MOLECULARLY IMPRINTED POLY (VINYL ALCOHOL) FOR THE SELECTIVE ABSORPTION OF GALLIC ACID FROM AQUEOUS SOLUTIONS

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Abstract: *Molecular imprinting represents an innovative method for designing materials with molecular memory, consisting of cavities bearing the shape and size of a template molecule. The cavities are highly specific towards the molecule that imprints the polymer, making molecularly imprinted materials suitable for use in separations. In this work, a new ecological method of alternative molecular imprinting to design imprinted poly (vinyl alcohol) films has been proposed. Gallic acid has been used as template molecule. To demonstrate the formation of the active cavities in the polymeric matrix, fluorescence microscopy as well as studies of gallic acid sorption and desorption have been performed.*

Key words: *molecular imprinting, poly (vinyl alcohol), gallic acid, fluorescence microscopy, absorption kinetic.*

1. Introduction

Molecular imprinting is a method to introduce molecular recognition sites into polymeric materials.

Traditional molecular imprinting involves the formation of a complex (ionic, hydrogen bonded or covalent) between the template molecule (the molecule which "imprints" the polymer) and the monomer. In the second step, the complex is polymerized and in the third step, the template is removed from the resulting polymer matrix, leaving specific binding sites that remember the dimensions and the structure of the template molecule [1-6], [12].

When the template molecule or other similar chemical species are in contact to the imprinted material, the recognition sites incorporate them preferentially, determining their separation from mixtures with other compounds [9], [10]. Among the most frequently used monomers we can mention carboxylic acids (e.g. acrylic, methacrylic and vinyl benzoic acids), sulphonic acids and heterocyclic bases (e.g. vinylpyridines, vinylimidazoles) [7-15].

Currently, great efforts are being made to broaden the range of templates that can be used and to improve the specificity of 'non-covalent' molecularly imprinted polymers [MIP]. The first systems developed were not very selective [1]. It was only once the experimental conditions had been optimized (conditions of synthesis, host/guest ratios, eluant etc.) that Mosbach et al. achieved materials with selectivities similar to those obtained with the covalent approach [13-25]. Owing to the weakness of the interactions occurring, a large excess of functional monomer must be added to shift the equilibrium towards

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formation of the complex (typical monomer: guest ratios are 4:1) [15-20]. This leads to the formation, inside the imprinted network, of sites with different affinities for the molecule to be recognized (polyclonality) and lowers the specificity of the MIP. In chromatographic applications, for instance, this causes broadening of the peaks and decreased resolution. To overcome this problem, new monomers interacting more specifically with the template at several points have been developed for addition in stoichiometric quantities [8-20].

In this work, a new technique of molecular imprinting has been used to prepare imprinted PVA [poly (vinyl alcohol)] towards the selective absorption of gallic acid [GAL] from aqueous solutions. Due to the hydrogen bondings generated by the -OH groups, PVA could generate interactions with many compounds, which means that it could be a suitable matrix for a wide range of template molecules [14-15].

Supplementary, it is a non-toxic, non-carcinogenic, biocompatible, biodegradable, water-soluble polymer, and consequently easy to handle and environment-friendly [11], [20].

The simplicity and the rapidity of the PVA imprinted matrix preparation, eliminating the polymerization step and the use of toxic volatile organic solvents for monomers, make our imprinting technique a promising trend line in the future of molecular imprinted materials obtaining.

Gallic acid (Figure 1) is an organic acid, also known as 3,4,5-trihydroxybenzoic acid, found in gallnuts, sumac, witch hazel, tea leaves, oak bark, and other plants, as free or as part of tannins [7-10]. Gallic acid seems to have anti-fungal and anti-viral properties. It also acts as an antioxidant and helps to protect cells against oxidative damage. Gallic acid was found to show cytotoxicity against cancer cells, without harming healthy cells. In homeopathic medicine it is used as a remote astringent in cases of internal haemorrhage, albuminuria and diabetes.

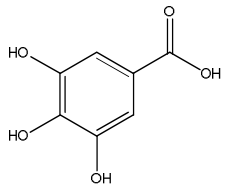

Fig. 1. *Gallic acid*

In this study we have used glutaraldehyde [GA] as crosslinker for PVA. Nevertheless GA is a toxic compound and in the field of separations it is necessary to avoid the existence of toxic unreacted crosslinker traces in the polymeric matrix. Taking into account that a reaction in gaseous phase leads to minimizing the unreacted cross-linker amount in the polymer matrix, avoiding the crosslinker sorption, in this paper we present our results concerning the imprinting of the PVA, crosslinked with GA in gaseous phase [10], [23].

The obtained imprinted PVA has been characterized by fluorescence microscopy and sorption kinetics (absorption and desorption) of GAL from aqueous solutions. The selectivity of the imprinted PVA film has been tested by comparing the amount of gallic acid absorbed with the amount of other related compounds, such as glycyrrhizinic acid (Figure 2).

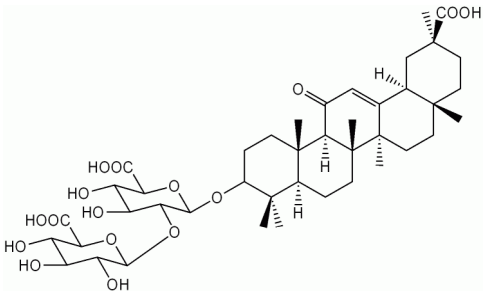

Fig. 2. *Glycyrrhizinic acid*

Also, the influence of the GAL: PVA ratio on the properties of the imprinted polymer has been studied, aiming a higher absorption yield.

2. Experimental

PVA 120-98 (1200 polymerization degree and 98% hydrolysis degree) was purchased from Chemical Enterprise Râşnov, Romania. Glutaraldehyde of 45% wt concentration was purchased from Sigma-Aldrich. Sulphuric acid 0.1N was of reagent grade. Gallic acid and glycyrrhizinic acid (Fluka) was of reagent grade.

The polymer solution was obtained by adding PVA powder into a determined volume of water and heating the mixture to 70 ^{0}C under magnetic stirring for 4 hours. The obtained solution had a solid content of 10%. Into 15 mL of PVA solution, at room temperature, certain amounts of gallic acid were added to obtain GAL: PVA ratios of 10%; 25%; 30% and 40% respectively. The solution was acidified with diluted sulphuric acid to $pH = 4$.

The films were prepared by PVA/GAL solution casting and solvent evaporation at room temperature.

The PVA films with GAL in composition, treated with the catalyst as mentioned above, were introduced into the crosslinking installation and placed over a recipient that contained a determined volume of 45% GA solution. The installation was connected to a vacuum pump, so that the film was in contact with GA vapours for 3 hours. Blank samples, without GAL in composition, were crosslinked following the same procedure.

The template molecule from the respective films was removed from the polymer by immersing them in a determined volume of distilled water for 5 days at room temperature. The immersing solution was replaced daily.

The imprinting testing was performed by comparing the amounts of gallic acid absorbed from aqueous solutions by the imprinted and non-imprinted films respectively.

The formation of the active cavities in the polymeric matrix was verified by fluorescence microscopy. The fluorescence microscope images were attained by a Motic AE31 inverted trinocular microscope equipped with a digital camera, using a violet excitation filter (λ_{max} = 455 nm), and a 40x objective with phase contrast. The imprinted PVA films were stained with a fluorescein fluorophore, by immersing them in a 0.1 mg/L fluorescein aqueous solution for 15 min.

The selectivity of the imprinted films was tested by comparing the amount of GAL absorbed in the polymeric matrix with the amount of glycyrrhizinic acid [GZ] absorbed. The sorption of GAL in the polymeric matrix was determined by the difference from the initial amount of GAL present in the solution and the amount of GAL from the solution at different time intervals, using the spectrophotometric method (GAL shows an absorption band at 262 nm, in the UV domain).

The absorbed GZ was determined following the same procedure, at 259 nm. A Carl-Zeiss UV-VIS spectrophotometer was used, with standard quartz cuvets of 1 cm optical path.

The gallic acid, respectively GZ solutions were of 0.001 g/L concentration and for each time interval the sample was immersed in a fresh solution, to maintain a convenient concentration gradient between the sterols from the solution and the sterols from the imprinted polymeric matrix.

Desorption of GAL from the polymeric matrix was studied by immersing the GAL loaded imprinted films in distilled water and by determining the amount of carboxylic acid desorbed at determined time intervals.

3. Results and Discussion

The absorption kinetic of GAL in the polymeric matrix is presented in Figure 3, for the imprinted films and reference, in terms of absorbed GAL (g), reported to 1 g of dry polymer [xerogel].

The experimental points have been fitted using a Weibull type equation (Eq. 1):

$$y = a - (a - b) \cdot e^{-(kx)^d}, \quad (1)$$

where a is the equilibrium value of the kinetic, b is the starting point of the kinetic (in this case 0); k and d are coefficients characteristic to the sorption/desorption kinetic (Tables 1 and 2).

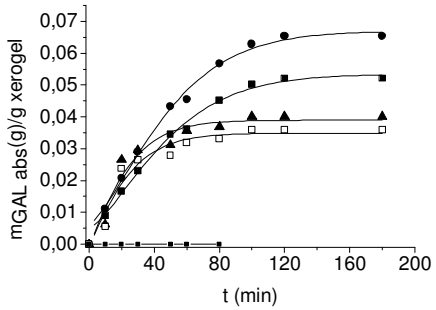

Fig. 3. *Absorption kinetic of GAL in the imprinted PVA films:* (○) - *non-imprinted PVA films;* (●) - *GAL: PVA = 10%;* (■) - *GAL: PVA = 25%;* (▲) - *GAL: PVA = 30%;* (□) - *GAL: PVA = 40%*

Table 1

Sorption kinetic fitting parameters

GAL: PVA [%]	***a***	***b***	***k***	***d***	R^2
10	0.066	0	0.018	1.39	0.995
25	0.053	0	0.018	1.39	0.983
30	0.038	0	1.185	0.04	0.913
40	0.034	0	1.185	0.04	0.953

As it can be seen from Figure 3, the impregnation has been successful. The imprinted films absorb a higher amount of GAL than the non-imprinted reference film.

The highest amount of GAL absorbed is recorded for the film with 10% GAL: PVA ratio. This could be due to the aggregation of the template molecules at higher template: polymer ratios and the deformation of the active cavities. Also, at higher template: polymer ratios insufficient crosslinking of the polymeric matrix could occur, due to a lower amount of present polymer.

The kinetics of GAL desorption from the imprinted films is presented in Figure 4, in terms of desorbed amount of GAL (g) reported to 1 g of xerogel. The experimental points have been fitted using a Weibull type equation.

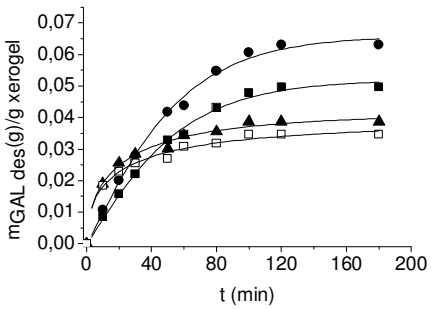

Fig. 4. *Desorption kinetic of GAL from the PVA imprinted films:* (●) - *GAL: PVA = 10%;* (■) - *GAL: PVA = 25%;* (▲) - *GAL: PVA = 30%;* (□) - *GAL: PVA = 40%*

Figure 5 shows the percentage release of GAL from the polymeric matrix as a function of time.

Table 2

Desorption kinetic fitting parameters

GAL: PVA [%]	***a***	***B***	***k***	***d***	R^2
10	0.065	0	0.02	1.14	0.993
25	0.051	0	0.02	1.15	0.936
30	0.034	0	1.185	0.04	0.907
40	0.032	0	0.029	0.27	0.908

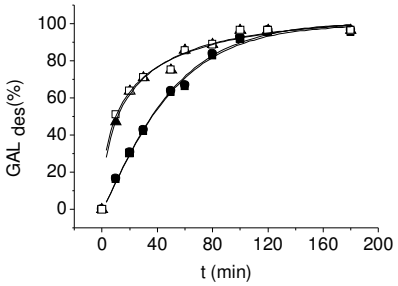

Fig. 5. *Percentage GAL release from the PVA imprinted films:* (●) - *GAL: PVA = 10%;* (■) - *GAL: PVA = 25%;* (▲) - *GAL: PVA = 30%;* (□) - *GAL: PVA = 40%*

As can be seen from Figures 4 and 5, the entire amount of GAL is desorbed from the polymeric matrix.

The average absorption/desorption rate in/from the imprinted polymeric matrix is calculated as the slope of the linear portion of the fitted kinetic, prior to equilibrium. Results are presented in Table 3:

Table 3

Sorption rate of GAL in/from the polymer

Process	**GAL:PVA [%]**	**Sorption rate · 10^4 [g GAL sorbed/g xerogel/min]**
Absorption	10	4.98
	25	6.30
	30	6.38
	40	5.14
Desorption	10	4.97
	25	5.51
	30	9.49
	40	8,27

As it can be seen from Table 3, as the concentration gradient between the template from the solution and the film increases, the absorption/desorption rate increases, except for the 40% GAL: PVA ratio, probably due to associations between template molecules and/or the deformation of the active cavities.

The GZ absorption kinetic into the GAL imprinted PVA film that showed the highest efficiency for GAL absorption is presented in Figure 6:

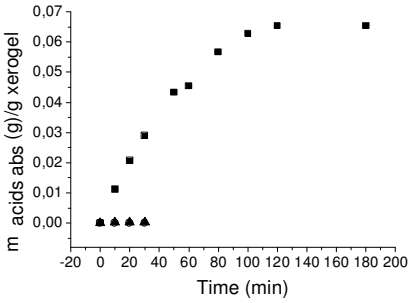

Fig. 6. *Absorption kinetic of carboxylic acids in the GAL:PVA = 10% imprinted film:* (○) - *Abs. GZ non-imprinted film*; (■) - *Abs. GAL;* (▲) - *Abs. GZ*

The selectivity factor of the imprinted films (K) can be calculated as the mass of GZ absorbed at equilibrium in the imprinted film (g) reported to the amount of GAL absorbed at equilibrium (g):

$$K = \left(1 - \frac{m_{GZ\ abs,eq}(g)}{m_{GAL\ abs,eq}(g)}\right) 100\,. \qquad (2)$$

The selectivity factors presented in Table 4 show that the obtained imprinted material is suitable for use in sterols solid phase extraction (SPE) assays.

Table 4

Selectivity factors for PVA imprinted films concerning GAL separation

Sample	***K* [%]**
Non-imprinted PVA	0
GAL: PVA = 10%	99.68

Fluorescence microscopy images of the four imprinted films with gallic acid as the template molecule are shown in Figures 7-11. As it can be seen the distribution of the fluorophore on the surface of the polymeric film shows that the ideal GAL: PVA ratio is 10%.

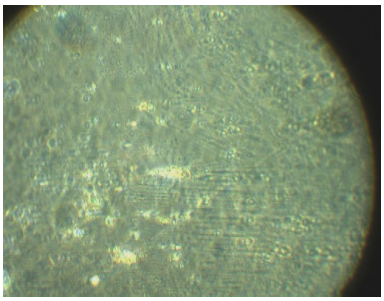

Fig. 7. *Fluorescence microscope image of the non-imprinted PVA film*

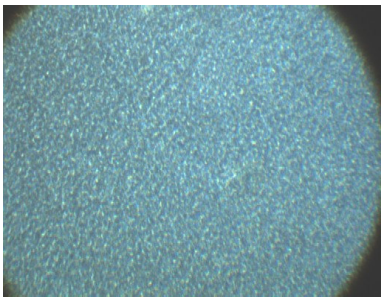

Fig. 8. *Fluorescence microscope image of the GAL:PVA = 10% imprinted film*

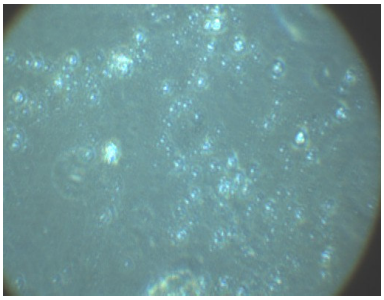

Fig. 9. *Fluorescence microscope image of the GAL:PVA = 25% imprinted film*

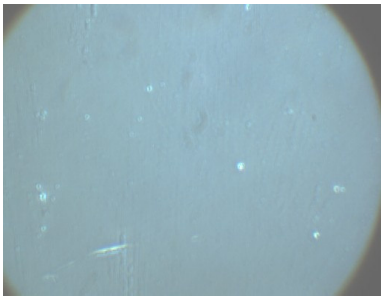

Fig. 10. *Fluorescence microscope image of the GAL:PVA = 30% imprinted film*

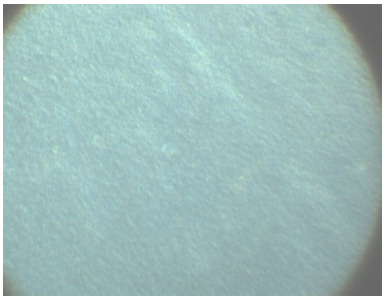

Fig. 11. *Fluorescence microscope image of the GAL:PVA = 40% imprinted film*

Above 10% percent, GAL molecules seem to associate, leading to the formation of non-uniform active cavities.

4. Conclusions

Imprinted films with gallic acid as the template molecules have been obtained and characterized. Sorption and desorption analyses have been performed. The results indicated that the impregnation of poly (vinyl alcohol) with gallic acid was successful. All the imprinted films absorb a higher amount of GAL than the non-imprinted PVA.

The imprinted films also show selectivity to GAL. Glycyrrhizinic acid amount absorbed into the GAL-PVA imprinted

films is lower than that of GAL.

The imprinted films are transparent, homogenous and have good resistance to solvent action, owing to crosslinking.

Taking into account the non-toxicity, biocompatibility, biodegradability of PVA and the possibility of obtaining molecular imprinted materials based on PVA/GAL, new applications in special fields (medicine, pharmacy, separation processes) could be developed.

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References

1. Arshady, R., Mosbach, K.: *Synthesis of Substrate-Selective Polymers by Host Guest Polymerization*. In: Makro-molecular Chemistry **182** (1981) No. 17, p. 687-692.
2. Byrne, M., Mark, E., Park, K., Peppas, N.: *Molecular Imprinting within Hydrogels.* In: Advanced Drug Delivery Reviews **54** (2002) No. 1, p. 149-161.
3. Cormack, P., Mosbach, K.: *Molecular Imprinting: Recent Developments and the Road Ahead*. In: Reactive and Functional Polymers **41 (**1999) No. 3, p. 115-124.
4. Dumitru, P., Lagowski, J., Lepage, C.J.: *Computationally Designed Monomers for Molecular Imprinting of Chemical Warfare Agents - Part V*. In: Polymer **47** (2006) No. 25, p. 8389-8399.
5. Flam, F.: *Molecular Imprints Make a Mark*. In: Science **263** (1994) No. 1, p. 1221-1222.
6. Hart, B.R., Shea, K.J.: *Synthetic Peptide Receptors: Molecularly Imprinted Polymers for the Recognition of Peptides Using Peptide-Metal Interactions.* In: Journal of American Chemistry Society **123** (2001) No. 1, p. 2072-2073.
7. Ian, A., Nicholls, J., Rosengren, J.P.: *Molecular Imprinting of Surfaces*. In: Bioseparation **10** (2002) No. 1, p. 301-305.
8. Jian-Du, L., Tian-Wei, T.: *Enantioselective Separation of Naproxen and Investigation of Affinity Chromatography Model using Molecular Imprinting.* In: Biochemical Engineering Journal **11 (**2002) No. 3, p. 175-179.
9. Lavine, B., David, J.W., Kaval, N., Nikhil, M., Leah, O., Mwangi, K.G.: *Swellable Molecularly Imprinted Polyn-(N-Propyl)Acrylamide Particles for Detection of Emerging Organic Contaminants using Surface Plasmon Resonance Spectroscopy*. In: Talanta **10** (2007) No. 1, p. 233-239.
10. Mehmet, O., Ridvan, S., Adil, D.: *Molecular Imprinted Particles for Lysozyme Purification*. In: Materials Science and Engineering: C **27** (2007) No. 1, p. 90-99.
11. Mosbach, K., Ramstrom, O.: *The Emerging Technique of Molecular Imprinting and its Future Impact on Biotechnology*. In: Biotechnology **14** (1996) No. 3, p. 163-170.
12. Nicholls, I.A., Rosengren, J.P.: *Molecular Imprinting of Surfaces.* In: Bioseparation **10** (2002) No. 4, p. 301-305.
13. Nicholls, I.A., Svenson, J.: *On the Thermal and Chemical Stability of Molecularly Imprinted Polymers.* In: Analytica Chimica Acta **435** (2001) No. 4, p. 19-24.
14. Paţachia, S.: *Blends Based on Poly* (*Vinyl Alcohol*) *and the Products Based on this Polymer*. In: Vasile, C., Kulshreshtha, AK. (Eds.), Handbook of Polymer Blends and Composites,

RAPRA Technology Ltd, Shrewsbury, UK, 2003.

15. Paţachia, S., Croitoru, C., Paixao, P.: *Comparision Between Crosslinking Degree of PVA Films Designed Using Different Crosslinking Techniques*. In: Buletinul Institutului Politehnic Iaşi, Secţia Ştiinţa şi Ingineria Materialelor **53** (2007), p. 1453-1690.
16. Rechichi, A., Cristallini, C., Vitale, U., Ciardelli, G., Barbani, N., Vozzi, G., Giusti, P.: *New Biomedical Devices with Selective Peptide Recognition Properties. Part 1: Characterization and Cytotoxicity of Molecularly Imprinted Polymers.* In: Journal of Cellular and Molecular Medicine **11** (2007) No. 6, p. 1367-1376.
17. Sellergren, B., Lepistö, M.: *Drug Assay using Antibody Mimics Made by Molecular Imprinting.* In: Journal of American Chemistry Society **110** (1988), p. 5853-5860.
18. Tada, M., Yasuhiro, I.: *Design of Molecular-Imprinting Metal-Complex Catalysts.* In: Journal of Molecular Catalysis A: Chemical **199** (2003) No. 1, p. 115-137.
19. Tanabe, K., Takeuchi, T., Matsui, J., Yano, K., Ikebukuro, K.: *2-(Trifluoromethyl)Acrylic Acid: A Novel Functional Monomer in Non-Covalent Molecular Imprinting.* In: Analytica Chimica Acta **343** (1997) No. 1, p. 1-4.
20. Yoshikawa, M.: *Molecularly Imprinted Polymeric Membranes.* In: Bioseparation **10** (2002) No. 5, p. 277-286.
21. Yoshimatsu, K., Reimhult, R., Krozer, A., Mosbach, K., Sode, K., Lei, Y.: *Uniform Molecularly Imprinted Microspheres and Nanoparticles Prepared by Precipitation Polymerization: The Control of Particle Size Suitable for Different Analytical Applications.* In: Analytica Chimica Acta **584** (2007) No. 1, p. 112-121.
22. Wang, H.I., Kobayashi, T., Fujii, N.: *Molecular Imprint Membranes Prepared by the Phase Inversion Precipitation Technique*. In: Langmuir **12** (1996) No. 3, p. 4850-4856.
23. Wulff, G., Karsten, K.: *Stoichiometric Noncovalent Interaction in Molecular Imprinting.* In: Bioseparation **10** (2002) No. 2, p. 257-276.
24. Wulff, G., Gross, T., Schoenfeld, R.: *High-Throughput Synthesis and Direct Screening for the Discovery of Novel Hydrolytic Metal Complexes*. In: Angewandte Chemie International Edition **36** (1996), p. 1962-1964.
25. Zhifeng, X., Xu, L., Daizhi, K., Fuxing, Z., Jianqiu, W.: *Exploiting β-Cyclodextrin as Functional Monomer in Molecular Imprinting for Achieving Recognition in Aqueous Media.* In: Materials Science and Engineering **28** (2008) No. 8, p. 1516-1521.