

1           **Hydrophilic magnetic ionic liquid for magnetic headspace**  
2           **single-drop microextraction of chlorobenzenes prior to thermal**  
3           **desorption-gas chromatography-mass spectrometry**

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10  
11           **Abstract**

12           A new, fast, easy to handle and environmentally friendly magnetic  
13           headspace single-drop microextraction (Mag-HS-SDME) based on a magnetic  
14           ionic liquid (MIL) as extractant solvent is presented. A small drop of the MIL 1-  
15           ethyl-3-methylimidazolium tetrakisothiocyanatocobaltate (II) ([Emim]<sub>2</sub>[Co(NCS)<sub>4</sub>])  
16           is located on one end of a small neodymium magnet to extract nine  
17           chlorobenzenes (1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-  
18           dichlorobenzene, 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, 1,3,5-  
19           trichlorobenzene, 1,2,3,4-tetrachlorobenzene, 1,2,4,5-tetrachlorobenzene and  
20           pentachlorobenzene) as model analytes from water samples prior to thermal  
21           desorption-gas chromatography-mass spectrometry determination. A  
22           multivariate optimization strategy was employed to optimize experimental  
23           parameters affecting Mag-HS-SDME. The method was evaluated under  
24           optimized extraction conditions (i.e., sample volume, 20 mL; MIL volume, 1 µL;  
25           extraction time, 10 min; stirring speed, 1500 rpm; and ionic strength, 15% NaCl  
26           (w/v)), obtaining a linear response from 0.05 to 5 µg L<sup>-1</sup> for all analytes. The

27 repeatability of the proposed method was evaluated at 0.7 and 3  $\mu\text{g L}^{-1}$  spiking  
28 levels and coefficients of variation ranged between 3 and 18% (n=3). Limits of  
29 detection were in the order of  $\text{ng L}^{-1}$  ranging from 4  $\text{ng L}^{-1}$  for 1,4-  
30 dichlorobenzene and 1,2,3,4-tetrachlorobenzene to 8  $\text{ng L}^{-1}$  for 1,2,4,5-  
31 tetrachlorobenzene. Finally, tap water, pond water and wastewater were  
32 selected as real water samples to assess the applicability of the method.  
33 Relative recoveries varied between 82 and 114% showing negligible matrix  
34 effects.

35

36 **Keywords:** magnetic ionic liquid, magnetic headspace single-drop  
37 microextraction, thermal desorption-gas chromatography-mass spectrometry,  
38 chlorobenzenes, water samples.

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40 **List of acronyms:** CV, coefficient of variation; DBB, dibromobenzene;  
41 DCB, dichlorobenzene;  $[\text{Emim}]_2[\text{Co}(\text{NCS})_4]$ , 1-ethyl-3-methylimidazolium  
42 tetrakisothiocyanatocobaltate (II); GC, gas chromatography; ILs, ionic liquids; IS,  
43 internal standard; LOD, limit of detection; LOQ, limit of quantification; LPME,  
44 liquid-phase microextraction; Mag-HS-SDME, magnetic headspace single-drop  
45 microextraction; MIL, magnetic ionic liquid; MS, mass spectrometry; PeCB,  
46 pentachlorobenzene; TCB, trichlorobenzene; TD, thermal desorption; TeCB,  
47 tetrachlorobenzene; TG, thermogravimetry.

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## 52 **1. Introduction**

53 Ionic liquids (ILs) are a group of organic salts with melting points at or below  
54 100 °C. ILs possess versatile and relevant physico-chemical properties  
55 (namely, low vapor pressure, good chemical and thermal stability,  
56 nonflammability, high ionic conductivity, wide electrochemical potential window,  
57 and good extractability for organic compounds and metal ions), being  
58 responsible of the vast number of applications in analytical chemistry, including  
59 liquid-phase microextraction (LPME) techniques [1]. The use of ILs in these  
60 techniques not only has helped to overcome problems associated with the use  
61 of organic solvents (i.e., instability, volatility and irreproducibility) [2], but also  
62 has enabled the development of new methods, such as temperature-controlled  
63 IL dispersive liquid-liquid microextraction [3] or in-situ IL formation dispersive  
64 liquid-liquid microextraction [4, 5], among others.

65 A novel subclass of ILs named magnetic ionic liquids (MILs) has been  
66 recently presented as new extractant solvents for LPME techniques in few  
67 reports [6–16]. MILs include a paramagnetic cation or anion in their structure  
68 and possess similar physico-chemical properties to ILs but, additionally, show  
69 response under the application of an external magnetic field (i.e., magnet) [17].  
70 Specifically in LPME techniques, the reported studies have been performed with  
71 MILs including  $[\text{FeCl}_4^-]$  [6–10],  $[\text{FeCl}_3\text{Br}^-]$  [8, 11],  $[\text{MnCl}_4^{2-}]$  [12, 13], Ni(II)  
72 hexafluoroacetylacetonate  $([\text{Ni}(\text{hfacac})_3])$  [14, 15] or Mn(II)  
73 hexafluoroacetylacetonate  $([\text{Mn}(\text{hfacac})_3])$  [16] anions. The resulting  
74 paramagnetic behavior of these solvents enhances their manipulation providing  
75 remarkable advantages. For example, time-consuming centrifugation step is  
76 avoided in dispersive liquid-liquid microextraction [18] since phases separation

77 is accomplished using an external magnetic field (i.e., magnet) [6–15], whereas  
78 in single-drop microextraction [19], the stability of the drop held by a small  
79 magnet is higher than the suspended drop in the needle tip of a syringe [8, 13,  
80 16]. The main drawback regarding the use of MILs as extractant phase could be  
81 related to the intrinsic hydrophilic nature and the hydrolytic instability of some  
82 halometallate-based MILs [17]. Thus, some investigations have addressed the  
83 synthesis and characterization of new hydrophobic and stable MILs suitable for  
84 the treatment of aqueous samples [8, 11–13]. In most of the reported works, a  
85 final dilution step of the enriched MIL drop [9, 10, 12, 13] or a back-extraction  
86 procedure [11] are included after extraction in order to achieve a suitable  
87 medium for instrumental analysis by graphite furnace atomic absorption  
88 spectrometry [9] or liquid chromatography coupled to different detection  
89 systems (e.g., diode array, fluorimetric or UV-vis detectors) [10–13].

90 The purpose of this work is to present for the first time a magnetic  
91 headspace single-drop microextraction (Mag-HS-SDME) method based on the  
92 thermally stable MIL 1-ethyl-3-methylimidazolium tetrakisothiocyanatocobaltate  
93 (II) ([Emim]<sub>2</sub>[Co(NCS)<sub>4</sub>]). This MIL possesses hydrophilic properties but, in  
94 headspace mode, the direct contact between the sample solution and the  
95 extractant phase is avoided and, therefore, also the limitations imposed by their  
96 miscibility. After Mag-HS-SDME, the enriched MIL drop was directly analyzed  
97 using thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS).  
98 This system has been previously employed to analyze the IL 1-hexyl-3-  
99 methylimidazolium hexafluorophosphate ([C<sub>6</sub>mim][PF<sub>6</sub>]) [20] and the MIL  
100 trihexyl(tetradecyl)phosphonium Ni(II) hexafluoroacetylacetonate  
101 ([P<sub>6,6,6,14</sub>][Ni(hfacac)<sub>3</sub>]) [14, 15], after HS-SDME and stir bar dispersive liquid

102 microextraction, respectively. In addition, other previous publication has  
103 reported the use of a static headspace TD system followed by GC-MS to  
104 analyze the MIL trihexyl(tetradecyl)phosphonium Mn(II)  
105 hexafluoroacetylacetonate ( $[P_{6,6,6,14}][Mn(hfacac)_3]$ ) after vacuum Mag-HS-  
106 [SDME \[16\]](#). The high boiling point of ILs and MILs provides advantages to  
107 perform stable and reproducible extractions in headspace mode whereas this  
108 lack of volatility dirties the GC system and even blocks the column in its direct  
109 injection. TD systems enabled the desorption of model analytes from the (M)ILs,  
110 while preventing the (M)ILs from entering the GC system. Analytes signal is  
111 expected to increase at higher desorption temperatures but the MILs used up to  
112 now show all of them limited thermal [stability \[14–16\]](#). Therefore, the  
113 investigation based on MILs with better thermal properties seems mandatory to  
114 extend the applicability of TD-GC-MS to less volatile analytes.

115 Nine chlorobenzenes were used as model analytes due to their volatility  
116 and good extractability in ILs [\[20–23\]](#). Chlorobenzenes are a class of pollutants  
117 released to the environment during manufacture of other chemicals and as a  
118 direct result of their application as deodorizers fumigants, degreasers,  
119 insecticides, herbicides, and defoliant [\[24, 25\]](#). Chlorobenzenes possess toxic  
120 and potential carcinogenic properties [\[24, 25\]](#), therefore, the control of their  
121 presence in water samples is of great interest.

122 To the best of our knowledge, this is the first time that  $[Emim]_2[Co(NCS)_4]$   
123 has been employed as extractant phase in an approach based on Mag-HS-  
124 SDME coupled to TD-GC-MS. Various parameters of the proposed extraction  
125 method have been optimized by the use of a multivariate optimization strategy.  
126 Finally, the aforementioned method was evaluated in order to demonstrate its

127 applicability to determine chlorobenzenes in real water samples.

128

## 129 **2. Experimental part**

### 130 **2.1. Reagents and water samples**

131 Target model analytes, namely 1,2-dichlorobenzene (1,2-DCB), 1,3-  
132 dichlorobenzene (1,3-DCB), 1,4-dichlorobenzene (1,4-DCB), 1,2,3-  
133 trichlorobenzene (1,2,3-TCB), 1,2,4-trichlorobenzene (1,2,4-TCB), 1,3,5-  
134 trichlorobenzene (1,3,5-TCB), 1,2,3,4-tetrachlorobenzene (1,2,3,4-TeCB),  
135 1,2,4,5-tetrachlorobenzene (1,2,4,5-TeCB), and pentachlorobenzene (PeCB),  
136 and 1,4-dibromobenzene (1,4-DBB) used as internal standard (IS) were all  
137 obtained from Riedel-de Haën (Seelze, Germany). Stock solutions of individual  
138 compounds ( $1000 \text{ mg L}^{-1}$ ), and mix stock solutions containing the nine  
139 chlorobenzenes ( $1$  and  $0.1 \text{ mg L}^{-1}$ ) were prepared in LC grade acetonitrile from  
140 Sigma-Aldrich (St. Louis, MO, USA) and stored at  $4 \text{ }^{\circ}\text{C}$  protected from light.  
141 Working solutions were daily prepared in ultrapure water (resistivity of  $18.2 \text{ M}\Omega$   
142  $\text{cm}$  at  $25 \text{ }^{\circ}\text{C}$ ) from a Millipore Direct System Q5<sup>TM</sup> purification system from  
143 Ibérica S.A. (Madrid, Spain). Reactive grade NaCl was obtained from ACS  
144 Scharlau (Barcelona, Spain).

145 The MIL [Emim]<sub>2</sub>[Co(NCS)<sub>4</sub>] was supplied by the Department of Inorganic  
146 Chemistry of the University of Rostock (Germany). All details regarding the  
147 synthesis have been previously published [26].

148 Tap water was collected from the water-supplied network of the lab in the  
149 Department of Analytical Chemistry, Nutrition and Food Sciences of the  
150 University of Alicante (Spain). Pond water was collected in San Vicente del

151 Raspeig (Alicante, Spain). Wastewater was from a wastewater treatment plant  
152 in A Coruña (Spain).

153

## 154 **2.2. Materials and instrumentation**

155 Rod shape NdFeB (Nd) magnets (N48, 3 mm diameter, 8 mm height) with a  
156 nickel-plated (Ni-Cu-Ni) coating from Supermagnete (Gottmadingen, Germany)  
157 were employed to support the drop of the MIL during Mag-HS-SDME (Fig. 1).  
158 After desorption, Nd magnets were rinsed with distilled water and acetone, and  
159 dry at 240 °C for 2 h before reused. Nd magnets were deposited in small glass  
160 beakers and introduced in the central part of the oven. Considering these  
161 cautions, no attraction with any metallic part of the oven was observed.

162 The sample compartment was a 22 mL glass vial with screw top (solid  
163 green Melamine cap and PTFE liner) from Supelco (Bellefonte, PA, USA).  
164 Sample solution was agitated during Mag-HS-SDME using a 1 cm length  
165 magnetic stir bar and a VWR® Advanced hot plate stirrer from VWR  
166 International (Radnor, PA, USA).

167 Thermogravimetric (TG) analysis was performed on a simultaneous TG-  
168 DTA system (model TGA/SDTA851e/SF/1100) from Mettler Toledo (Columbus,  
169 OH, USA). Measurements were done from 25 to 550 °C at a heating rate of 10  
170 °C min<sup>-1</sup> and under He atmosphere.

171 Magnetic susceptibility measurements were performed at 300 K in the  
172 magnetic field range -50 to 50 kOe using a MPMS XL (SQUID) magnetometer  
173 from Quantum Design (San Diego, CA, USA).

174 A Gerstel TDS 2 thermodesorption system equipped with a Gerstel CIS-4  
175 cooled injection system programmable temperature vaporization inlet from

176 Gerstel (Mülheim an der Ruhr, Germany) was used to carry out the TD process.  
177 A Gerstel TD glass tube (187 mm length, 4 mm I.D., 6 mm O.D.) and pesticide  
178 grade glass wool from Supelco were used to introduce the enriched MIL in the  
179 TD device (Fig. 1). This device was installed in a gas chromatograph (model  
180 6890N) coupled to a mass spectrometer (model 5973) both from Agilent  
181 Technologies (Santa Clara, CA, USA). A capillary column HP-5ms (5%  
182 diphenyl-95% dimethylpolysiloxane, 30 m × 0.25 mm I.D., 0.25 μm film  
183 thickness) from Agilent Technologies (J&W GC columns) was employed for  
184 separation.

185

### 186 **2.3. Magnetic headspace single-drop microextraction**

187 For Mag-HS-SDME, 20 mL of aqueous sample solution containing 15%  
188 NaCl (w/v) were placed in a glass vial. 1 μL of MIL was held on the bottom of a  
189 rode shape Nd magnet (the lower magnet) and fixed to the vial cap using  
190 another Nd magnet (the upper magnet). Then, the MIL was exposed to the  
191 headspace of the aqueous sample solution stirred at 1500 rpm for 10 min at  
192 room temperature. After extraction, the lower magnet maintaining the enriched  
193 MIL was carefully dropped into a TD glass tube by removing the upper magnet  
194 and TD-GC-MS analysis was carried out. Fig. 1 shows a scheme of the overall  
195 procedure.

196

### 197 **2.4. TD-GC-MS conditions**

198 The TD system was adjusted according to previously published works [20,  
199 27] as follows: splitless mode; desorption temperature, from 25 °C (0.5 min) to  
200 240 °C at 60 °C min<sup>-1</sup>; desorption time, 5 min; helium flow rate, 100 mL min<sup>-1</sup>;



201 and transfer line temperature, 300 °C. The desorbed compounds were  
202 cryofocused in the cooled injection system at 0 °C. Then, the temperature was  
203 rapidly increased at 12 °C s<sup>-1</sup> up to 250 °C, transferring the compounds to the  
204 GC column by operating in solvent vent mode for 1 min. The oven temperature  
205 was initially set at 40 °C for 2 min, followed by a ramp of 5 °C min<sup>-1</sup> up to 130  
206 °C, and then at 10 °C min<sup>-1</sup> to 240 °C (5 min). Helium (99.999%) was used as  
207 the carrier gas at a constant flow rate of 1 mL min<sup>-1</sup>. The MS detector voltage  
208 was set at 1700 V. Electron impact ionization was used with ionization energy of  
209 70 eV. The mass source and quadrupole were set at 230 and 150 °C,  
210 respectively. Measurements were taken with a solvent delay of 2 min and in  
211 selected ion monitoring (SIM) mode at the following *m/z* ratios: 146 from minute  
212 2 to 12 for dichlorobenzenes determination, 180 and 236 from minute 12 to 18  
213 for trichlorobenzenes and IS, 216 from minute 18 to 22 for tetrachlorobenzenes  
214 and 250 from minute 22 to the end for PeCB. Fig. 2 shows typical  
215 chromatograms after Mag-HS-SDME of a blank and a standard solution spiked  
216 at 0.7 µg L<sup>-1</sup> with chlorobenzenes.

217

218

## 219 **2.5. Data processing**

220 A multivariate optimization strategy was carried out to determine the  
221 optimum conditions for Mag-HS-SDME. The statistical software NEMRODW®  
222 (“New Efficient Methodology for Research using Optimal Design”) from LPRAI  
223 (Marseille, France) was used to build the experimental design matrix and  
224 evaluate the results. As response functions, the peak area of individual  
225 compounds was considered.

226

### 227 **3. Results and discussion**

#### 228 **3.1. MIL characterization**

229 [Emim]<sub>2</sub>[Co(NCS)<sub>4</sub>] has been deeply characterized in previous publications  
230 [26, 28]. Briefly, this MIL possesses good stability towards water and oxygen,  
231 good solubility in many solvents (e.g., water, acetonitrile, etc.) and low viscosity,  
232 even though doubly charged anion is present [26, 28]. Fig. S1 shows the  
233 magnetic susceptibility of the studied MIL at 300 K in the magnetic field range -  
234 50 to 50 kOe. The straight line obtained between the magnetic susceptibility  
235 and the applied magnetic field indicates the paramagnetic behavior of  
236 [Emim]<sub>2</sub>[Co(NCS)<sub>4</sub>] [29]. In addition, magnetic susceptibility was estimated from  
237 the slope of the linear fit to the data being 2.67 emu K mol<sup>-1</sup>, which it is similar to  
238 data previously reported in the literature for MILs containing the same type of  
239 anion [30].

240 Since a TD system was employed to analyze the MIL drop after Mag-HS-  
241 SDME, TG analysis was carried out in order to ensure that [Emim]<sub>2</sub>[Co(NCS)<sub>4</sub>]  
242 was not evaporated under employed temperature conditions and, therefore, did  
243 not reach the GC column. According to TG curve (Fig. S2), this MIL was very  
244 stable at temperatures lower than 250 °C, with a minimum loss of mass (i.e.,  
245 <5%) even at 300 °C. Thus, it was concluded that [Emim]<sub>2</sub>[Co(NCS)<sub>4</sub>] was  
246 suitable for the proposed analytical method.

247

#### 248 **3.2. Mag-HS-SDME multivariate optimization**

249 A multivariate optimization strategy was carried out to optimize the  
250 proposed Mag-HS-SDME method. Plackett-Burman design was considered for

251 screening purposes since a large number of factors could potentially affect  
252 extraction yield. The Plackett-Burman design is a fractional factorial design  
253 employed to study up to  $k=N-1$  factors in  $N$  runs, where  $N$  is a multiple of 4 [31].  
254 This design assumes that interaction between factors can be ignored so the  
255 main effects can be calculated with a reduced number of experiments [31].

256 On the basis of the literature and of the previous experience of the research  
257 group [21], the considered factors selected at two levels were: sample volume,  
258 MIL volume, extraction time, stirring speed and ionic strength (NaCl  
259 concentration). Extraction temperature is another key factor in some HS-SDME  
260 applications [32]. However, this factor was omitted in the present study since it  
261 showed non-significant effect for the extraction of chlorobenzenes in our  
262 previous works [21, 20]. Table S1 shows the experimental factors and levels  
263 considered in the Plackett-Burman design whereas Table S2 shows the matrix  
264 of experiments. The eight experiments were randomly performed using  
265 aqueous standards containing  $1 \mu\text{g L}^{-1}$  of target analytes. The peak area of  
266 each chlorobenzene was employed as response function in order to evaluate  
267 the effect of different factors over each individual compound.

268 The data obtained were analyzed by ANOVA and the results were  
269 visualized with the Pareto charts shown in Fig. 3 and Fig. S3. Fig. 3 shows the  
270 Pareto charts for 1,3-DCB, 1,3,5-TCB, 1,2,4,5-TeCB, and PeCB as  
271 representative compounds. Charts for 1,4-DCB, 1,2-DCB, 1,2,4-TCB, 1,2,3-  
272 TCB, and 1,2,3,4-TeCB are shown in Fig. S3 since they show similar results.  
273 The length of each bar was proportional to the influence of the corresponding  
274 factor, and negative and positive signals revealed whether the system  
275 responses decreased or increased, respectively, when passing from the lowest

276 to the highest level of the corresponding factor. A reference vertical line would  
277 indicate the significance of a factor with 95% of probability. However, the  
278 vertical line did not appear in any of the charts, meaning that effects were far  
279 from the significance level. Although none of studied factors had a significant  
280 effect on the system responses, negative and positive signals indicated the  
281 most convenient level at which each factor should be fixed. Sample volume,  
282 stirring speed and ionic strength showed positive effects. On the one hand,  
283 greater sample volume involved greater amount of analytes, and therefore the  
284 responses increased. In addition, headspace volume was reduced when  
285 increasing sample volume (22 mL glass vials were employed in all experiments)  
286 and, according to theoretical calculations, low headspace volumes maximize  
287 extraction efficiency [32]. On the other hand, high stirring speed and NaCl salt  
288 content promoted the transfer of analytes from the sample solution to the  
289 headspace due to a better diffusion and salting out effect [32]. MIL volume  
290 showed a negative effect. This fact revealed that, at working concentration, the  
291 amount of analytes extracted did not increase with extractant volume.  
292 Experimentally, it was interesting to notice that 1  $\mu\text{L}$  of MIL deposited onto the  
293 magnet almost like film, whereas 2  $\mu\text{L}$  had a more appreciable drop-shaped. In  
294 the former case (i.e., 1  $\mu\text{L}$ ), interfacial contact area between the headspace and  
295 the MIL could be higher than for 2  $\mu\text{L}$ , thus increasing extraction efficiency. On  
296 the other hand, this effect was not significant probably because of the closeness  
297 between the two studied levels. Higher volumes than 2  $\mu\text{L}$  could not be  
298 investigated because MIL drop spilled over the walls of the desorption tube  
299 when introducing the lower magnet, affecting desorption process and, therefore,  
300 repeatability between measurements. Finally, the effect of extraction time was

301 also negative revealing a rapid and effective mass transfer in the proposed  
302 Mag-HS-SDME system.

303 According to the results obtained from the Plackett-Burman design, the  
304 optimum conditions were finally established as follows: sample volume, 20 mL;  
305 MIL volume, 1  $\mu$ L; extraction time, 10 min; stirring speed, 1500 rpm; and ionic  
306 strength, 15% NaCl (w/v).

307

### 308 **3.3. Analytical figures of merit**

309 Calibration curve for each chlorobenzene was obtained by plotting the ratio  
310 of the peak area of the analyte to peak area of the IS versus concentration of  
311 the analyte under the optimum experimental condition. The concentration of IS  
312 (1,4-DBB) was maintained constant at 0.5  $\mu$ g L<sup>-1</sup> in all experiments. The main  
313 analytical parameters of the proposed method are summarized in Table 1.

314 The working range (from 0.05 to 5  $\mu$ g L<sup>-1</sup>) showed good linearity with  
315 correlation coefficients ranging from 0.988 to 0.999 (Table 1). Student's *t*-test  
316 was also applied to assess linearity [33], obtaining *t* calculated values from 12.8  
317 (*r*=0.988; *N*=6) for 1,2,3-TCB, to 50.0 (*r*=0.999; *N*=6) for 1,3-DCB, being in all  
318 cases higher than the *t* tabulated value (*t*<sub>0.05,4</sub>=2.78). Hence, the null hypothesis  
319 of non-linear correlation for a 5% significance level and 4 degrees of freedom  
320 was rejected. The sensitivity of the instrumental measurements estimated by  
321 the slope of the calibration curves ranged between (21.0±0.4) au  $\mu$ g<sup>-1</sup> L for 1,3-  
322 DCB and (60±3) au  $\mu$ g<sup>-1</sup> L for PeCB. As can be seen from Table 1, the method  
323 provided the highest sensitivity for high molecular weight compounds (i.e.,  
324 1,2,4,5-TeCB, 1,2,3,4-TeCB and PeCB), which possess highest volatilities  
325 according to Henry's law constants [34]. The repeatability of the measurements

326 was evaluated by three replicate analysis of aqueous standards spiked at 0.7  
327 and 3  $\mu\text{g L}^{-1}$ . The obtained coefficients of variation (CV) varied between 3 and  
328 18% (Table 1).

329 Limit of detection (LOD) and limit of quantification (LOQ) (Table 1) were  
330 estimated according to  $3S_b$  and  $10S_b$  criteria [33], respectively, where  $S_b$  is the  
331 standard deviation of the blank. LODs ranged from 4 to 8  $\text{ng L}^{-1}$ , whereas LOQs  
332 varied from 12 to 25  $\text{ng L}^{-1}$ .

333 For comparative purposes, the characteristics of previously reported  
334 methods including IL-based HS-SDME for chlorobenzenes determination in  
335 water samples are summarized in Table 2.

336 As can be seen, the proposed method showed comparable or lower LODs  
337 than previous works using shorter extraction times. In addition, extractions were  
338 performed at room temperature, thus saving energy. Finally, Mag-HS-SDME  
339 showed unique advantages related with the easy manipulation of the solvent  
340 with the magnet and the low volume employed (i.e., 1  $\mu\text{L}$ ), which reduced the  
341 generation of wastes.

342

### 343 **3.4. Analysis of water samples**

344 The applicability of the proposed method to determine chlorobenzenes in  
345 real water samples was evaluated studying matrix effects in tap water, pond  
346 water and wastewater. Preliminary analyses with the proposed method revealed  
347 that none of the selected water samples had initial detectable concentrations of  
348 target analytes. Thus, water samples were spiked at two different spiking levels  
349 (i.e., 0.7 and 3  $\mu\text{g L}^{-1}$ ) and analyzed by triplicate. Results are summarized in  
350 Table 3, showing the relative recoveries determined as the ratio of the signals

351 found after Mag-HS-SDME in real and ultrapure water samples spiked at the  
352 same concentration levels. CV values ranged between 1 and 23% and relative  
353 recoveries varied from 88 and 110%, 82 and 113%, and 84 and 114% for tap  
354 water, pond water and wastewater, respectively, indicating the absence of  
355 significant matrix effects for the determination of chlorobenzenes in the three  
356 investigated water samples.

#### 357 **4. Conclusions**

358 A new, fast and easy to handle Mag-HS-SDME method using thermally  
359 stable  $[\text{Emim}]_2[\text{Co}(\text{NCS})_4]$  as extractant solvent has been proposed in this work.  
360  $[\text{Emim}]_2[\text{Co}(\text{NCS})_4]$  is a water-miscible solvent but it has been successfully  
361 applied for the extraction of chlorobenzenes from water samples due to the  
362 direct contact between sample solution and extractant phase is avoided in  
363 headspace mode. The paramagnetic properties of  $[\text{Emim}]_2[\text{Co}(\text{NCS})_4]$  provided  
364 high stability to the MIL drop held by a Nd magnet and facilitated the  
365 manipulation. Additionally, the new MIL investigated extends the applicability of  
366 proposed system (i.e., Mag-HS-SDME-TD-GC-MS) to less volatile analytes. On  
367 the other hand, the commercial TD system allowed the sensitive and direct  
368 determination of analytes by GC-MS, without needing further dilution or back-  
369 extraction steps, opening new possibilities and broadening future applications  
370 for MIL-based LPME techniques.

371 The proposed method has been successfully applied for the extraction of  
372 chlorobenzenes from water samples as model analytical application. Results  
373 showed that comparable or even lower LOD values than previously reported  
374 works based on analogous systems (i.e., IL-based HS-SDME) were obtained  
375 with shorter extraction times and lower IL amount. Finally, our study

376 demonstrates the ability of the proposed method to determine trace levels of  
377 chlorobenzenes in real water samples.

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## 392 **Conflict of Interest**

393 The authors declare that they have no conflicts of interest

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