

2-Propylpiperidine-1-carbodithioate로 수식화한 Octadecyl 실리카 막으로 구리(II)의 예비농축 및 불꽃 원자흡수분광법으로의 정량

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Preconcentration and Determination of Copper(II) Using Octadecyl Silica Membrane Disks Modified by 2-Propylpiperidine-1-carbodithioate and Flame Atomic Absorption Spectrometry

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요약. 2-Propylpiperidine-1-carbodithioate(PPCD)I 로 수식화한 octadecyl로 결합된 실리카 막 디스크로 구리(II) 이온의 잔유량의 추출과 간단하고 빠르게 원자흡수분광법(AAS)으로의 정량법을 소개한다. 추출효율과 흐름속도, pH, 형태, 벗김 산의 가장 적은 양에 대해 연구되었다. Anthraquinone 유도체의 2 mg로 수식한 막디스크의 최대 용량은 425 μg Cu^{2+} 이었다. 제안한 방법의 검출한계는 7 ng/ml이다. 이 방법은 다른 시료와 온천수 시료로부터 Cu^{2+} 의 회수에 적용하였다.

주제어: 구리(II), SPE, Octadecyl 실리카 디스크, AAS, 2-Propylpiperidine-1-carbodithioate (PPCD) I

ABSTRACT. A simple and fast method for extraction and determination of trace amounts of copper(II) ions using octadecyl-bonded silica membrane disks modified with 2-propylpiperidine-1-carbodithioate (PPCD)I and atomic absorption spectrometry (AAS) is introduced. Extraction efficiency and the influence of flow rates, pH, and type and smallest amount of stripping acid were investigated. Maximum capacity of the membrane disks modified with 2 mg of the anthraquinone derivative used was found to be 425 μg Cu^{2+} . The limit of detection of the proposed method is 7 ng/ml. The method is applied to the recovery of Cu^{2+} from different synthetic samples and a spring water sample.

Keywords: Copper(II), SPE, Octadecyl Silica Disks, AAS, 2-Propylpiperidine-1-carbodithioate (PPCD) I

INTRODUCTION

Copper is both vital and toxic for many biological systems.^{1,2} Thus, the determination of trace amounts of Cu is becoming increasingly important because of the increased interest in environmental pollution.³ Flame and graphite furnace atomic absorption spectrometry and spectrophotometric methods provides accurate and rapid determination of copper in natu-

ral waters and wastewaters.⁴ Nevertheless, very frequently for the extremely low concentration copper in waters, a direct determination cannot be applied without their previous preconcentration and separation. The most widely used techniques for the separation and preconcentration of trace amounts of Cu are liquid-liquid extraction⁴, precipitation^{5,6} and chelating resins.⁷ The large distribution ratios possible in solvent extraction systems allow the analyti-

cal determination of substances present in otherwise non-detectable concentrations.

A proper choice of extractant may lead to an increase in concentration by several orders of magnitude. In other words, a large increase in sensitivity is obtained in the analytical method, even when the analyte is analytically detectable in the original sample; its preconcentration by means of solvent extraction permits use of smaller samples, simplification of the procedure, and increased accuracy of the samples. Very often, both separation and preconcentration are required, and an advantage of solvent extraction is that both can be obtained in the same step.⁸ Solvent extraction of metal chelate complexes has been used as a separation method for a long time. Recovery of metals from an aqueous phase by solvent extraction is achieved by contacting the aqueous phase with an organic phase that contains a metal selective chelating agent dissolved in a diluent.⁹ For extraction of metal ions, it is preferable that the chelating reagent used has a high distribution coefficient and pH dependence in the system chosen.¹⁰⁻¹⁴ Different methods, especially Liquid-Liquid extraction of copper in the presence of various classical¹⁵⁻¹⁹ and macrocyclic^{20,21} co-extractant ligands has attracted considerable attention. However, the use of classical extraction methods for this purpose is usually time-consuming, labor-intensive and requires large amounts of high purity solvents for extraction. Nevertheless, several other techniques for the preconcentration and separation of copper have been proposed including liquid chromatography²² supercritical fluid extraction,²³ flotation,²⁴ aggregate film formation,²⁵ liquid membrane,²⁶ column adsorption of pyrocatechol violet-copper complexes on activated carbon,²⁷ ion pairing,²⁸ ion pairing,²⁹ preconcentration with yeast,³⁰ and solid phase extraction using C₁₈ cartridges and disks.³¹⁻³³

Solid phase extraction (SPE) or liquid-solid extraction is popular and growing techniques that are used to sample preparation for analysis. It is an attractive alternative for classical liquid-liquid extraction methods that reduce solvent usage and exposure, disposal costs and extraction time for sample sepa-

ration and concentration purposed.³⁴⁻³⁶ In recent years, the octadecyl-bonded silica SPE disks have been utilized for the extraction and separation of different organic compounds from environmental matrices.³⁷⁻⁴⁰ Moreover, the SPE disks modified by suitable ligands are successfully used for selective extraction and concentration of metal ions.^{41-42,46}

In a recent series of papers,⁴³⁻⁴⁵ we have described the application of metal-DNA conjugates to nucleic acid sequence determination with catalytic signal amplification; the assay relies on the esterase activity of a DNA-linked Cu complex. For optimization of the system and exploration of structure-activity relationships, a sensitive probe would be useful, which allows straightforward detection of esterase activity of ligated Cu²⁺ in low concentration. The aim of this work was the development of a rapid, efficient and highly sensitive method for selective extraction and concentration of ultra trace amounts of Cu²⁺ ions from aqueous media using octadecyl silica membrane disks modified by 2-propylpiperidine-1-carbodithioate (PPCD) I and AAS determination.

MATERIALS AND METHODS

Reagents

All acids were of the highest purity available from Merck Chemical Company and were used as received. Acetonitrile, methanol, and 2-propanol were of HPLC grade from Aldrich Chemical Company. Analytical-grade nitrate salts of copper, sodium, magnesium, calcium, strontium, barium, cobalt, nickel, lead, zinc, cadmium, and mercury (all from Merck) were of the highest purity available and used without any further purification except for vacuum drying over P₂O₅. Double-distilled, deionized water was used throughout.

Synthesis of sodium 2-propylpiperidine-1-carbodithioate reagent

Carbondisulphide (1.05 mol) was slowly added to a solution of 2-propyl-piperidine (1.43 mol) in 25 ml of water at 5 °C with constant stirring, followed by 1.0 mol of sodium hydroxide dissolved in 20 ml of water to form sodium 2-propylpiperidine-1-carbodithio-

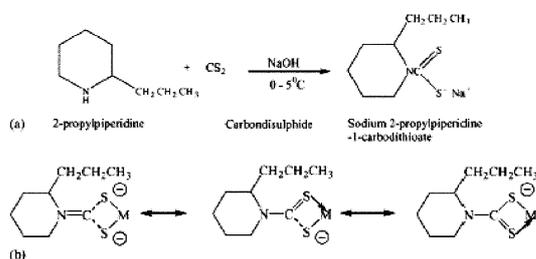


Fig. 1. (a) Synthesis of sodium 2-propylpiperidine-1-carbodithioate reagent. (b) Resonance hybrid of the 2-propylpiperidine-1-carbodithioate with metal (I).

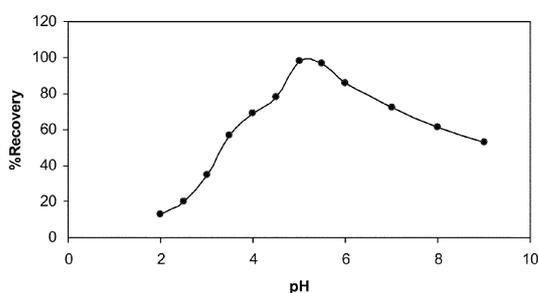


Fig. 2. Influence of sample pH and dissolving solvent of I on the percentage recovery of Cu(II).

ate as shown in Fig. 2(a). The product was warmed to room temperature and washed 2-3 times with purified acetone. The reaction product was recrystallized from warm acetone. The purified compound has a melting point of 303-308 °C at 740 mm pressure. Crystallization of water is less in 2-propylpiperidine-1-carbodithioate when compared with other carbodithioate, therefore, the extractability of the complex become easier. The metal salt of this reagent is a resonance hybrid of the structures, which contributed to the stability of metal complexes as shown in Fig. 2(b).

Apparatus

Determination of Cu²⁺ contents in working samples were carried out by a Varian spectra A.200 model atomic absorption spectrometer equipped with a high intensity hollow cathode lamp (HI-HCL) according to the recommendations of the manufacturers. These characteristics are tabulated in (Table 1).

AAS determinations of all other cations were performed under the recommended conditions for each metal ion. The pH measurements were carried out

Table 1. The operational conditions of flame for determination of copper

Slit width	0.7 nm
Operation current of HI-HCL	15 mA
Resonance fine	324.8 nm
Type of background correction	Deuterium lamp
Type of flame	Air/acetylene
Air flow	7.0 mL.min ⁻¹
Acetylene flow	1.7 mL.min ⁻¹

by an ATC pH meter (EDT instruments, GP 353).

Sample extraction

Solid phase extractions were carried out by glassy membrane disks, ENVI-18DISK™ 47 mm diameter × 0.6 mm thickness containing octadecyl silica bonded phase (30 μm particles, 70 Å pore size) obtained from Supelco in conjunction with a standard Millipore 47 mm filtration apparatus equipped with a vacuum pump.

After the membrane was placed in the filtration apparatus, it was washed with 10 ml methanol and then with 10 ml acetonitrile to remove all contaminants arising from the manufacturing process and the environment. After the disk was dried by passing air through it for several minutes, a solution of 2 mg I dissolved in 2 ml of 2-propanol was introduced into the reservoir of the apparatus and drawn slowly through the disk by applying a slight vacuum until the ligand penetrated the membrane completely. The solvent was evaporated at 50 °C. Finally, the disk was washed with 25 ml water and dried by passing air through it. The membrane disk modified with I was now ready for sample extraction.

The general procedure for the extraction of Cu²⁺ ions on the modified membrane disk was as follows. The disk was first washed with 25 ml water. This step prewets the surface of the modified disk prior to the extraction of Cu²⁺ from water. Then 500 ml of the sample solution containing 7 μg Cu²⁺ was passed through the membrane (flow rate = 20 ml min⁻¹). After extraction, the disk was dried completely by passing air through it for a few minutes. The extracted copper was then stripped from the membrane disk using 20 ml of a 1 M solution of nitric acid into a 25.0 ml volumetric flask and

diluted to the mark with water, and the copper concentration was determined by AAS.

RESULTS AND DISCUSSION

It is well known that various derivatives of carbodithioates are able to form stable 2:1 (ligand: metal) complexes with a variety of metal ions in some nonaqueous solvents;^{51,52} the resulting Cu^{2+} complexes are among the most stable complexes formed.⁵⁵ Due to its water insolubility as well as its tendency to form a selective and stable complex with Cu^{2+} ,⁵⁵ the synthetic **I** was employed in this work as a proper ligand for selective SPE of copper from aqueous solutions. Thus, some preliminary experiments were carried out to investigate the quantitative retention of Cu^{2+} by the octadecyl silica membrane disks in the absence and presence of **I**. It was found that, while the membrane disk itself does not show any tendency for the extraction of copper ions, a membrane disk modified with **I** is capable of retaining Cu^{2+} in the sample solutions quantitatively (the test solutions used contained 0.1 and 1.0 μg copper in 10 ml water). This is most probably due to the existence of a strong interaction between Cu^{2+} and the carbodithioate used.

To choose a proper eluent for the retained Cu^{2+} on the modified disks, after extraction of 7 μg copper from 500 ml water, the copper ions were stripped with varying amounts of 1 M concentrations of different acids and the results are summarized in Table 2. It is seen that the elution of copper from the modified membrane disk was quantitative with 20 ml of 1 M HNO_3 , while this could not be done even with greater than 25-ml volumes of the other acids

tested. In other experiments it was found that the lower the concentration of nitric acid, the larger the volume of acid solution needed for the quantitative stripping of the cations. Thus, 20-ml portions of 1 M HNO_3 were used for further studies. It is noteworthy that when nitric acid of concentrations higher than 1 M was used, there was some leaching of **I** from the disk.

The influence of flow rates of the sample and stripping solutions from the modified membrane disks on the retention and recovery of 7 μg of copper ions was investigated. It was found that, in the range 1060 ml min^{-1} , the retention of copper by the membrane disk is not affected by the sample solution flow rate considerably. Some similar results for the extraction of organic^{47,49} and inorganic materials^{50,51} by octadecyl silica disks have already been reported in the literature. On the other hand, quantitative stripping of Cu^{2+} ions from the modified membrane disks was achieved in the flow rate range $0.5\text{-}5 \text{ ml min}^{-1}$, using 20 ml of 1 M HNO_3 as stripping solution. At higher flow rates, larger volumes of 1 M HNO_3 were necessary for quantitative stripping of Cu^{2+} .

The effect of the pH

The pH of the sample solutions were adjusted to different values between 2-9 by addition of hydrochloric acid or a suitable buffer such as sodium acetate-acetic acid or sodium dihydrogen phosphate- disodium hydrogen phosphate, and then solutions passed through the disks.

Eventually, the metal ions were stripped by pure methanol or ethanol solutions followed by flame atomic absorption determination of the eluted copper(II). Then, percentage recovery at various pH

Table 2. Percentage Recovery of Copper Ion from the Modified Membrane Disks Using Different Volumes of 1 M Solutions of Different Acids^a

Acetic acid	Hydrochloric acid	Recovery (%)		Volume (ml)
		Hydrochloric acid	Nitric acid	
22.4	35.7	38.4	40.7	5
39.7	46.9	47.8	64.3	10
48.3	69.0	68.0	88.1	15
78.2	79.4	83.6	99.8	20
82.5	85.6	92.4	98.9	25

^aInitial samples contained 7 μgCu^{2+} in 1000 ml solution.

values was determined (Fig. 2). According to the results shown in Fig. 2 up to pH 5.0-5.5, complete recoveries are obtained. However, at higher pH values, percentage recovery decreases. This is due to fact that in an acidic solution the protonation of **I** occurs and there is a weak tendency for retention between Cu(II) and **I**, whereas at higher values (pH>5), Cu(II) reacts with hydroxide ions to produce Cu(OH)₂. Therefore, sodium acetate-acetic acid buffer with pH=5 was used for the preconcentration step. Other solvents used for dissolving **I** were methanol and ethanol. The influences of these solvents on the recoveries as a function of pH are compared and shown in Fig. 2. Mean while, other organic solvents were not tested because of their restricted solubility and formation of two phases with aqueous solutions and incompatibility with flame. Higher pH values (>7) were not tested because of the possibility of the hydrolysis of octadecyl silica in

Disk efficiency

Undoubtedly, one of the major parameters affecting in the SPE determinations is the efficiency of the used membrane disks. However, to the best of our knowledge this case has not been discussed elsewhere in similar reports. Under the optimum experimental conditions, it was found out that each ENV-18 DISK™ disk could perform at least 15 replicate analyses if organic eluting solvents are used. On the other hand, acidic, eluents practically decrease the number of time a disk could be used to 10 replicates. These observations are represented in Fig. 3.

The maximum capacity of the membrane disk modified with 2 mg of **I** was studied by passing 500-ml portions of an aqueous solution containing 2000 µg copper through the disk, followed by determination of the retained metal ions using AAS. The maximum capacity of the disk thus obtained was found to be 425 µg of Cu²⁺ on the disk.

The breakthrough volume of sample solutions was tested by dissolving 7 µg of copper in 50, 250, 500, 1000, and 1500 ml water and applying the recommended procedure. In all cases the extraction by the membrane disk was found to be quantitative.

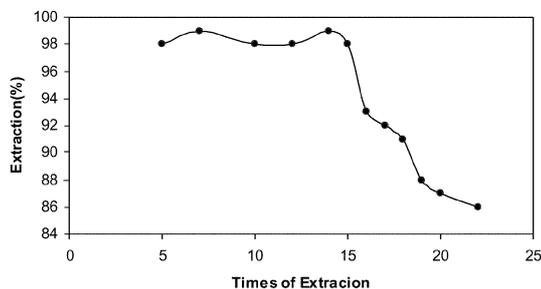


Fig. 3. Influence of eluent type on disk efficiency.

Thus, the breakthrough volume for the method should be greater than 1500 ml. The limit of detection (LOD) of the proposed method for the determination of copper(II) was studied under optimal experimental conditions. The LOD obtained from $C_{LOD} = K_b S_b m^{-156, 57}$ is 7 ng ml⁻¹. The reproducibility of the proposed method for the extraction and determination of 7 µg Cu²⁺ from 500 ml water was also studied. The results obtained on 10 replicate measurements revealed a RSD of 2.0%.

To investigate the selective separation and determination of Cu²⁺ from its binary mixtures with diverse metal ions, an aliquot of an aqueous solution (1000 ml) containing 7 µg Cu²⁺ and milligram amounts of other cations was taken and the recommended procedure was followed. The results are

Table 3. Separation of Copper from Binary Mixtures^a

Diverse ion	Amount taken (mg)	Diverse found ion (%)	Recovery of Cu ²⁺ (%)
Na ⁺	2.1	NAPD ^b	99.8 (0.9) ^c
Mg ²⁺	1.2	NAPD	98.2 (1.1)
Ca ²⁺	1.2	NAPD	99.0 (1.1)
Sr ²⁺	2.0	2.5 (1.1)	100.7 (1.9)
Ba ²⁺	1.4	NAPD	100.1 (1.3)
Co ²⁺	2.1	NAPD	99.5 (1.7)
Ni ²⁺	1.6	NAPD	98.5 (1.7)
Pb ²⁺	1.3	NAPD	96.4 (1.6)
Zn ²⁺	2.1	NAPD	97.3 (1.5)
Cd ²⁺	1.2	NAPD	102.5 (1.8)
Hg ²⁺	1.1	NAPD	98.5 (0.9)

^aInitial samples contained 7 µg Cu²⁺ and different amounts of diverse ions in 1000 ml water.

^bNo adsorption, passes through disk.

^cValues in parentheses are RSDs based on three replicate analyses.

Table 4. Recovery of 7 µg Copper Added to 1000-ml Solutions of the Synthetic and Water Samples

Recovery of Cu ²⁺ (%)	Sample
96.7 (2.0)	Synthetic sample 1 (Na ⁺ , Mg ²⁺ , Ca ²⁺ , Co ²⁺ , Hg ²⁺ , 2 mg of each cation)
98.9 (1.7)	Synthetic sample 2 (Na ⁺ , Mg ²⁺ , Sr ²⁺ , Ba ²⁺ , Co ²⁺ , Hg ²⁺ , 2 mg of each cation)
98.5 (1.5)	Synthetic sample 3 (Na ⁺ , Mg ²⁺ , Zn ²⁺ , Cd ²⁺ , Hg ²⁺ , 2 mg of each cation)

summarized in Table 3. The data in Table 3 reveal that Cu²⁺ in binary mixtures is retained almost completely by the modified membrane disk, even in the presence of up to 2100 µg of the diverse metal ions. It is interesting to note that, with the exception of Sr²⁺, retention of other cations by the modified disk is negligible and they can be separated completely for the Cu²⁺ ion. However, in the case of Sr²⁺, its retention by the disk is only 2.5%, which seems to be relatively low. It should be mentioned that the accompanying anions were found to have no measurable effect on the retention and recovery of copper ions.

Analysis of water samples

The applicability of the method to real samples with different matrices containing different amounts of a variety of diverse ions was assessed by using it to separate and recover copper ions from different synthetic and water samples. The results are given in Table 4. The results of three analyses of each sample show that, in all cases, copper recovery is almost quantitative.

To assess the applicability of the method to real samples, it was applied to the extraction and determination of copper from different water samples.

Table 5. Recovery of copper added to 1000 mL of different water samples (containing 0.1 M acetate at pH=5.5-6.0).

Sample	Cu ²⁺ added (µg)	Cu ²⁺ determined (ng. mL ⁻¹)
Tap water	0.0	1.88(0.9) ^a
	10.0	12.20(1.3)
Snow water	0.0	4.86(0.9)
	10.0	14.93(1.9)
Rain water	0.0	2.52(1.7)
	10.0	12.72(0.9)
Sea Water	0.0	13.56(1.7)
	10.0	23.98(1.8)

^aValues in parentheses are RSDs based on five individual replicate analysis

Tap water (Tehran, taken after 10 min operation of the tap), rain water (Tehran, 23 January, 2007), Snow water (Saveh, 8 February, 2006) and Sea water (taken from Caspian sea, near the Mahmoud-Abad shore) samples were analyzed (Table 5). As can be seen from Table 5 the added copper ions can be quantitatively recovered from the water samples used.

CONCLUSION

The proposed method is simple, highly selective, and reproducible. The reproducibility of the procedure is at the most 2%. It is rapid compared with the previously reported procedures for the separation and determination of copper;⁵¹⁻⁵⁵ the time taken for the separation and analysis of copper ion in a 1000 ml water sample is at most 20 min. The method can be successfully applied to the separation and determination of copper in real samples.

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