O.A. Kosyrev, V.K. Runov, Y.A. Zolotov, Mendelev Commun. 2 (1991) 75.
- [32] S.G. Dmitrienko, L.V. Goncharova, A.V. Zhigulev, R.E. Nosov, N.M. Kuzmin, Y.A. Zolotov, Anal. Chim. Acta 373 (1998) 131.
- [33] S.G. Dmitrienko, O.A. Sviridova, L.N. Pyatkova, V.A. Zhukova, Y.A. Zolotov, Anal. Chim. Acta 405 (2000) 231.
- [34] S.G. Dmitrienko, O.M. Medvedeva, A.A. Ivanov, O.A. Shpigun, Y.A. Zolotov, Anal. Chim. Acta 469 (2002) 295.
- [35] V.V. Apyari, S.G. Dmitrienko, V.M. Ostrovskaya, E.K. Anae, Y.A. Zolotov, Anal. Bioanal. Chem. 391 (2008) 1977.
- [36] E.E. Baldez, N.F. Robaina, R.J. Cassella, J. Hazard. Mater. 159 (2008) 580.
- [37] E.E. Baldez, N.F. Robaina, R.J. Cassella, Sep. Sci. Technol. 44 (2009) 3128.
- [38] M. Mori, R.J. Cassella, Quim. Nova 32 (2009) 2039.
- [39] P.P. Selvam, S. Preethi, P. Basakalingam, N. Thinakaran, A. Sivasamy, S. Sivanesan, J. Hazard. Mater. 155 (2008) 39.
- [40] Y. Zhang, X. Li, J. Liu, X. Zeng, J. Disp. Sci. Technol. 23 (2002) 473.