Electrochemical Behavior and the Determination of Furan in Beverage Samples Using Glassy Carbon Electrode

Hoveidi, H.[1], Sid Kalal, H.[2*], Nabi Bidhendi, G.[1], Rashedi, H.[3] and Vafaei Mehr, D.[4]

[1]Graduate Faculty of Environment, University of Tehran, Tehran, Iran

[2]NFCRS, Nuclear Science and Technology Research Institute, AEOI, P.O. Box 11365-3486, Tehran, Iran

[3]Biotechnology Group School of chemical Engineering College of Engineering, University of Tehran P.o.Box:11155-4563,Tehran, Iran

[4]University of Tehran, Aras International Campus, Aras, Iran

ABSTRACT: Furan is a possible human carcinogen in many types of foods. A new and sensitive electro analytical method for determination of furan has been developed and validated. The best condition for electrochemical response was obtained with 0.1 M britton-rabinson buffer solution (pH=5) a glassy carbon electrode (GCE) was used as the working electrode, a Ag/AgCl/ KCl(sat.) electrode served as the reference electrode, and a platinum wire as the auxiliary electrode under the Differential Pulse Voltammetry (DPV) mode. The peak current obtained from DPV was linearly dependent on the Furan concentration in the range 12–360 μM (0.81–24.5 ppm) with correlation coefficients of 0.999 and a limit of detection (LOD) of 3 μM (0.2 ppm) and limit of quantification (LOQ) of 10 μM (0.68 ppm) were calculated, respectively. The values of the electron-transfer coefficient (α) involved in the rate determining step calculated from the linear plots of Ep against ln (v) in the pH range investigated were 0.8 confirming the irreversible nature of the oxidation peak. The reproducibility of the method was tested by analyzing 10 samples containing 30 μM of Furan. The RSD % of the method thus obtained was 3.0 % which showed excellent reproducibility for this developed methods.

Key words: Furan, Electrochemical studies, Differential pulse voltammetry, Beverage Samples

INTRODUCTION

As a result of industrialization, synthetic chemicals have imposed adverse effects on human beings and other organisms (Vinodhini and Narayanan, 2009; Agbozu and Opuene, 2009; Abdullahi *et al.,* 2009; Aktar *et al.,* 2009; Chibunda, 2009; Hasan *et al., 2010;* Sadashiva Murthy *et al.,* 2009; Dutta and Dalal, 2008; Srivastava *et al.,* 2008; Banaee *et al.,* 2008; Asi *et al.,* 2008; Wasim Aktar *et al.,* 2008; Priju and Narayana, 2007; Jafari and Ebrahimi, 2007; Nasrollahzadeh *et al.,* 2007; Shahidi Bonjar, 2007; Shegefti *et al.,* 2010; Adjei-Boateng *et al.,* 2010; Belarbi and Al-Malack, 2010; Hassani *et al.,* 2010; Ghaderi *et al.,* 2012). Furan is a heterocyclic organic compound, consisting of a five-membered aromatic ring with four carbon atoms and one oxygen. The class of compounds containing such rings is also referred to as furans. Furan is a colorless, flammable, highly volatile liquid with a boiling point close to room temperature. It is soluble in common organic solvents, including alcohol, ether and acetone, but is insoluble in water (Jakubke and Jeschkeit 1994). It is toxic and may be carcinogenic. Furan is used as a starting point to other specialty chemicals (Hoydonckx *et al.,*2005). Furan is used as an intermediate in the synthesis of many chemicals and pharmaceutical agents such as solvents, resins, and lacquers (Carfagna *et al.,*1993). Furan yields a tumor incidence, where more than 90% of the tumors are adenocarcinomas, and the remainders are squamous cell tumors.In rats, furan induces cholangiocarcinomas, which are tumors that arise from the intrahepatic epithelium. Cholangiocarcinomas tend to grow slowly and to infiltrate the surrounding hepatic parenchyma (NTP, 1993). Furan is formed in many common foods during the thermal treatment of either ascorbate, carbohydrates (with or without amino

*Corresponding author E-mail:hsidkalal@aeoi.org.ir

acids), unsaturated fatty acids, carotenes, or organic acids (Becalski and Seaman, 2005). During recent decades, a variety of pioneer methods for detection of xenobiotics have been introduced (Ashraf *et al.,* 2012; Clemente *et al.,* 2012; Shwetha *et al.,* 2012; Maheswari and Ramesh, 20112; Garcia-Flores *et al.,* 2013; Etale and Drake, 2013; Ashan and Del Valls, 2011; Annabi *et al.,* 2011; Kapdan *et al.,* 2011; Chen *et al.,* 2011; Akhtar and Tufail, 2011; Naim *et al.,* 2011; Heidari *et al.,* 2011; Saeedi *et al.,* 2013; Jovic *et al.,* 2013; Bhuvaneshwari *et al.,* 2013; Olivalla *et al.,* 2013; Blagojevic *et al.,* 2012; Lopez-Pineiro *et al.,* 2012; Sotelo *et al.,* 2012). There are currently a large number of analytical methods for the determination of furan in foods, the analytical problems first reported (Senyuva, and Gökmen, 2005 ; Goldmann *et al.,* 2005; Bianchi *et al.,* 2006; Hasnip *et al.,* 2006; Wenzl, *et al.,* 2007; Sarafraz-Yazdi *et al.,* 2012; Sid kalal *et al.,* 2012; Byrns *et al.,*2006; Fan., 2005; Kallio *et al.,* 1989; Locas *et al.,*2004; Maga., 1979; Mark *et al.,*2006; Merritt *et al.,* 1963; Persson *et al.,* 1973; Stoffelsma *et al.,* 1968; Tatum *et al.,* 1969; Zoller *et al.,* 2007). In recent years, the electrochemical techniques have led to the advancement in the field of analysis because of their sensitivity, low cost and relatively short analysis time, as compared with other techniques. Electrochemical have proven to be useful for development of very sensitive and selective methods for the determination of organic molecules. In this work, differential pulse voltammetry (DPV) was method with good precision and accuracy for the determination of furan in beverage samples developed.

MATERIALS & METHODS

Furan (>99.0% purity), was purchased from Merck and Co. Inc. (Darmstadt, Germany).

A stock solution of furan (1mM) was prepared in methanol-water (10:90, v/v),britton-rabinson buffers from pH 2.0-10 (0.1 M) which used for pH experiment and also supporting electrolyte, were prepared in doubly distilled water. All Other reagents were of analytical grade and obtained from Merck, and all solutions were prepared with doubly distilled water. Voltammetric experiments were performed using a μAutolab Type III electrochemical system. A conventional three-electrode cell consisting of a glassy carbon working electrode (2 mm in diameter), a platinum wire counter electrode and a saturated Ag/AgCl reference electrode were used for voltammetric experiments. A digital pH-meter (Ion Analyzer 827, Metrohm) with precision of ±0.001 was used for pH measurements. All the experiments carried out at room temperature. Before each experiment and transferring the glassy carbon electrode to the solution, it was cleaned by polishing with 0.05μm alumina slurry on a

polishing cloth and rinsed thoroughly with doubly distilled water.After each polishing step to get a stable and reproducible background current, Cyclic voltammetry were performed at scan rate of 100 mV/s between 0.0 and 1.6 V for 10 times in 0.1 M H_2SO_4 solution (Bagheri and Hosseini 2012). To study the accuracy and repeatability of the developed method, carried out using the standard addition method by adding the known amounts of Furan to the pre-analyzed samples then mixtures were analyzed by the developed method.

RESULTS & DISCUSSION

In order to understand the electrochemical process occurring at the GCE (glassy carbon electrode), cyclic voltammetry were applied. Fig.1 shows a cyclic voltammogram of 1mM Furan in 0.1 M britton-rabinson buffer solution (pH=5) at a glassy carbon electrode at 50 mv/sscan rate. As shown in Fig. 1, Furan gives one well-defined irreversible oxidation peak at +1.44 V.The effect of supporting electrolytes on current–potential curves was investigated by a 0.1 M solution of various supporting electrolytes (Fig.2). The results showed that the britton-rabinson buffers can give the best background and signal response. For studying the effect of pH of britton-rabinson buffer solution on voltammetric response of Furan, the cyclic voltammograms of 1.0 mM Furan were recorded from pH 2.0 to 10.0 at a scan rate of 50.0 mV/s. The anodic peak current was affected by the pH of the solution (Figs.3-4).As Fig. 4 shows, the maximum peak current was obtained at pH 5.0. So pH 5.0 was chosen for the subsequent analytical experiments.Useful data involving electrochemical mechanism mostly can be acquired from the scan rate and its relationship with peak current and potential. Therefore, the influence of potential scan rate on the electrochemical behavior of Furan at GCE was studied with the change of scan rate (Fig. 5A). As shown Fig. 5A, when the scan rate was increased, a linear relationship between the peak current and thesquare root of scan rate v (Fig. 5B) in the range from 25 to 250 mV/s was obtained, suggesting a diffusion-controlled process for oxidation of furan at GCE.

A plot of logarithm of anodic peak current vs. logarithm of scan rate gave a straight line with a slope of 0.612 (Fig. 6A) closes to the theoretical value of 0.5, which is expected for an ideal reaction for the diffusion-controlled electrode process (Laviron *et al.,* 1980; Hegde, *et al.,* 2009). In addition, the Ep of the oxidation peak was dependent on scan rate. The anodic peak potential shifted to positive values when the scan rate was increased, which these results also confirmed that the oxidation reaction was irreversible (Fig. 6B).
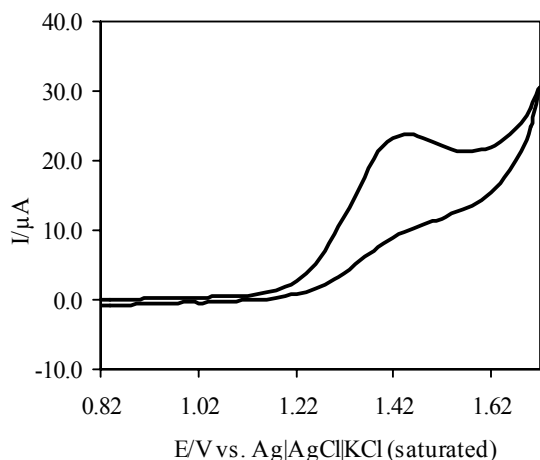
Fig. 1. a cyclic voltammogram of 1mM Furan solutions in methanol-water (10:90) and 0.1 M britton-rabinson buffer solution (pH=5) at a GCE and 50 mV/s scan rate to the Ag/AgCl reference electrode
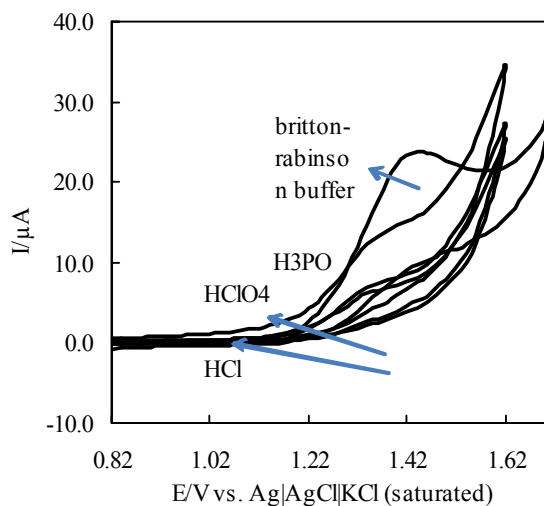

Fig. 2. Cyclic voltammogramms of furan with 0.1 M solution of various supporting electrolytes
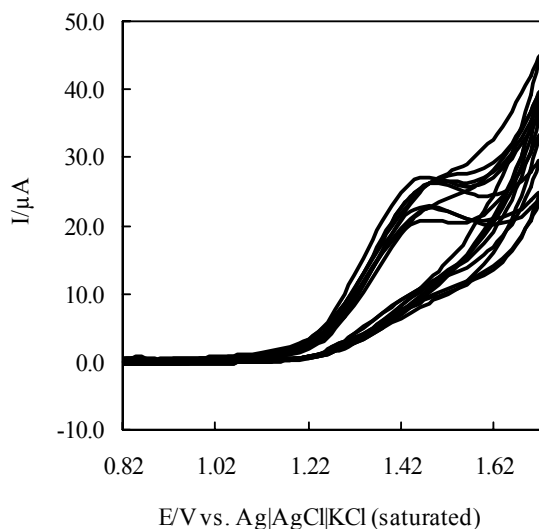

Fig. 3. DPVs of 1mM furan solutions in methanol-water (10:90) at a GCE in BR buffers at pH 2,3,4,5,6,7,8,9,10. The scan rate was 50 mv s-1. The reference electrode was Ag/AgCl
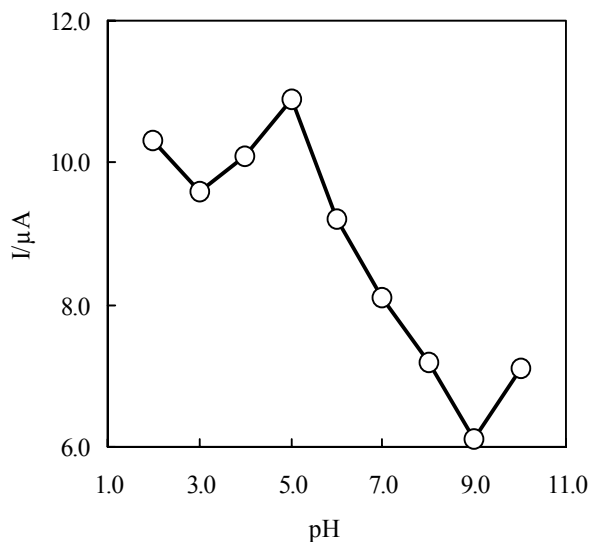

Fig. 4. Plot of I of the oxidation peak potential of 1mM Furan solutions in methanol-water (10:90) against pH for DPV at a GCE. The reference electrode was Ag/AgCl

According to Nicholson (Bard, and Faulkner, 2001), for an irreversible anodic reaction, the relationship between E_p and υ is described as follows:

$$E_P = E^0 + RT/(1-\alpha)n_\alpha F[0.780 + \ln(D^{1/2}/k_s) + \ln((1-\alpha)n_\alpha F\upsilon/RT)^{1/2}] \qquad (1)$$

where E is formal standard potential, α is the charge transfer coefficient, n_α is the number of the electrons

transferred in the rate determining step, D is the diffusion coefficient of Furan and k_s is the standard heterogeneous reaction rate constant. F, R and T have their usual meaning. Thus the value of $(1-\alpha)n_\alpha$ can be easily calculated from the slope of Ep vs. log õ. In this system, the slope is 0.149, taking T = 298 K, R = 8.314 J K^{-1} mol^{-1} and F = 96,480 C, $(1-\alpha)$ n_α was calculated to be 0.2. Generally, the results suggested that one-electron transfer process are the rate-limiting by step
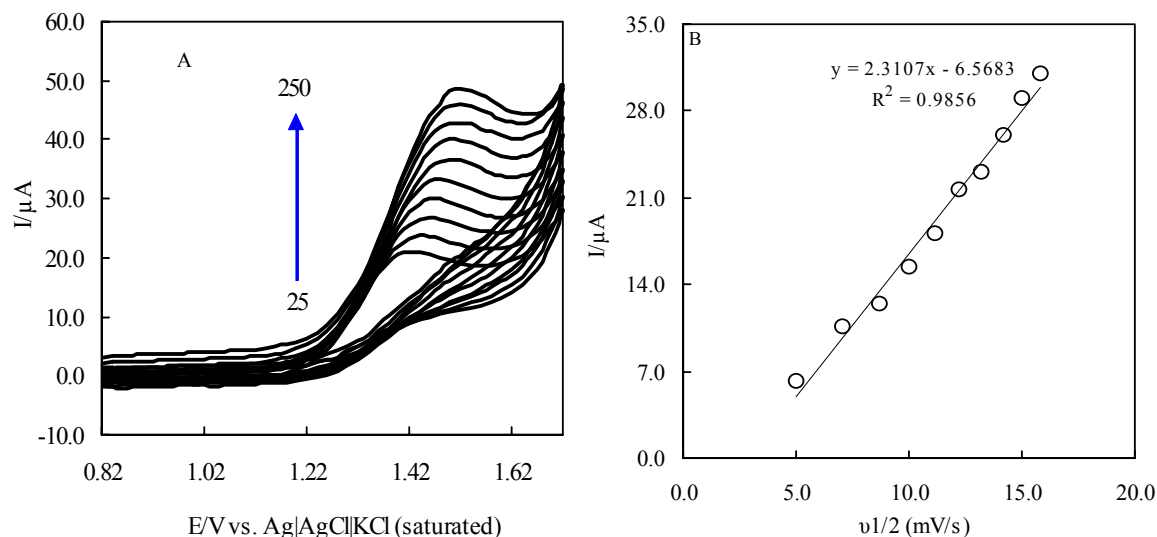
Fig. 5. A: Cyclic voltammograms of 1mM furan solutions in methanol-water (10:90) in 0.1 M britton-rabinson buffer solution (pH=5) , at various scan rates, from 25 to 250 mV/s.

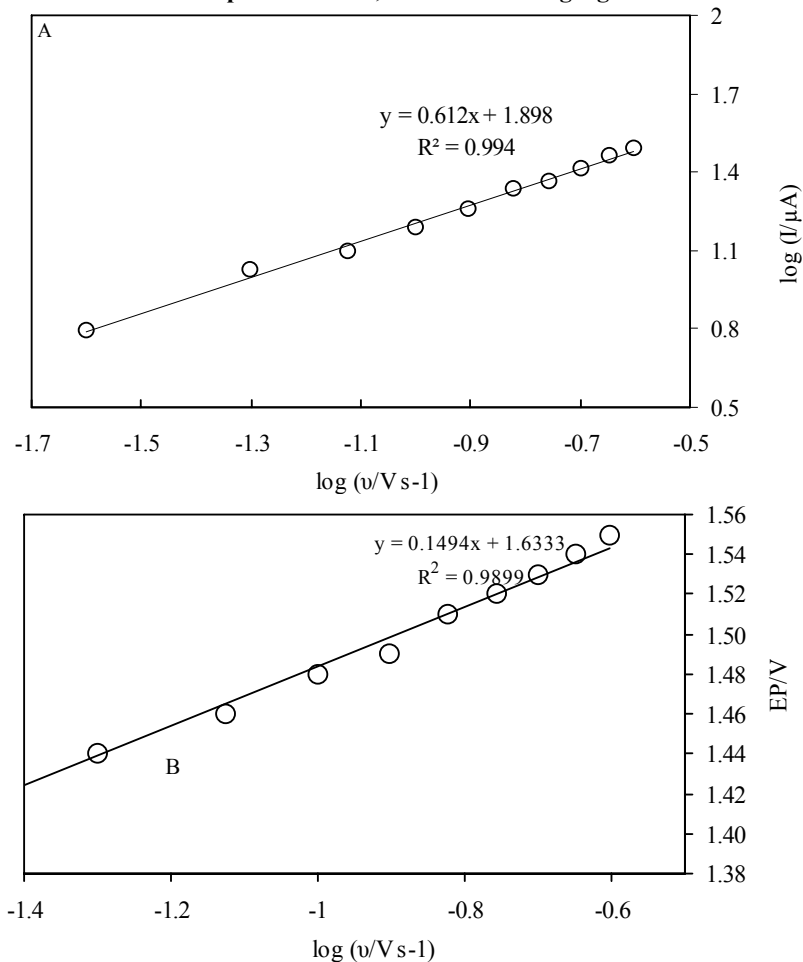**B: Variation of v $^{1/2}$ with anodic peak current I, at a GCE with Ag/AgCl as reference electrode**

Fig. 6. A:Variation of the logarithm of peak current I with the logarithm of the scan rate B:Variation of Ep versus the logarithm of the scan rate for 1mM Furan
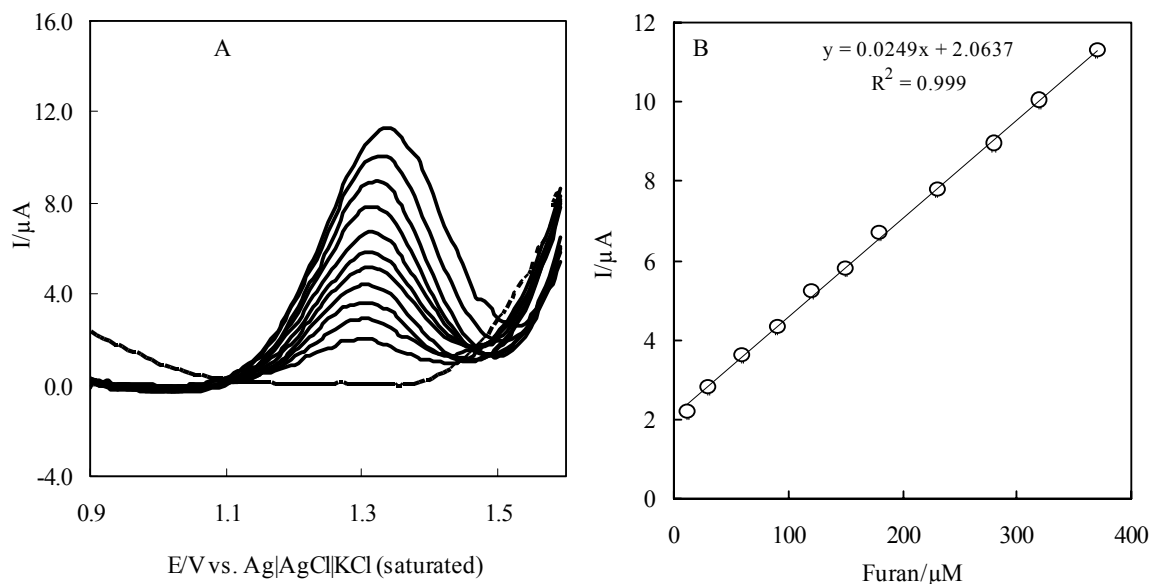
Fig.7. (A): differential pulse voltammograms of Furan at GCE in 0.1 M britton-rabinson buffer solution (pH 5.0). Furan concentrations (from bottom to up): 12, 30, 60, 90, 120, 150, 180, 230, 280, 320 and 370 µM. (B): corresponding linear calibration curves of the anodic peak currents vs. Furan concentration

Table 1. Determination of furan in beverage samples

Beverage	Spiked $(10^{-6}M)^a$	Found $(10^{-6}M)^a$	Recovery(%) + RSD%
Sample 1	30	30.3	101 ± 3.6
	50	49.7	99.4 ± 3.90
	70	69.1	98.7 ± 4.2
Sample 2	30	30.9	103 ± 4.1
	50	50.8	101.6 ± 3.2
	70	68.7	98.14 ± 3.6
Sample 3	30	29.7	99 ± 4.6
	50	48.3	96.6 ± 3.2
	70	68.2	97.4 ± 4.7

a: four determination

assuming charge transfer coefficient $\alpha = 0.8$ for Furan. Differential-pulse voltammetry (DPV) is one of the most sensitive electrochemical detection methods. Therefore, DPV was used for determination of Furan. Under the optimized experimental conditions, the DPV curves were obtained using different concentrations of Furan (Fig. 7A). As it can be seen, the height of the DPV peaks (Ipa) increases with increase in concentration of Furan. The calibration curve was obtained using data from these measurements (Fig. 7B). According to the obtained results, linear calibration graphs were obtained for Furan with the linear dynamic range of 12–360 µM (0.81–24.5 ppm). The linear regression equations were I_{pa} (µA)=2.063+0.024C_{Furan} (µM), with a correlation coefficient of 0.999 and a sensitivity of 0.024 µA/µM. A limit of detection (LOD) of 3 µM (0.2 ppm) and limit of quantification (LOQ) of

10 µM (0.68 ppm) were calculated according to the 3 s_b/m and 10 s_b/m criterions, respectively, where m is the slope value of the calibration curve and s_b is the calculated standard deviation for the peak currents of the blank (Four runs).

The reproducibility of the method was tested by analyzing 10 samples containing 30 µM of Furan. The RSD % of the method thus obtained was 3.0 % which showed excellent reproducibility for this developed methods. To demonstrate the efficiency of the method, the developed method was applied for determination of Furan in three different beverage samples. The recovery experiments were carried out using the standard addition method by adding the known amounts of Furan to the beverage samples, and the calibration plot was used for determination of spiked Furan in beveragesamples.The results of recovery

experiments were also shown in Table1. The results illustrated that the proposed method is accurate enough for practical applications.

CONCLUSION

A glassy carbon electrode was used as the working electrode for determination of Furan. The electro-catalytic activity of the GCE electrodes showed a good electro-catalytic effect toward Furan electro-oxidation. The results of oxidation kinetics of Furan indicated that the oxidation process is diffusion controlled. Finally, the oxidation current of Furan on GCE electrodes was used for determination of Furan in aqueous solution and a linear calibration was found in the range of 12–360 µM. Therefore this method can be used for quantitative determination of Furan in real samples.

REFERENCES

Abdullahi, M. S., Uzairu, A. and Okunola, O. J. (2009). Quantitative Determination of Heavy Metal Concentrations in Onion Leaves, Int. J. Environ. Res., **3 (2)**, 271-274.

Adjei-Boateng , D ., Obirikorang , K . A . and Amisah , S. (2010). Bioaccumulation of Heavy Metals in the Tissue of the Clam Galatea paradoxa and Sediments from the Volta Estuary, Ghana, Int. J. Environ. Res., **4 (3)**, 533-540.

Agbozu, I. E. and Opuene, K. (2009). Occurrence and Diagenetic Evolution of Perylene in the Sediments of Oginigba Creek, Southern Nigeria, Int. J. Environ. Res., **3 (1)**, 117-120.

Ahsan, D. A. and Del Valls, T. A. (2011). Impact of Arsenic Contaminated Irrigation Water in Food Chain: An Overview From Bangladesh, Int. J. Environ. Res., **5 (3)**, 627-638.

Akhtar, N. and Tufail, M. (2011). Cancer Risk in Pakistan Due to Natural Environmental Pollutants, Int. J. Environ. Res., **5 (1)**, 159-166.

Aktar, W., Paramasivam, M. and Sengupta, D. (2009). Persistence of Benthiocarb in Soil: Influence of Ultraviolet and Sunlight, Int. J. Environ. Res., **3 (3)**, 349-352.

Annabi, A., Messaoudi, I., Kerkeni, A. and Said, Kh. (2011). Cadmium Accumulation and Histological Lesion in Mosquitofish (Gambusia affinis) tissues Following Acute and Chronic Exposure, Int. J. Environ. Res., **5 (3)**, 745-756.

Ashraf, M. A., Maah, M. J. and Yusoff, I. (2012). Bioaccumulation of Heavy Metals in Fish Species Collected From Former Tin Mining Catchment, Int. J. Environ. Res., **6 (1)**, 209-218.

Asi, M. R. , Hussain, A. and Muhmood, S. T. (2008). Solid phase extraction of pesticide residues in water samples: DDT and its metabolites, Int. J. Environ. Res., **2 (1)**, 43-48.

Bagheri,A. and Hosseini, H. (2012). Electrochemistry of raloxifene on glassy carbon electrode and its determination in pharmaceutical formulations and human plasma, Bioelectrochemistry Volume **88**, 164–170.

Banaee, M. Mirvagefei, A. R. Rafei, G. R. and Majazi Amiri, B. (2008). Effect of sub-lethal Diazinon Concentrations on Blood Plasma Biochemistry, Int. J. Environ. Res., **2 (2)**, 189-198.

Bard, A. J. and Faulkner, L. R. (2001). Electrochemical Methods: Fundamentals and Applications, second ed., Wiley, New York.

Belarbi, H. and Al-Malack, M. H. (2010). Adsorption and Stabilization of Phenol by Modified Local Clay, Int. J. Environ. Res., **4 (4)**, 855-860.

Blagojeviæ, J., Jovanoviæ, V., Stamenkoviæ, G., Jojiæ, V., Bugarski-Stanojeviæ, V., Adnaðeviæ, T. and Vujoševiæ, M. (2012). Age Differences in Bioaccumulation of Heavy Metals in Populations of the Black-Striped Field Mouse, Apodemusagrarius(Rodentia, Mammalia), Int. J. Environ. Res., **6 (4)**, 1045-1052.

Becalski, A. and Seaman, S. (2005). Furan precursors in food: A model study and a development of a simple headspace method for determination of furan. J. AOAC Int., **88**, 102–106.

Bhuvaneshwari, R. , Babu Rajendran, R. and Kumar, K. (2013). Induction of DNA Damage and GADD45â gene Mutation in Zebra fish (Daniorerio) due to Environmentally Relevant Concentrations of Organochlorine Pesticides & Heavy Metals, Int. J. Environ. Res., **7 (1)**, 219-224.

Bianchi, F., Careri, M., Mangia, A. and Musci M. (2006) Development and validation of a solid phase micro-extraction-gas chromatography-mass spectrometry method for the determination of furan in baby-food. J. Chromatogr., A**1102**, 268–272.

Byrns, M. C., Vu, C. C., Neidigh, J. W., Abad, J. L., Jones, R. A. and Peterson, L. A. (2006). Detection of DNA adducts derived from the reactive metabolite of furan, cis-2-butene-1,4-dial. Chemical Research in Toxicology, **19**, 414-420.

Carfagna, M. A., Held, S. D. and Kedderis, G. L. (1993). Furan-induced cytolethality in isolated rat hepatocytes: correspondence with in vivo dosimetry. Toxicol. Appl. Pharmacol., **123**, 265–273.

Chen, Q. Y., Wu, Z. H. and Liu, J. L. (2011). Ecotoxicity of Chloramphenicol and Hg Acting on the Root Elongation of Crops in North China, Int. J. Environ. Res., **5 (4)**, 909-916.

Chibunda, R. T. (2009). Chronic Toxicity of Mercury (HgCl2) to the Benthic Midge Chironomus riparius, Int. J. Environ. Res., **3 (3)**, 455-462.

Clemente, Z., Castro, V. L., Jonsson, C. M. and Fraceto, L. F. (2012). Ecotoxicology of Nano-TiO2 – An Evaluation of its Toxicity to Organisms of Aquatic Ecosystems, Int. J. Environ. Res., **6 (1)**, 33-50.

Dutta, H. M. and Dalal, R. (2008). The Effect of Endosulfan on the Ovary of Bluegill Sunfish:A Histopathological Study (Lepomis macrochirus), Int. J. Environ. Res., **2 (3)**, 215-224.

Etale, A. and Drake, D. C. (2013). Industrial Pollution and Food Safety in Kigali, Rwanda, Int. J. Environ. Res., **7 (2)**, 403-406.

Fan, X. J. (2005). Formation of furan from carbohydrates and ascorbic acid following exposure to ionizing radiation and thermal processing. Journal of Agricultural and Food Chemistry, **53**, 7826-7831.

García-Flores, E., Wakida, F. T. and Espinoza-Gomez, J. H. (2013). Sources of Polycyclic Aromatic Hydrocarbons in Urban Storm Water runoff in Tijuana, Mexico, Int. J. Environ. Res., **7 (2)**, 387-394.

Ghaderi, A. A., Abduli, M. A., Karbassi, A. R., Nasrabadi, T. and Khajeh, M. (2012). Evaluating the Effects of Fertilizers on Bioavailable Metallic Pollution of soils, Case study of Sistan farms, Iran, Int. J. Environ. Res., **6 (2)**, 565-570.

Goldmann, T., Périsset, A., Scanlan, F. and Stadler, R. H. (2005) Rapid determination of furan in heated foodstuffs by isotope dilution solid phase micro-extraction-gas chromatography-mass spectrometry (SPME-GC-MS). Analyst, **130**,878–883.

Heidari, M., Moattar, F., Naseri, S., Samadi, M. T. and Khorasani, N. (2011). Evaluation of Aluminum-Coated Pumice as a Potential Arsenic(V) Adsorbent from Water Resources, Int. J. Environ. Res., **5 (2)**, 447-456.

Jafari, H. R. and Ebrahimi, S. (2007). A Study on Risk Assessment of Benzene as one of the VOCs Air Pollution, Int. J. Environ. Res., **1 (3)**, 214-217.

Jakubke, H. D. and Jeschkeit, H. (1994).Concise Encyclopedia of Chemistry. Walter de Gruyter. 001-1201. Hasan, M. A. A., Ahmed, M.K., Akhand, A. A., Ahsan, N. and Islam, M. M. (2010). Toxicological Effects and Molecular Changes Due to Mercury Toxicity in Freshwater Snakehead (Channa punctatus Bloch, 1973), Int. J. Environ. Res., **4 (1)**, 91-98.

Hassani, A. H., Jafari, M. A. and Torabifar, B. (2010). Trihalomethanes Concentration in Different Components of WaterTreatment Plant and Water Distribution System in the North of Iran, Int. J. Environ. Res., **4 (4)**, 887-892.

Hasnip, S., Crews, C. and Castle, L. (2006) Some factors affecting the formation of furan in heated foods. Food Addit. Contam., **23 (3),** 219–227.

Hegde, R. N., Kumara Swamy, B. E., Shetti, N. P. and Nandibewoor, S. T. (2009). Electro-oxidation and determination of gabapentin at gold electrode. J. Electroanal. Chem., **635**, 51-57.

Hoydonckx, H. E., Van Rhijn, W. M., Van Rhijn, W., De Vos, D. E. and Jacobs, P. A. (2005), "Furfural and Derivatives", Ullmann's Encyclopedia of Industrial Chemistry, Weinheim: Wiley-VCH, 12-119.

Jovic, M. S., Manojlovic, D., Stankoviæ, D. M., Miliæ, A., Sentiæ, M. and Rogliæ, G. (2013).Volta metric Behavior of Mesotrione using Silver/Amalgam Electrode, Int. J. Environ. Res., **7 (1)**, 165-172.

Kallio, H., Leino, M. and Salorinne, L. (1989). Analysis of the headspace of foodstuffs near room temperature. Journal of High Resolution Chromatography, **12**, 174-177.

Kapdan, E., Varinlioglu , A. and Karahan, G. (2011). Radioactivity Levels and Health Risks due to Radionuclides in the Soil of Yalova, Northwestern Turkey, Int. J. Environ. Res., **5 (4)**, 837-846.

Laviron, E. Roullier, L. Degrand, C. and Multilayer, A. (1980). Model For The Study Of Space Distributed Redox Modified Electrodes .2. Theory And Application Of Linear Potential Sweep Voltammetry For A Simple Reaction. J. Electroanal. Chem., **112, (1),** 11-23.

Locas, C. P. and Yaylayan, V. A. (2004). Origin and mechanistic pathways of formation of the parent furan: a food toxicant. Journal of Agricultural and Food Chemistry, **52**, 6830-6836.

López-PiñeiroA., Albarrán, A., Cabrera, D., Peña, D. and Becerra, D. (2012). Environmental Fate of Terbuthylazine in Soils Amended with Fresh and Aged Final Residue of the Olive-Oil Extraction Process, Int. J. Environ. Res., **6 (4)**, 933-944.

Maheswari, S. T. and Ramesh, A. (2012). Adsorption and Degradation of Anilofos in Different Soils and its Environmental Impact in Soils, Int. J. Environ. Res., **6 (2)**, 451-456.

Maga, J. A. (1979). Furan represent a class of compounds that have been reported in a wide variety of foods. Normally, they result from thermal decomposition reactions, and, as such, are important in foods. They also possess unique sensory. Critical Reviews in Food Science and Nutrition, **11**,355-400.

Mark, J., Pollien, P., Lindinger, C., Blank, I. and Mark, T. (2006). Quantitation of Furan and Methylfuran Formed in Different Precursor Systems by Proton Transfer Reaction Mass Spectrometry. Journal of Agricultural and Food Chemistry, **54**, 2786-2793.

Merritt, C., Bazinet, M. L., Sullivan, J. H. and Robertson, D. H. (1963). Mass spectrometric determination of the volatile components from ground coffee. Journal of Agricultural and Food Chemistry, **11**, 152-155.

Naim, R., Kisay, L., Park, J., Lee, Ch. Qaisar, M., Zulfiqar, A. B. and Noshin, M. (2011). Precipitation Chelation of Cyanide Complexes in Electroplating Industry Wastewater, Int. J. Environ. Res., **5 (1)**, 85-92.

Nasrollahzadeh, H. S., Najafpour, G. D. and Aghamohammadi, N. (2007). Biodegradation of Phenanthrene by Mixed Culture Consortia in Batch Bioreactor using Central Composite Face-Entered Design, Int. J. Environ. Res., **1 (2)**, 80-87.

NTP, (1993). National Toxicology Program, Toxicology and carcinogenesis studies of furan (CAS No. 1100-00-9) in F344/N rats and B6C3FI mice (gavage studies). NTP technical report no. 402. US Department of Health and Human Services. Public Health Service. National Institutes of Health. Research Triangle Park, NC.

Olivella, M. À., Fernández, I., Cano, L., Jové, P. and Oliveras, A. (2013). Role of Chemical Components of cork

on Sorption of Aqueous Polycyclic Aromatic Hydrocarbons, Int. J. Environ. Res., **7 (1)**, 225-234.

Persson, T. and von Sydow, E. (1973). Aroma of canned beef: Gas chromatographic and mass spectrometric analysis of the volatiles. Journal of Food Science**, 38**, 377-385.

Priju, C. P. and Narayana, A. C. (2007). Heavy and Trace Metals in Vembanad Lake Sediments, Int. J. Environ. Res., **1 (4)**, 280-289.

Sadashiva Murthy, B. M., Ramesh, H. S. and Mahadevaswamy, M. (2009). Pollution Migration Study in Subsurface Environment, Int. J. Environ. Res., **3 (4)**, 545-556.

Saeedi, M., Li, L.Y. and Moradi Gharehtapeh, A. (2013). Effect of Alternative Electrolytes on Enhanced Electrokinetic Remediation of Hexavalent Chromium in Clayey Soil, Int. J. Environ. Res., **7 (1)**, 39-50.

Sarafraz-Yazdi,A., Abbasian, M., Amiri, A., (2012). Determination of furan in food samples using two solid phase microextraction fibers based on sol–gel technique with gas chromatography–flame ionisation detector. Food Chemistry **131**, 698–704.

Senyuva, H.Z and Gökmen, V. (2005). Analysis of furan in foods. Is headspace sampling a fit for-purpose technique. Food Additives and Contaminants **22,**1198-1202.

Shahidi Bonjar, G. H. (2007). Potential Hazards of Gasoline Additives in Altering Soil Environment in Favor of Harmful Microorganisms, Int. J. Environ. Res., **1 (1)**, 1-4.

Shegefti, S., Sereshti, H. and Samadi, S. (2010). Determination of Endosulfan in Water Samples Using Dispersive Liquid-liquid Micro-extraction and Experimental Design for Optimization, Int. J. Environ. Res., **4 (2)**, 237-246.

Shimoda, M. and Shibamoto, T. (1990). Isolation and identification of headspace volatiles from brewed coffee with an on-column GC/MS method. Journal of Agricultural and Food Chemistry, **38**, 802-804.

Shwetha, A., Hosetti, B. B. and Dube, P. N. (2012). Toxic Effects of Zinc Cyanide on Some Protein Metabolites in Fresh water fish, Cirrhinus mrigala (Hamilton), Int. J. Environ. Res., **6 (3)**, 769-778.

Sid kalal, H., Khanchi, A. R., Konoz, E., Khaki, S., Taghiof, M., Baghdadi, M. and Ahmad Panahi, H. (2012). Pre-concentration of ultra-trace furan in beverage samples and its determination by high performance liquid chromatography. International Journal of Industrial Chemisty . **3 (19)**, 1-6.

Sotelo, J. L., Rodríguez, A., Álvarez, S. and García, J. (2012). Modeling and Elimination of Atenolol on Granular Activated Carbon in Fixed Bed Column, Int. J. Environ. Res., **6 (4)**, 961-968.

Srivastava, S., Narvi, S. S. and Prasad, S. C. (2008). Organochlorines and Organophosphates in Bovine Milk Samples in Allahabad Region, Int. J. Environ. Res., **2 (2)**, 165-168.

Stoffelsma, J., Simpa, G., Kettenes, D. K. and Pypker. J. (1968). New volatile components of roasted coffee. Journal of Agricultural and Food Chemistry, **16**, 1000-1004.

Tatum, J. H., Shaw, P. E. and Berry, R. E. (1969). Degradation products from ascorbic acid. Journal of Agricultural and Food Chemistry, **17**, 38–40.

Vinodhini, R. and Narayanan, M. (2009). Heavy Metal Induced Histopathological Alterations in Selected Organs of the Cyprinus carpio L.(Common Carp), Int. J. Environ. Res., **3 (1)**, 95-100.

Wasim Aktar, Md., Paramasivam, M. and Bhattacharyya, A. (2008). Dissipation Kinetics of Benthiocarb in Water at Different pH levels under Laboratory Condition, Int. J. Environ. Res., **2 (1)**, 71-74.

Wenzl, T., Lachenmeier, D. W. and Gökmen V. (2007). Analysis of heat-induced contaminants (acrylamide, chloropropanols and furan) in carbohydrate-rich food. Analytical and Bioanalytical Chemistry, **389,** 119-137.

Zoller, O., Sager, F. and Reinhard, H. (2007). Furan in food: Headspace method and product survey. Food Additives and Contaminants, **24 (S1),** 91–107.