



Biodegradable colorimetric sensor based on starch/Alizarin Red S for naked-eye detection of free formaldehyde content in hair care products

F.Movahedi¹, M.Ezoddin², L.Adlnasab^{3,*}, M.Aminpoor²

1. Cellulosic Materials and Packaging Research Group, Chemistry and Petrochemistry Research Center, Standard Research Institute, Karaj, Iran

2. Department of Chemistry, Payame Noor University(PNU), Tehran, Iran

3. Chemistry Research Group, Chemistry and Petrochemistry Research Center, Standard Research Institute, Karaj, Iran

We present the construction of a biodegradable colorimetric sensor on the microtube lid for formaldehyde determination via naked-eye detection and /or UV-Vis spectrophotometry. Alizarin Red S (ARS) was subjected as the effective reagent for formaldehyde detection by incorporation in a thin film of starch. The sensor was accredited by the reaction of formaldehyde with ARS based on a color response from purple to yellow at pH 12. The sensor characterization was obtained by Fourier-transform infrared (FT-IR) spectroscopy, field emission scanning electron microscope (FE-SEM), and energy-dispersive X-ray (EDX) spectroscopy analytical methods. The effect of the main parameters on the detection of formaldehyde was studied and optimized. Under optimal conditions, the linearity range of colorimetric response was obtained in the concentration range of 0.15-10 mg L⁻¹ with a determination coefficient (R²) of 0.9923. A limit of detection (LOD) of 0.05 mg L⁻¹ and a relative standard deviation (RSD, n=5) of 1.2 % were achieved. This method presented a short response time (within 15 min) for the application as biosensing. Subsequently, the concentrations of formaldehyde in hair care products (hair shampoo and conditioner samples) were successfully obtained with good recoveries. This is an open access article which permits unrestricted reuse of the work in any medium, provided the original work is properly cited. [DOI: 10.22034/ASAS.2022.355540.1011] All rights reserved.

Keywords: Biodegradable sensor; Starch; Formaldehyde; Hair-care products; Naked eye

Manuscript submitted August 14, 2022; Accepted December 12, 2022.

Introduction

Formaldehyde is known as a natural organic compound and used as a precursor many materials and chemical compounds in industrial operations. Formaldehyde is used in different formulations, such as shampoo, conditioner, liquid hand washes, cosmetic products, and preservatives [1, 2]. Despite its widespread applications, it is known as a toxic substance with adverse effects on human health such as destruction of the central nervous system and disorders in the immune system [2, 3]. The World Health Organization (WHO) has declared limits of exposure to formaldehyde at a maximum of 0.08 mg L⁻¹ for 30 min [4]. Also, the toxicology studies of formaldehyde show a risk of detergents and cosmetic formulations with a minimum concentration of 0.05% free formaldehyde [2]. Therefore, there is a great deal of interest in detecting free/emitted formaldehyde. Some studies for the determination of formaldehyde have been achieved based on analytical methods including gas chromatography [5, 6], high-performance liquid

chromatography [7-10], and capillary electrophoresis [11]. However, these instruments are time-consuming along with high cost. Recently, colorimetric sensors have given significant attention due to selective and efficient naked-eye detection of different compounds. They indicate advantages including fast detection, assay of multiple analytes in a single experiment, low-cost and easy operation [12-16]. These sensors are designed based on the entrapment of colorimetric reagents within various supports, such as sol-gel matrices [4,17], porous glass [18,19], and molecularly imprinted polymer [20, 21]. However, some of these supports are non-degradable and expensive and can also provide environmental concerns [22]. To eliminate these drawbacks, biodegradable films based on natural polymers are applied to obtain simple colorimetric sensors. Starch is the most abundant polymeric carbohydrate composed of numerous glucose units that is considered as biodegradable support due to its non-toxic nature, high biodegradability, and cost-effectiveness [22-24]. Given the functional groups on the starch molecule, it can increase the number of available active sites for ad-

* e-mail: laleh_adlnasab@yahoo.com

sorption [25, 26]. In the present work, we developed a green sensor based on the incorporation of alizarin red S (ARS) into the thin film of starch to detect the formaldehyde in hair care products (hair shampoo and conditioner samples) by the naked eye or the spectrophotometer. ARS as an anthraquinone dye with hydroxyl groups was introduced as a colorimetric reagent and provided a color change at different pH levels. The results showed that the synthesized sensor is suitable for the quantitative detection of formaldehyde, as its color changes are easily distinguished by the naked eye. The proposed biodegradable colorimetric sensor has high selectivity and sensitivity, cost-effective and portable detection in real samples.

Experimental

Materials

All reagents used were analytical purity. Tapioca starch was purchased from a local supermarket in Tehran-Iran. ARS, glycerol, formaldehyde solution (37 %), NaCl, NaOH, and HCl were obtained from Merck (Darmstadt, Germany). In order to prepare water for the solutions, a Milli-Q purification system was applied. The working solutions of formaldehyde were made by a proper diluting of the stock solution in ultrapure water daily.

Instruments

Formaldehyde detection was performed by a UV-Vis spectrophotometer (PerkinElmer Lambda 35: USA). A digital pH meter (Mettler Toledo, M225, Switzerland) was used for the pH measurements. Fourier-transform infrared (FT-IR) spectroscopy of Bruker Vertex 70 spectrometer (Germany) was used to study the functional groups of the sensor in the frequency range of 400–4000 cm^{-1} by pelletizing a homogenized film. The morphology of the sensor was performed by field emission scanning electron microscope (FE-SEM) (MIRA3 TESCAN) along with energy-dispersive X-ray spectroscopy (EDX) to obtain elemental compositions.

Preparation of the biodegradable starch/ ARS sensor

First, 0.5 g of tapioca starch was taken into a beaker and dispersed in 10 mL of ultrapure water. Then, 0.2 g of glycerol was dissolved into the mixture and heated at 100 °C along with stirring to gelatinize the starch. After that, a clear viscous solution was obtained. To prepare the films containing the reagent, 0.02 g of ARS was added to 8 mL of the prepared starch and a few drops of 1 mol L^{-1} NaOH was added to the mixture. Then, the mixture was stirred for 15 min to obtain a homogeneous solution. Subsequently, one drop of this mixture was transferred into the microtube lid to make a thin film. The microtube lid was dried in an oven at 30 °C for 1 h.

Sample preparation

Two commercial hair care products containing hair shampoo and conditioner samples were purchased from a local market (Tehran, Iran). The labels of these hair care products showed the presence of formaldehyde. A portion of 1 g of each sample (hair shampoo or conditioner samples) was taken into a 100 mL volumetric flask and diluted with deionized water to a final volume. After shaking, 2 mL of the samples with pH adjusted were transferred to the test microtube.

Evaluation of the sensor for formaldehyde determination

To evaluate the sensor, 2 mL of the standard solution of formaldehyde in the concentration range of 0.15 to 10 mg L^{-1} was added to the microtube and the cap was quickly closed onto the tube. After shaking for 15 min, a color change was observed due to the reaction of the formaldehyde with ARS under basic conditions. Finally, the absorbance of formaldehyde in the solution was determined by the UV-Vis spectrophotometer at the wavelength of 425 nm.

Result and discussion

Characterization of sensor

The FE-SEM images of the colorimetric sensor before and after the addition of the reagent into the film are shown in Figure 1 (a-b) at 10000 magnification. As seen in Fig.1a, a smooth surface was found in the film without ARS, while the starch film incorporated with ARS had a heterogenous structure (Figure 1b). Thus, the differences observed in the morphology between the two images can be attributed to the presence of the reagent in the sensor structure.

The IR spectra of pure starch, ARS, and sensor were assessed by FTIR analysis and shown in Figure 2. A broad peak centered at 3000–3500 cm^{-1} was attributed to the stretching vibration of free, inter, and intra-molecular bound hydroxyl groups in the starch, ARS, and sensor. The broad band of the O–H stretching band in the native starch, decreased after the reaction with ARS. The shape changes occurring in the –OH stretching band showed that the ARS was attached to the starch and replaced with the water molecules. Some peaks at 1350-1550 cm^{-1} were related to stretching vibrations of multiple bonded C=O and aromatic C=C bonds in the ARS. The absorption intensities of peaks attributed to the C=O and C=C groups in ARS were significantly decreased in the synthesized sensor. All of these results confirmed a successful reaction of ARS with the film. The absorption peaks from 1149 to 934 cm^{-1} were related to C–O vibrations of amylopectin from the starch and ARS. The peaks at 857 and 759 cm^{-1} were attributed to the skeletal stretching of the starch. In the FT-IR spectrum of sensor other peaks were observed due to the interaction ARS and the starch. Several peaks

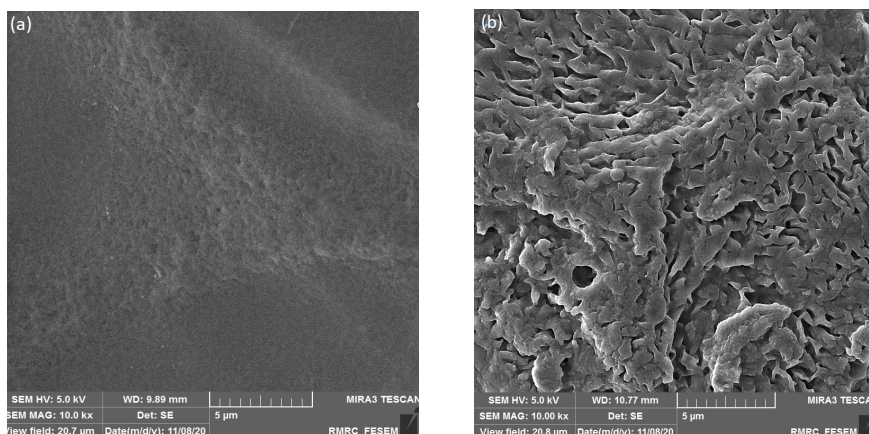


Figure 1- FE-SEM images of the biodegradable colorimetric film (a) without reagent at 10,000X and (b) with reagent at 10,000X

at $1420-1500\text{ cm}^{-1}$ in ARS and sensor can be assigned to the combination of vibrations of ether C–C, C–OH, C–O, or C–H groups in ARS. The broad peak around $1000-1400\text{ cm}^{-1}$ ascribed to the vibration of S–O groups in ARS, and also observed in the FT-IR spectrum of the sensor, but in lower transmittance.

Elemental mapping and EDX analysis were employed to verify the composition of the sensor.(Fig.3). The mapping image and EDX spectrum in Fig.3a shows the presence of carbon and oxygen percentages originated from the starch. An EDX spectrum of the sensor and the mapping image were shown in Fig.3b in which C (71.12%), O (26.19%), and S (1.67%) elements present in the sensor structure. The presence of sulfur and an increase in the amount of carbon in the sensor structure confirmed the interaction of ARS with the starch.

Effect of pH

The pH-dependent experiments for the adsorption of formaldehyde on the sensor were adjusted at different pH levels. As the sensor was exposed to different pH levels (1-12), color changes were observed from dark purple to yellow (Figure 4). With increasing pH up to 12, the intensification of the yellow color and the absorbance values increased. It can be attributed to the

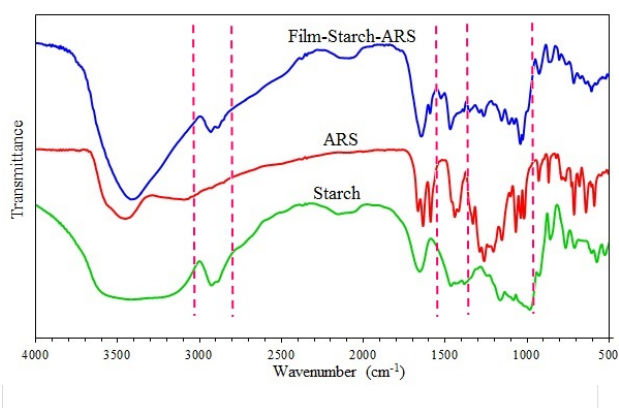


Figure 2- FT-IR spectra of pure starch, ARS, and Starch/ARS samples

adsorption of formaldehyde on the sensor due to the hemiacetal and acetal formation between formaldehyde and the functional groups of the ARS (Figure 5). The reaction of formaldehyde with ARS under the basic conditions is based on the nucleophilic addition of the hydroxyl group of ARS to the carbonyl group of formaldehyde followed by hydrogen transfer from oxygen

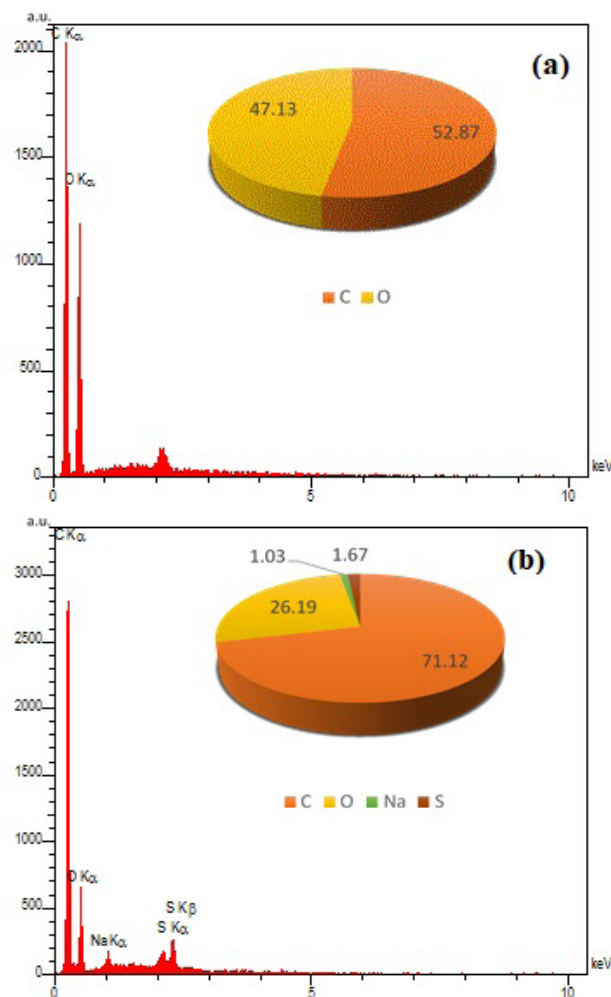


Figure 3- Typical EDX images on (a) film without reagent and (b) sensor

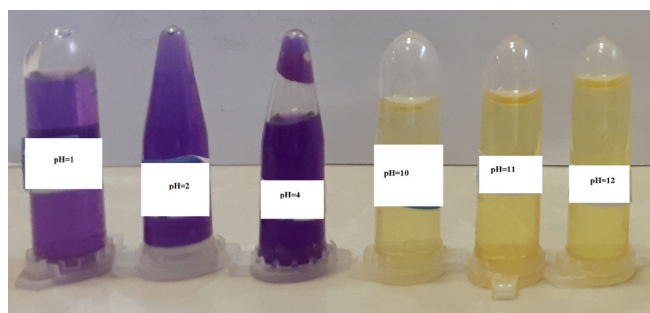


Figure 4- Effect of pH on the adsorption of formaldehyde on the sensor

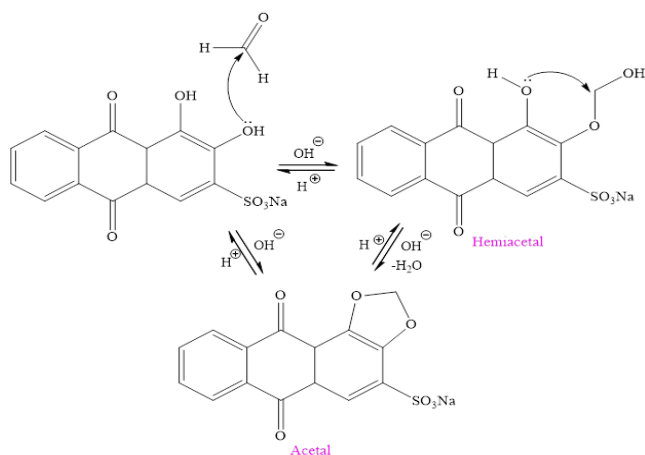


Figure 5- Mechanism of the interaction between ARS and formaldehyde

to oxygen. In this sense, the hemiacetal is formed while the other hydroxyl groups in ARS cause the formation of acetal by removing the water formed during the reaction. As a result, the reaction can proceed toward the formation of a five-membered acetal ring, fused to the main skeleton of the ARS resulting in the color change of the sensor. Therefore, pH 12 was selected for all further experiments.

Effect of initial formaldehyde concentration and naked-eye detection

The effects of initial formaldehyde concentrations on the colorimetric sensitivity of the sensor were tested in the range from 0 to 5 mg L⁻¹. As shown in Figure 6, significant color changes were easily observed by the naked eye detection. It was obvious that the absorbance increased with increasing the initial formaldehyde concentration up to 1.5 mg L⁻¹ using a constant amount of ARS (1 drop of the sensor). At high concentrations of formaldehyde (1.5-5 mg L⁻¹) and a constant amount of the ARS (1 drop of the sensor), the color intensity gradually decreased in line due to the shortage of the reagent diminishing the reaction with formaldehyde. In order to use high concentrations of formaldehyde 2 drops of the sensor were required.

Effect of reaction time

In order to achieve maximum adsorption, the effect of reaction time was also investigated. It indicated that

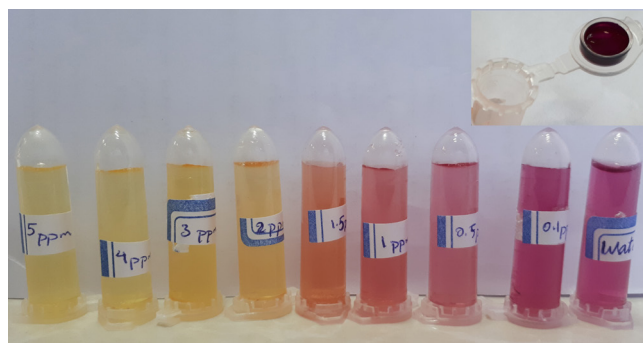


Figure 6- Effects of initial formaldehyde concentrations on the colorimetric sensitivity of sensor

with increasing the reaction time up to 5 min, the absorbance value of formaldehyde increased and approximately 50% of formaldehyde was reacted. The fast reaction rate during the initial times can be attributed to the fast diffusion of formaldehyde from the solution into the sensor due to the presence of many unloaded active sites, which gradually saturated up to 15 min, followed by a steady state. Therefore, equilibrium time was obtained in 15 min.

Effect of ionic strength on formaldehyde adsorption

The effect of ionic strength on formaldehyde adsorption was studied with the addition of 0-10% of NaCl salt. The results demonstrated that an increase in the ionic strength decreased the adsorption efficiency. It can be attributed to the decrease in the formaldehyde aggregation as a result of the salt effect and the competition of Cl⁻ with the formaldehyde for the ion exchange over the sensor. Therefore, the strategy of no salt addition was used.

Analytical performance and method validation

The validation of the method was performed against UV-Vis measurements in the presence of different concentrations of formaldehyde (Table.1). The linear range of formaldehyde concentration was 0.15-10 mg L⁻¹ with the determination coefficient (R²) of 0.9906. The limit of detection (LOD) and limit of quantification (LOQ) were obtained based on 3 and 10 Sd/m, respectively, where Sd and m were the standard deviations of the blank signal (n = 10) and the slope of the calibration plot respectively. The LOD and LOQ were determined to be 0.05 mg L⁻¹ and 0.15 mg L⁻¹, respectively. The reproducibility sensor based on the relative standard deviation (RSD %, n=5) of the spiked sample containing 5 mgL⁻¹ of formaldehyde was calculated to be 1.2 %

Real sample analysis

The performance of the sensor was evaluated for determination of the formaldehyde concentration in the shampoo and conditioner samples. According to the

Table 1- Analytical performance of the proposed sensor for the detection of formaldehyde

Analyte	Detection	LOD (mg L ⁻¹)	LOQ (mg L ⁻¹)	LR (mg L ⁻¹)	R ²	RSD (n=5) (%)
Formaldehyde	UV-Vis	0.05	0.15	0.15-10	0.9906	1.2
	Naked eye	0.5	1.5	-	-	1.4

obtained results in Table.2, the average concentrations of formaldehyde in hair shampoo and conditioner samples were acquired to be 13.3 and 20.5 µg kg⁻¹, respectively. Also, all the samples were spiked at different concentrations of the formaldehyde (10-50 µg kg⁻¹) to assess the accuracy based on the recovery. The relative recovery values obtained were determined as follows;

$$RR\% = \frac{C_{found} - C_{real}}{C_{added}} \times 100$$

Where C_{found}, C_{real}, and C_{added} demonstrate the found concentration of the formaldehyde after adding a known amount of standard to real samples, the concentration of the formaldehyde in the real sample, and a standard

solution spiked in the real sample, respectively. According to the results in Table.2, RR% was found to be 94.0% to 98.6% with RSD values between 1.1% and 2.1% (n = 5).

Comparison of the proposed method with other methods

A comparison of the proposed method with different methods for formaldehyde detection indicated in Table 3. In comparison with other methods, it has a short reaction time, low LOD and LOQ along with low RSD. In brief, the proposed sensor is fast and economical with simple synthesis, which can be applied successfully to determine formaldehyde in different matrices.

Table 2- Concentration of formaldehyde in hair shampoo and conditioner samples with spectrophotometer

	Added formaldehyde (µg g ⁻¹)	Found (µg g ⁻¹)	RR (%)
Tap water	0	-	-
	10	9.6 (2.1) ^a	96.0
	50	48.7 (1.2)	97.4
Hair shampoo	0	13.3 (1.6)	-
	10	22.7 (1.4)	94.0
	50	62.6 (1.1)	98.6
Conditioner	0	20.5 (1.4)	-
	10	30.1 (1.3)	96.0
	50	68.9 (1.1)	96.8

^aRSD%(n=3)

Table.3. Comparison of the proposed method with different methods for the detection of formaldehyde

Method	Detection	LOD (mg L ⁻¹)	LOQ (mg L ⁻¹)	RSD (%)	Reaction time (min)	Reference
Colorimetric sensor	Spectrophotometer /Naked eye	0.05-0.5	0.15-1.5	1.2	15	This work
Sol-gel-sensor	Spectrophotometer	0.03	-	4.6-6.3	360	[4]
Gas diffusion microextraction	Spectrophotometer	0.15	0.5	1.7-5.60	4	[27]
Colorimetric film	DIC	0.7	2.3	<4.2	-	[22]
Spectrophotometric method(colored reaction)	Spectrophotometer	0.290	0.88	1.02-2.73	35	[28]
Colorimetric film	Spectrophotometer	5	16.8	0.12-1.21	5	[29]

Conclusion

A biodegradable sensor was developed by incorporation of ARS into a starch thin film for the colorimetric determination of the concentration of formaldehyde in hair care products. The sensor obtained onto the micro-tube lid showed to be cost-effective and portable along with in-tube detection by adding the sample solutions directly. This sensor exhibited a naked-eye detectable color response from purple to yellow at a basic media through the reaction ARS and formaldehyde. A low detection limit (0.05 mg L⁻¹) along with the wide linear range in the calibration curve was constructed. The proposed method has benefits including simplicity, low toxicity, and low consumption of the reagent along with a short response time (within 15 min) for the application as biosensing. Also, the combination of this sensor with a spectrometer can provide a powerful method for the sampling and analysis of formaldehyde in different matrices.

Acknowledgments

Support of this investigation by the Standard Research Institute (Karaj, Iran) is gratefully acknowledged.

Conflict of Interest

It is announced by authors that there are no conflicts of interest.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article

References

- [1] Lavilla I, ; Cabaleiro N, Pena F, de la Calle I, Bendicho C. Ultrasound-assisted emulsification microextraction with simultaneous derivatization coupled to fibre optics-based cuvetteless UV-vis micro-spectrophotometry for formaldehyde determination in cosmetic samples. *Anal. Chim. Acta*, 2010, 674, 59–63.
- [2] Gholami A, ; Mohsenikia A, Masoum S. Determination of Very Low Level of Free Formaldehyde in Liquid Detergents and Cosmetic Products Using Photoluminescence Method. *J Anal Methods Chem*, 2016 DOI: 10.1155/2016/1720530
- [3] Chang S.M, ; Hu S.C, Shiue A, Lee P.Y, Leggett G. Adsorption of silver nano-particles modified activated carbon filter media for indoor formaldehyde removal. *Chem. Phys. Lett*, 2020, 757, 137864
- [4] Bunkoed O, ; Davis F, Kanatharana P, Thavarungkul P, Higson S. P.J. Sol-gel based sensor for selective formaldehyde determination. *Anal. Chim. Acta*, 2010, 659, 251–257
- [5] Hopkins J.R, ; Still T, Al-Haider S, Fisher I.R, Lewis A.C, Seakins P.W, A simplified apparatus for ambient formaldehyde detection via GC-pHID. *Atmos. Environ*, 2003, 37, 2557–2565.
- [6] Yeh T.S, ; Lin T.C, Chen C.C, Wen H.M. Analy-

sis of free and bound formaldehyde in squid and squid products by gas chromatography–mass spectrometry. *J. Food Drug Anal*, 2013, 21, 190–197.

[7] Büldt A, ; Lindahl R, Levin J.-O, Karst U. A diffusive sampling device for the determination of formaldehyde in air using N-methyl-4-hydrazino-7-nitrobenzofurazan (MNBDH) as reagent *J. Environ. Monit*, 1999, 1, 39–43.

[8] Wahed P, ; Razzaq M. A, Dharmapuri S, Corrales M. Determination of formaldehyde in food and feed by an in-house validated HPLC method. *Food Chem*, 2016, 202, 476–483.

[9] Wang H, ; Ding J, Du X, Sun X, Chen L, Zeng Q, Xua Y, Zhang X, Zhao Q, Ding L. Determination of formaldehyde in fruit juice based on magnetic strong cation-exchange resin modified with 2,4-dinitrophenylhydrazine. *Food Chem*, 2012, 131, 380–385

[10] Lü C, ; Huang C, Chen M, Xie W, Chen X. Determination of free formaldehyde in cosmetics by precolumnderivatization, extraction inhibition and high performance liquid chromatography. *Chin. J. Chromatogr* 2012, 30, 1287–1291

[11] Rocha F.R, ; Coelho G.H.G, Lopes M.L.A, Carvalho L.F.R, Fracassi da Silva J.A, do Lago C.L, Gutz I.G.R. Environmental formaldehyde analysis by active diffusive sampling with a bundle of polypropylene porous capillaries followed by capillary zone electrophoretic separation and contactless conductivity detection, *Talanta*, 2008, 76, 271–275.

[12] Ding Y, ; Zhu W, Xu Y, Qian X. A small molecular fluorescent sensor functionalized silica microsphere for detection and removal of mercury, cadmium, and lead ions in aqueous solutions. *Sens. Actuators B Chem*, 2015; 220, 762–77

[13] Kangas M.J, ; Burks R. M, Atwater J, Lukowicz R. M, Williams P, Holmes A. E. Colorimetric Sensor Arrays for the Detection and Identification of Chemical Weapons and Explosives. *Crit Rev Anal Chem*, 2017, 47, 138–153

[14] Hajilari F, ; Farhadi K, Eskandari H, Allahnouri F, Application of Cu/porous silicon nanocomposite screen printed sensor for the determination of formaldehyde. *Electrochim. Acta*, 2020, 355, 13675

[15] Wang X, ; Li Y, Li, Yu J, Al-Deyab S. S, Ding B. Equipment-free chromatic determination of formaldehyde by utilizing pararosaniline-functionalized cellulose nanofibrous membranes *Sens. Actuators B Chem*, 2014, 203, 333–339.

[16] Dolai B, ; Hazarika S. I, Giri S. Atta A. K, Selective and sensitive colorimetric naked-eye detection of Cu²⁺ ion by a triazole-linked glucofuranose derivative in aqueous medium. *Inorganica Chim. Acta*, 2018, 483, 496

- [17] Choodum A, Kanatharana P, Wongniramaikul W, NicDaeid N, A sol-gel colorimetric sensor for methamphetamine detection. *Sens. Actuators B Chem*, 2015, 215, 553-560
- [18] Maruo Y. Y.,; Nakamura J, Uchiyama M, Higuchi M, Izumi K, Development of formaldehyde sensing element using porous glass impregnated with Schiff's reagent. *Sens. Actuators B Chem*, 2008,129, 544–550.
- [19] Izumi K.,; Utiyama M, Maruo Y. Y. Colorimetric NO_x sensor based on a porous glass-based NO₂ sensing chip and a permanganate oxidizer, *Sens. Actuators B Chem*, 2015, 216,128-133
- [20] Feng L.,; Liu Y, Zhou X, Hu J, The fabrication and characterization of a formaldehyde odor sensor using molecularly imprinted polymers. *J. Colloid Interface Sci*, 2005, 284,378–382.
- [21] Deng H.,; Wang B., Wu M, Deng B, Xie L, Guo Y, Rapidly colorimetric detection of caffeine in beverages by silver nanoparticle sensors coupled with magnetic molecularly imprinted polymeric microspheres. *Int. J. Food Sci. Technol*, 2019, 54, 202-211.
- [22] Wongniramaikul W.,; Limsakula W, Choodum A, A biodegradable colorimetric film for rapid low-cost field determination of formaldehyde contamination by digital image colorimetry. *Food Chem*, 2018, 249, 154-161.
- [23] Oluwasina O.O.,; Olaleye F.K, Olusegun S.J, Oluwasina O.O, Mohallem N.D, Influence of oxidized starch on physicochemical, thermal properties, and atomic force micrographs of cassava starch bioplastic film. *Int. J. Biol. Macromol*, 2019; 135, 282–293
- [24] Shalviri A, ; Liu Q, Abdekhodaie M. J, Wu X. Y, Novel modified starch–xanthan gum hydrogels for controlled drug delivery: Synthesis and characterization. *Carbohydr. Polym*, 2010, 79, 898–907
- [25] Naushad M, ; Ahamad T, Sharma G, Al-Muhtaseb A. H, Albadarin A.B, Alam M.M, AlOthman Z.A, Alshehri S.M, Ghfar A.A, Synthesis and characterization of a new starch/SnO₂ nanocomposite for efficient adsorption of toxic Hg²⁺ metal ion. *Chem. Eng. J*, 2016, 300, 306–316.
- [26] Mohiuddin I.,; Grover A, Singh Aulakh J, Malik A. K, Lee S. S, Brown R. J.C, Kim K.H, Starch-Mg/Al layered double hydroxide composites as an efficient solid phase extraction sorbent for non-steroidal anti-inflammatory drugs as environmental pollutants. *J Hazard Mater*, 2021, 401, 123782.
- [27] Lamarca R. S.,; Luchiari N. d. C, Bonjorno A. F, Filho J. P, Cardoso A. A, de Lima Gomes P. C. F, Determination of formaldehyde in cosmetic products using gas-diffusion microextraction coupled with a smartphone reader. *Anal. Methods*, 2019, 11, 3697-3705
- [28] Yasri N. G.,; Seddik H, Mosallb M.A, Spectrophotometric determination of formaldehyde based on the telomerization reaction of tryptamine. *Arab. J. Chem*, 2015, 8, 487-494.
- [29] Rovina K.,; Vonnice J. M, Shaera S. N, Yi S. X, Halid N. F. A. Development of biodegradable hybrid polymer film for detection of formaldehyde in seafood products. *Sens. Bio-Sens. Res*, 2020, 27, 100310