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Preconcentration of Total Thallium with a New Dispersive Suspended Droplet Microextraction Method and Its Determination by Flame Atomic Absorption Spectrometry

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A fast and centrifuge-less method called dispersive–restoration suspended droplet microextraction was developed for selective determination of trace amounts of Tl(III) by flame atomic absorption spectroscopy. In this method, 8-hydroxy quinoline was used as a complexing agent and toluene was used as an extracting solvent. The effective parameters for determination of Tl(III), such as type of extraction solvent, dispersive time, resting time, magnetic stirrer speed and time, and pH were optimized. Under the optimum conditions, the calibration curve was found to be linear in the range of 8.0-1000 $\mu\text{g l}^{-1}$ with $R^2 = 0.997$. The percent of relative standard deviation ($n = 15$), limit of detection, and enrichment factor were 1.4%, 3.1 $\mu\text{g l}^{-1}$ and 33, respectively. The method was successfully applied for determination of total thallium in real samples including water, nail and hair samples. The good recoveries in the range of 96-103% for real samples confirmed the accuracy and applicability of the present method.

Keywords: Thallium determination, Suspended droplet microextraction, Liquid phase microextraction, Flame atomic absorption spectroscopy

INTRODUCTION

The determination of toxic elements is important in environmental sample analysis and can provide important knowledge about human exposure information. The safeguarding of humans from pollutions depends on this knowledge. Thallium is one of the highly toxic pollutants that exists in the earth's outer crust in concentration of about 1.3 mg kg^{-1} [1] at two chemical forms of Tl(I) and Tl(III) with different toxicity levels [2]. Thallium is more toxic than other toxic elements such as mercury, lead, cadmium and copper which can increase risk of environmental poisoning [3]. However, determination of thallium is not an easy work because the natural contents in environmental samples are at ng g^{-1} levels or less [4].

Several methods have been reported for determination of thallium in environmental samples such as flame atomic

absorption spectroscopy (FAAS) [5], inductively coupled argon plasma mass spectrometry (ICP-MS)[6], graphite-furnace atomic absorption spectrometry [7], spectrophotometry [8] and potentiometry [9]. The FAAS and spectrophotometry methods are insensitive for determination of trace amounts of thallium, and matrix interference can also affect the correct determination of thallium. Graphite furnace atomic absorption spectrometry is more sensitive than the FAAS and spectrophotometry, however, in this method, a background correction is always necessary for quantitative work [5]. On the other hand, direct analysis with electrothermal atomic absorption analysis leads to many difficulties due to spectral and non-spectral interferences [10]. ICP-MS is a suitable technique for determination of thallium, but this technique requires very expensive instrument that increases the price per sample analysis [10].

FAAS is a relatively fast, cheap and simple method for determination of metal ions. The problems with low

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sensitivity and high limit of detection of this method can be overcome by using a preconcentration procedure before final determination. Thus, several methods for preconcentration of thallium were developed such as dispersive liquid-liquid microextraction (DLLME) [11,12], ultrasound assisted emulsification solidified floating organic drop microextraction (USAE-SFODME) [13], single drop microextraction (SDME) [14], preconcentration with chromosorb 105 resins [15], solid phase extraction (SPE) [16,17], dispersive solid phase extraction (DSPE) [18,19], ion-imprinting polymer [20-22] and egg shell membrane technology (ESM) [23]. However, because of its simplicity and speed, DLLME is a powerful method for preconcentration of analytes from sample solution. However, one of the major drawbacks of DLLME is time-consuming centrifugation step for collection of extracting phase [24,25]. Thus other liquid-phase microextraction (LPME) methods have been developed to diminish the drawbacks [24, 26]. Directly suspended droplet microextraction is a new microextraction centrifugation-less method introduced in 2006 [27]. The method is based on rotation of a single droplet of organic solvent on the surface of a sample solution. The rotation of the microdroplet around a symmetrical axis increases mass transfer rate inside the droplet. The method is simple and provides more flexibility in the choice of the operational parameters, especially amount of solvent and stirring frequency [28]. The main problem of the method is very long extraction time due to small interfacial area between extraction solvent and aqueous sample [29]. To overcome this drawback, Barfi et al. proposed a modified method named dispersive suspended-solidified floating organic droplet microextraction (DSDME) [30]. A combination of dispersive microextraction method and directly suspended method can be used for fast extraction of solute and collection of liquid without need to a centrifugation step.

Extraction Procedure

In this paper, we describe a new liquid-phase microextraction method (LPME) based on the dispersive-restoration suspended droplet microextraction (DRSDME) technique for extraction and determination of trace amount of thallium(III) from water samples. The DRSDME method is based on the DSDME [30] with adding a resting time step

that leads to an increase in recovery of sample solution. For this purpose, 0.5 ml 6×10^{-4} M 8-hydroxyquinoline in ethanol was added to 5.0 ml sample solution containing 0.3 mg l^{-1} of thallium(III) at pH = 5.0. Then, 180 μl of toluene solution as an extracting solvent was injected in the surface of mixture. The solution was stirred at 1000 rpm for 15 s until the organic phase dispersed in the mixture and a cloudy solution was appeared. After that, the magnetic stirrer was turned off for three minutes up to the organic solvent with lower density than water distance from the magnet. Then, the magnet speed was adjusted again at optimum speed of 600 rpm for three minutes until central force of vortex flow began to gather up the organic droplet. Hereafter, the organic solvent was separated by a microsyringe and diluted to 0.5 ml with dimethylformamide (DMF) and then injected to FAAS for thallium measurement.

EXPERIMENTAL

Apparatus

A shimadzu model AA-670 atomic absorption spectrometer equipped with thallium hollow cathode lamp with a wavelength 276.8 nm, slit width 0.5 nm and air-acetylene flame was used for determination of the Thallium ion. All pH settings were carried out by a Metrohm E-691 digital pH meter with a combined glass electrode.

Chemicals and Reagents

All materials used in this work were of analytical grade from Merck Co. (Darmstadt, Germany). Stock standard solutions of thallium (1000 mg l^{-1}) were prepared by dissolving appropriate amount of $\text{Tl}(\text{NO}_3)_3 \cdot 3\text{H}_2\text{O}$ in 0.5 ml of HNO_3 from Merck (Darmstadt, Germany) [10]. Lower concentrations of standards were prepared daily by suitable dilution of the stock solution with deionized water and adjusted to suitable pH.

Preparation of Real Samples

Nail and hair. An appropriate amount of hair and nail samples was soaked in acetone for 20 min to remove external contamination. The mixture was washed with acetone, chloroform and with water, then it was dried. A 3.0 g of hair and 2.0 g of nail samples were weighted and

put separately into two 50 ml beakers. To the beakers, 5.0 ml of HNO₃ (65%) were added and heated for 45 min at 100 °C and then 15 min at 150 °C. The mixtures were cooled to 70 °C and 2.0 ml of H₂O₂ (30%) was added and heated to dryness at 200 °C. A 10.0 ml of HNO₃ 0.1 M was added to the mixtures and then heated for 5 min at 100 °C [31]. Then, for oxidation of Tl(I) to Tl(III), 1.2 ml Ce(IV) and 1.2 ml Mn(II) 0.01 M were added to the residues and the mixtures were heated for 30 min at 70 °C. The mixture was filtered by filter paper and adjusted by 0.1 M NaOH to pH = 5.0. The solution was diluted by 0.1 M phosphate buffer in 25 ml volumetric flask.

Water samples. A 5.0 ml of 0.01 M Ce(IV) and 5.0 ml of Mn(II) 0.01 M were added into 35.0 ml of water samples in a 250 ml beaker. For oxidation of Tl(I) to Tl(III), the solution was heated for 30 min at 70 °C. Then, the solution was diluted to the mark in 50.0 ml volumetric flask by 0.1 M phosphate buffer. A 5.0 ml of this solution was used by described procedure at optimum condition.

RESULTS AND DISCUSSION

Some parameters, having a significant effect on the microextraction process, were investigated on the thallium's extraction.

Type of Extraction Solvent

The extraction solvent has a significant effect on dispersive-restoration suspended droplet microextraction. Therefore, different organic solvents lighter than water such as methyl isobutyl ketone (MIBK), dimethyl sulfide (DMS), n-hexane and toluene were investigated. As can be seen in Fig. 1, the toluene was the best extraction solvent for extraction of Tl(III).

An important factor in DRSDME is the resting time that is the time between turn off of the magnet and turn on with different speed. To study this factor, 150 µl of toluene was added into 5.0 ml of sample containing 0.3 mg l⁻¹ of Tl(III). The dispersion was carried out for 5s at magnetic speed of 1000 rpm. One experiment was done without resting time and one with a resting time of 5 min under the same experimental conditions, the results are shown in Fig. 2. As seen in Fig. 2a and b, the absorbance signal increases with a resting time of 5 min. This is due to the fact that sample

solution in vicinity of magnet is turbulent, causing the dispersed organic solvent cannot gather up under this condition. Due to the resting time, the organic solvent distances from the magnet and is accumulated on the surface of solution.

Effect of pH

In all extraction methods, the percentage of extraction depends on pH when the ligand or target ions have acid-base character [32-34]. To study this effect, 5.0 ml of sample solution containing 0.3 mg l⁻¹ of Tl(III) was studied at pHs 3.0-8.0, the results are shown in Fig. 3. As seen, the best pH for Tl(III) extraction is 5.0. At pHs less than 5.0, the absorbance signal decreases due to protonation of ligand, and in pHs above 5.0, there is a slightly decrease in the absorbance signal due to interaction of hydroxyl ions with Tl(III) ions. Therefore, pH 5.0 was chosen for subsequent studies and the pH adjustment was done with 0.1 M phosphate buffer.

Dispersive Time

Dispersive time is an important factor causing the dispersion of micro droplets of organic solvent into aqueous phase and increasing the surface contact between immiscible phases. In this experiment, the absorbance was measured at constant stirring rate of 1000 rpm at different dispersive times. The results show that the best dispersive time for extraction of thallium is 15 s, after that the absorbance decreases. The decrease in absorbance after 15 s is due to more dispersion of organic solvent in the aqueous phase making collection of microdroplets difficult by vortex flow.

Duration of Resting Time

For optimizing the resting time duration, 150 µl of toluene containing 1 × 10⁻³ M oxine was added to 5.0 ml of sample containing 0.3 mg l⁻¹ thallium at pH 5.0 After 15 s dispersion at 1000 rpm the magnetic stirrer was turned off from 0.0-7 min (resting time). The results show that absorbance increases with increasing the resting time until 3 min, after that the increase in resting time did not have any effect on the absorbance signals. Therefore, for the subsequent experiments, resting time of 3 min was chosen as an optimum value.

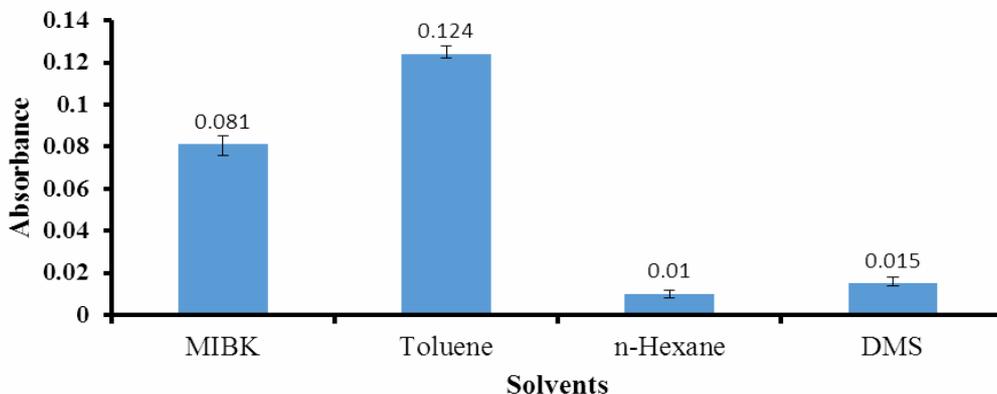


Fig. 1. Effect of different organic solvents in extraction of 0.3 mg l^{-1} of Tl(III), $1.0 \times 10^{-3} \text{ M}$ 8-hydroxy quinoline(oxine), $150 \mu\text{l}$ of different solvents, magnetic speed 1000 rpm (5 s), collection speed 500 rpm (10 min), diluent DMF.

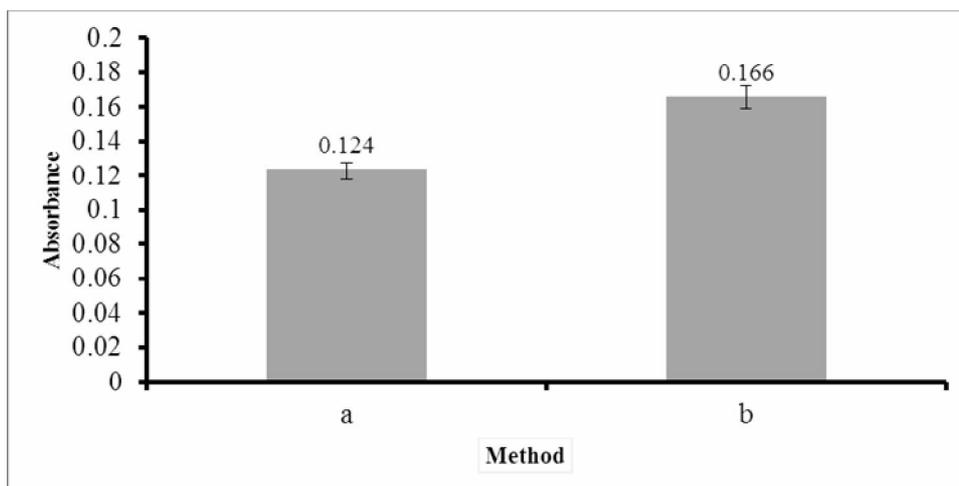


Fig. 2. Effect of resting time on extraction of Tl(III), (a) without resting time, (b) with 5 min resting time. Experimental conditions: 0.3 mg l^{-1} of Tl(III), $1.0 \times 10^{-3} \text{ M}$ 8-hydroxy quinoline(oxine), $150 \mu\text{l}$ of toluene, magnetic speed 1000 rpm (5 s), collection speed 500 rpm (10 min), diluent DMF.

Magnetic Stirrer Speed and Time for Accumulation of Microdroplet

Effect of magnetic stirrer speed and time were investigated on microextraction of thallium and the results are shown in Figs. 4 and 5. As shown in Fig. 4, the absorbance signals increase linearly with increasing the magnetic speed until 600 rpm, but at speeds of more than

600 rpm, the microdroplets were dispersed again and were not accumulated on the surface. Thus, the 600 rpm was chosen as the best speed for vortex flow. Figure 5 also shows that the best time for magnetic speed is 3 min.

Volume of Organic Phase

The volume of extracting solvent on microextraction of

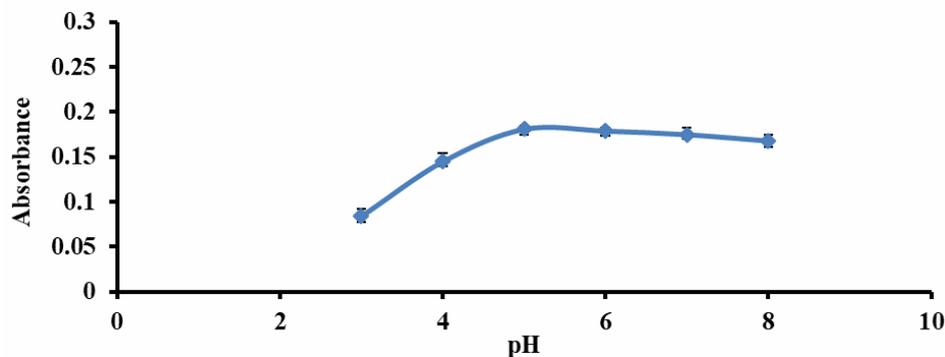


Fig. 3. Effect of pH on microextraction of Tl(III). Experimental conditions: 0.3 mg l^{-1} of Tl(III), $1.0 \times 10^{-3} \text{ M}$ 8-hydroxy quinoline(oxine), $150 \text{ }\mu\text{l}$ of toluene, magnetic speed 1000 rpm (5 s), collection speed 500 rpm (10 min), 3 min resting time at different pHs, diluent DMF.

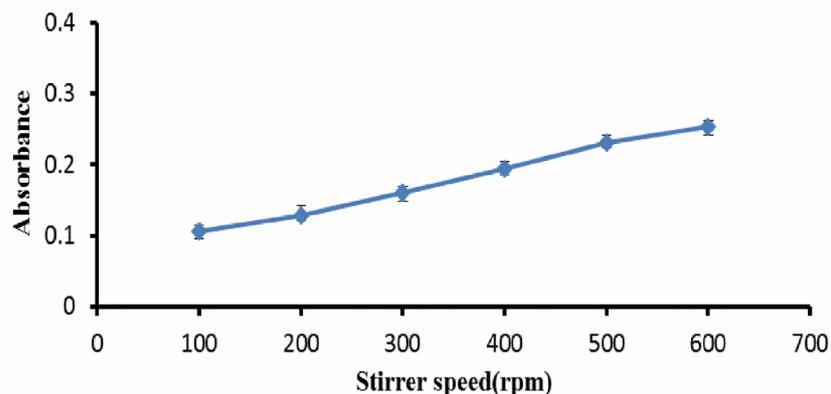


Fig. 4. Effect of magnetic stirrer speed for accumulation of microdroplet at different collection speeds. Experimental conditions: 0.3 mg l^{-1} of Tl(III), $1.0 \times 10^{-3} \text{ M}$ 8-hydroxy quinoline(oxine), $150 \text{ }\mu\text{l}$ of toluene, magnetic speed 1000 rpm (15 s), resting time 3 min, pH 5.0, diluent DMF.

thallium was studied from 40-240 μl of toluene and the results are shown in Fig. 6. It is seen that absorbance increases with increasing the toluene volume up to 180 μl and then it becomes constant by any increase in volume of extraction solvent. The amount of extracted thallium complexes increases by increasing in solvent volume, and therefore signal increases too. After extracting the maximum amounts of complexes, further increase in the solvent volume does not have any effect on extraction, and the signal becomes constant in the volume range studied. Hence, 180 μl was chosen for further studies.

Ligand Concentration

The ligand concentration is another factor that needs to be optimized in any liquid phase microextraction methods. To do so, the absorbance of thallium was measured versus different concentrations of 8-hydroxy quinoline and the results are shown in Fig. 7. As seen in this figure, the absorbance increases with increasing oxine concentration until $6 \times 10^{-4} \text{ M}$, after that it becomes constant. This observation implies maximum extraction of thallium in these conditions. Thus, $6 \times 10^{-4} \text{ M}$ was chosen for further studies.

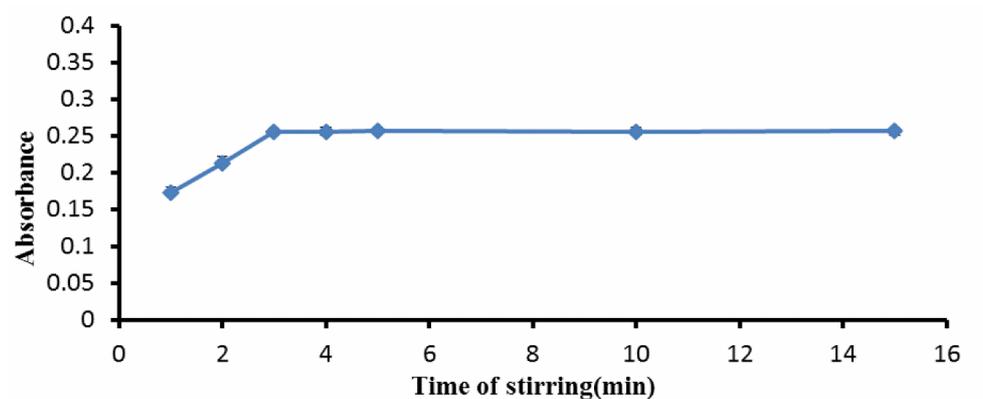


Fig. 5. Effect of time of magnetic speed on microextraction Tl(III). Experimental conditions: 0.3 mg l^{-1} of Tl(III), $1.0 \times 10^{-3} \text{ M}$ 8-hydroxy quinoline(oxine), $150 \mu\text{l}$ of toluene, magnetic speed 1000 rpm (15 s), resting time 3 min, pH 5.0, collection speed 600 rpm (3 min), diluent DMF.

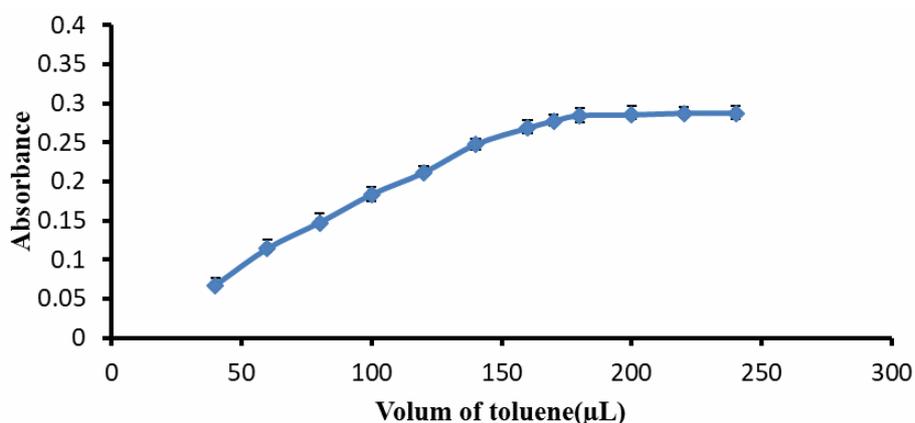


Fig. 6. Effect of volume of toluene on microextraction of Tl(III). Experimental conditions: 0.3 mg l^{-1} of Tl(III), $1.0 \times 10^{-3} \text{ M}$ 8-hydroxy quinoline(oxine), different volumes of toluene, magnetic speed 1000 rpm (15 s), resting time 3 min, pH 5, collection speed 600 rpm (3 min), diluent DMF.

Type of Diluent

After extraction of thallium, the organic phase was diluted to 0.5 ml with different organic phases including, DMF, AN, ethanol, methanol and toluene, the results are shown in Fig. 8. As seen, the best diluent is DMF.

Salt Effect

The effect of salt was investigated with addition of different concentrations of NaCl from 0.0-5.0% w/v. Based on the results, the salt had no significant effect on

absorbance and extraction of thallium from sample solution.

Potential Interference on Extraction of Thallium

Effect of several cationic and anionic ions on extraction and determination of thallium was also investigated. For doing so, different potential interference ions were added to 5.0 ml of sample containing 0.3 mg l^{-1} thallium in optimum conditions (pH 5.0, ligand concentration $6 \times 10^{-4} \text{ M}$, $180 \mu\text{l}$ toluene, 15 s dispersion time, 3 min resting time and 3 min collection time in 600 rpm). The interferes are ions which

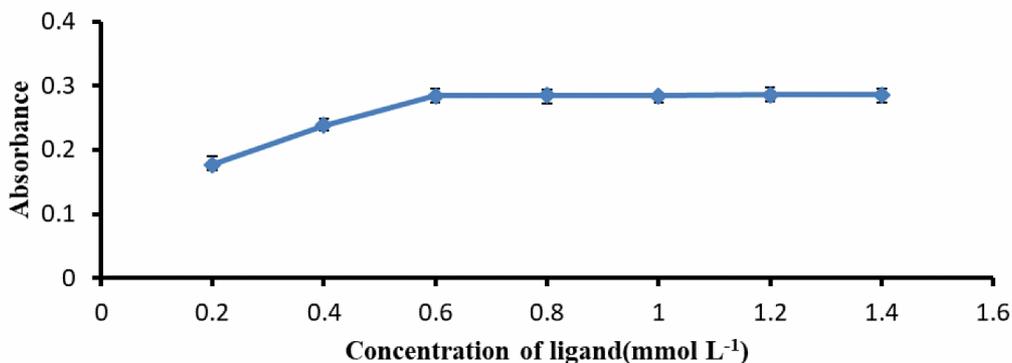


Fig. 7. Effect of ligand concentration on microextraction of Tl(III). Experimental conditions: 0.3 mg l⁻¹ of Tl(III), different 8-hydroxy quinoline concentration, 180 µl volume of toluene, magnetic speed 1000 rpm (15 s), resting time 3 min, pH 5, collection speed 600 rpm (3 min), diluent DMF.

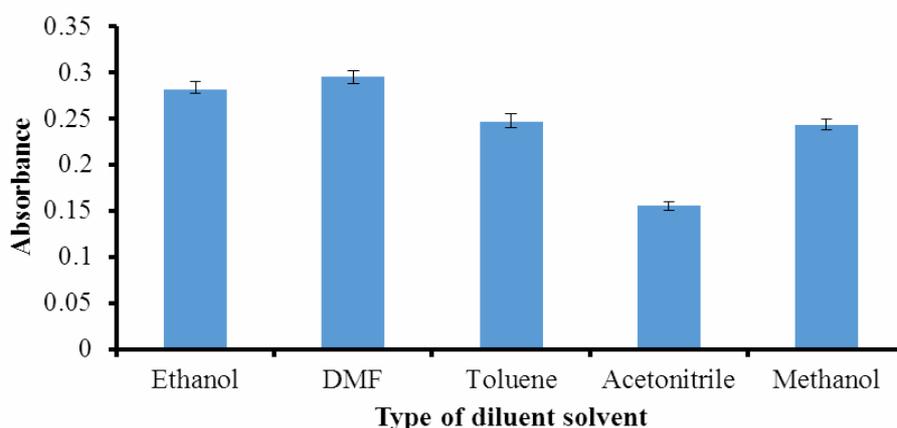


Fig. 8. Effect of diluent type on absorbance of Tl(III). Experimental conditions: 0.3 mg l⁻¹ of Tl(III), 6 × 10⁻⁴ M 8-hydroxy quinoline concentration, 180 µl volume of toluene, magnetic speed 1000 rpm (15 s), resting time 3 min, pH 5, collection speed 600 rpm (3 min), different diluent.

produce a ±5% change in absorbance determination of thallium [34]. The results are shown in Table 1. As seen in Table 1 there was no any interference effect from different ions in determination of thallium. This means the method is highly selective for determination of thallium in this pH.

Performance of the DRSDME Procedure

In order to evaluate the analytical performance of the method, linear dynamic range (LDR), enrichment factor

(EF), limit of detection (LOD), and precision (RSD) were used for determination of thallium. The linear dynamic range was linear from 8.0-1000 µg l⁻¹ with correlation coefficient of 0.997. The enrichment factor was 33 for 5.0 ml of sample solution. The limit of detection (LOD), calculated as $LOD = 3S_b/m$ (where S_b and m are the standard deviation of the blank ($n = 3$) and the slope of the calibration graph, respectively), was 3.1 ng ml⁻¹. The relative standard deviation (R.S.D.) for 15 replicate

Table 1. Effect of Different Potential Interference Ions on Determination of Thallium

Ion	Added as	Tolerance limit ion ratio ($C_{\text{Ion}}/C_{\text{Tl}^{3+}}$)
Co ²⁺	Co(NO ₃) ₂ .6H ₂ O	100
Mn ²⁺	Mn(NO ₃) ₂ .4H ₂ O	500
Hg ²⁺	Hg(NO ₃) ₂ .H ₂ O	50
Ni ²⁺	Ni(NO ₃) ₂ .6H ₂ O	100
Cu ²⁺	Cu(NO ₃) ₂ .3H ₂ O	1000
Zn ²⁺	Zn(NO ₃) ₂ .6H ₂ O	100
Pb ²⁺	Pb(NO ₃) ₂	100
Al ³⁺	Al(NO ₃) ₃ .9H ₂ O	50
Fe ³⁺	Fe(NO ₃) ₃ .9H ₂ O	50
Bi ³⁺	Bi(NO ₃) ₃ .5H ₂ O	50
Cr ³⁺	CrCl ₃ .6H ₂ O	100
Cd ²⁺	Cd(NO ₃) ₂ .4H ₂ O	100
Ca ²⁺	Ca(NO ₃) ₂ .4H ₂ O	1000
Mg ²⁺	Mg(NO ₃) ₂ .6H ₂ O	1000
Ag ⁺	AgNO ₃	500
Na ⁺	NaNO ₃	5000
K ⁺	KCl	5000
Cl ⁻	NaCl	5000
Br ⁻	KBr	5000
I ⁻	KI	100
NO ₃ ⁻	KNO ₃	5000
SO ₄ ²⁻	K ₂ SO ₄	1000

measurements of 0.3 mg l⁻¹ of thallium was 1.4%.

Application for Real Samples

The reliability of the recommended procedure was verified with the analysis of real samples (including tap water, well water, sea water, hair and nail man samples), the results are shown in Tables 2 and 3.

Comparison of DRSDME with other Microextraction Methods

Comparison of this method with other methods for determination of thallium is shown in Table 4. Based on the results, the method has a higher linear range in comparison with the other methods, in addition, the proposed method

Table 2. Analysis of Different Water Samples Using the Proposed Method. Mean \pm Standard Deviation of Three Replicate Determinations

Sample	Added ($\mu\text{g l}^{-1}$)	Found ($\mu\text{g l}^{-1}$)	Recovery
Tap water	-	$\leq \text{DL}^{\text{a}}$	-
	10	10.2 ± 0.4	102%
	50	50.4 ± 0.2	101%
Well water	-	$\leq \text{DL}$	-
	10	9.8 ± 0.4	98.5%
	50	49.8 ± 0.1	99.5%
Caspian sea water	-	$\leq \text{DL}$	-
	10	10.3 ± 0.4	103%
	50	50.4 ± 0.2	101%

^aBelow or equal detection limit.**Table 3.** Determination of Hair and Nail Samples Using the Proposed Method. Mean \pm Standard Deviation of Three Replicate Determinations

Sample	Found ($\mu\text{g g}^{-1}$)	Recovery	Added ($\mu\text{g g}^{-1}$)
Hair man	0.08 ± 0.03	-	-
	0.18 ± 0.02	100%	0.1
	1.1 ± 0.02	102%	1.0
Nail	0.17 ± 0.03	-	-
	0.37 ± 0.04	100%	0.2
	2.2 ± 0.01	101.5%	2.0

has a good limit of detection with a good enrichment factor. It is quite simple and does not require a time-consuming centrifugation step.

CONCLUSIONS

A method based on DRSDME was introduced for the first time for trace determination of total thallium. The

Table 4. Comparison of DRSDME Method with other Methods for Determination of Thallium

Extraction method	Detection technique	LDR ($\mu\text{g l}^{-1}$)	Centrifugation step	Enrichment factor	LOD ($\mu\text{g l}^{-1}$)	Ref.
SA-DLLME ^a	Uv-Vis	-	Yes	23	0.2	[35]
DLLME-SFO ^b	FAAS	6.0-900	Yes	42.7	2.1	[10]
Ion-pair DLLME	ETAAS	0.1-2.0	Yes	125	0.03	[11]
Spectrophotometry	Uv-Vis	0.5-4.0 mg l ⁻¹	-	-	10	[8]
SDME ^c	ETAAS	3-22	No	50	0.7	[14]
SPE ^d	UV-Vis	-	No	25	800	[36]
IL-USA-DLLM ^e	FAAS	5-400	Yes	98.2	0.64	[37]
DRSDME	FAAS	8-1000	No	33	3.1	This work

^aSurfactant assisted dispersive liquid-liquid microextraction. ^bDispersive liquid-liquid microextraction solidification of floating organic droplet. ^cSingle drop microextraction. ^dSolid phase extraction. ^eIonic liquid-ultrasound assisted-dispersive liquid-liquid microextraction.

method is easy, selective, inexpensive and without need to a time-consuming centrifugation step, thus it is a good method for laboratories with limited budget. The method provides reliable results that are comparable or better than other methods (Table 4). Under optimum conditions, the developed method shows wide linear dynamic range and low detection limit that is useful for determination of total thallium in different samples.

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REFERENCES

- [1] E. Waidmann, K. Hilpert, M. Stoepler, *Fresenius J. Anal. Chem.* 338 (1990) 572.
- [2] C.H. Lan, T.S. Lin, *Ecotoxicol. Environ. Saf.* 61 (2005) 432.
- [3] B. Rezaei, S. Meghdadi, N. Majidi, *Spectrochim. Acta, Part A* 67 (2007) 92.
- [4] B. Griepink, M. Sager, G. Tolg, *Pure Appl. Chem.* 60 (1988) 1425.
- [5] C.D. Wall, *Clin. Chim. Acta* 76 (1977) 259.
- [6] P. Medek, J. Pavlíčková, J. Zbíral, E. Čižmarová, V. Kubáň, *Int. J. Environ. Anal. Chem.* 81 (2001) 207.
- [7] H.A. Hamid, M.I. Al Joboury, A.K. Mohammed, *Anal. Chim. Acta* 243 (1991) 239.
- [8] H.D. Revanasiddappa, T.N. Kiran Kumar, *Turk. J. Chem.* 29 (2005) 265.
- [9] G. Khayatian, S. Shariati, A. Salimi, *Bull. Korean Chem. Soc.* 24 (2003) 421.
- [10] S.Z. Mohammadi, A. Sheibani, A. Abdollahi, E. Shahsavani, *Arab. J. Chem.* 9 (2016) S1510.
- [11] F. Javedani-Asleh, M. Eftekhari, M. Chamsaz, *Spectrosc. Lett.* 49 (2016) 420.
- [12] L.B. Escudero P. Berton, E.M. Martinis, R.A. Olsin, R.G. Wuilloud, *Talanta* 88 (2012) 277.
- [13] H. Fazelirad, M.A. Taher, *Talanta* 103 (2013) 375.
- [14] M. Chamsaz, M.H. Arbab-Zavar, A. Darroudi, T. Salehi, *J. Hazard. Mater.* 167 (2009) 597.
- [15] A. Karatepea, M. Soylak, L. Elci, *Talanta* 85 (2011) 1974.

- [16] S. Chen, J. Yan, J. Li, Y. Zhang, D. Lu, *Microchim. Acta* 184 (2017) 2797.
- [17] E. Biaduń, M. Sadowska, N. Ospina-Alvarez1, B. Krasnodębska-Ostręga, *Microchim. Acta* 183 (2016) 177.
- [18] Z. Dehghani Firouzabadi, A.M. Haji Shabani, S. Dadfarnia, M.H. Ehrampoush, *Microchem. J.* 130 (2017) 428.
- [19] N. Raphael Biata, K. Mogolodi Dimpe, J. Ramontja, N. Mketi, P.N. Nomngongo, *Microchem. J.* 137 (2018) 214.
- [20] M. Fayazi, M. Ghanei-Motlagh, M.A. Taher, R. Ghanei-Motlagh, M.R. Salavati, *J. Hazard. Mater.* 309 (2016) 27.
- [21] M.H. Arbab-Zavar, M. Chamsaz, G. Zohuri, A. Darroudi, *J. Hazard. Mater.* 185 (2011) 38.
- [22] M. Nasiri-Majd, M.A. Taher, H. Fazelirad, *Talanta* 144 (2015) 204.
- [23] M. Naghizadeh, M.A. Taher, L.Z. Zeidabadi Nejada, F. Hassani Moghaddam, *Environ. Nanotechnol. Monit.* 10 (2018) 171.
- [24] Y. Yamini, M. Rezazadeh, S. Seidi, *TrAC, Trends Anal. Chem.* 112 (2019) 264.
- [25] Q. Wang, R. Chen, W. Shatner, Y. Cao, Y. Bai, *Ultrason. Sonochem.* 51 (2019).
- [26] S. Moinfar, G. Khayatian, M.R. Milani-Hosseini, *Talanta* 129 (2014) 309.
- [27] Y. Lu, Q. Lin, G. Luo, Y. Dai, *Anal. Chim. Acta* 566 (2006) 259.
- [28] S. Hassanpoor, G. Khayatian, *J. Brazil. Chem. Soc.* 25 (2014) 734.
- [29] A. Sarafraz-Yazdi, A.H. Amiri, *TrAC, Trends Anal. Chem.* 29 (2010) 1.
- [30] B. Barfi, A. Asghari, M. Rajabi, N. Mirkhani, *RSC Adv.* 5 (2015) 106574.
- [31] S. Dadfarnia, T. Assadollahi, A.M. Haji Shabani, *J. Hazard. Mater.* 148 (2007) 446.
- [32] G. Khayatian, S. Hassanpoor, F. Nasiri, A. Zolali, *Quim. Nova.* 35 (2012) 535.
- [33] M. Fayazi, M. Ghanei-Motlagh, *Anal. Bioanal. Chem. Res.* 4 (2017) 189.
- [34] G. Khayatian, S. Hassanpoor, *J. Chin. Chem. Soc.* 59 (2012) 659.
- [35] L. George, A. Varghese, A. Nizam, A, *Eur. J. Chem.* 6 (2015) 183.
- [36] L. Zhang, T. Huang, X. Liu, M. Zhang, K. Li, *J. Anal. Chem.* 66 (2011) 368.
- [37] N.H. Nadiki, M.A. Taher, H. Ashkenani, *Int. J. Environ. Anal. Chem.* 93 (2013) 623.