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A nanostructured suitable platform based on multi wall carbon nanotubes and graphene nano sheets composite for determination of mefenamic acid

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Abstract: A mefenamic acid sensor was prepared by the modification of a glassy carbon electrode (GCE) with graphene nano-sheets (Gr) and multi wall carbon nanotubes (MWCNT). The designed sensor (MWCNT/Gr/GCE) indicated an electrocatalytic behaviour when applied for mefenamic acid (MFA) oxidation due to good conductivity, low electron transfer resistance and catalytic effect. The suggested sensor revealed a lower overvoltage and enhanced current compared with bare GCE for the oxidation of MFA. The observations indicated that the oxidation potential of MFA is decreased more than 200 mV using the designed sensor. The percentages of MWCNTs and Gr nano materials, and pH solution were optimized. Under the optimum conditions, some kinetic parameters, such as surface coverage in a 0.5 mM $[\text{Fe}(\text{CN})_6]^{3-/4-}$ solution was obtained by cyclic voltammetric method. The diffusion coefficient of MFA (D) was calculated to be $2.88 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$ by chronoamperometric technique. The MWCNT/Gr/GCE sensor exhibited a linear dynamic range for MFA (2–100 μM) with a detection limit of 0.66 μM by differential pulse voltammetry (DPV) technique. This sensor revealed a suitable applicability for determination of MFA in real samples (drug samples and serum solutions).

Keywords: mefenamic acid (MFA); graphene nano-sheets; differential pulse voltammetry; multi wall carbon nanotubes; real samples.

INTRODUCTION

Mefenamic acid (MFA, 1 2-[(2,3-dimethylphenyl)amino]benzoic acid) is a nonsteroidal anti-inflammatory drug which possesses analgesic and antipyretic properties. It is used in the treatment of several pathological states such as osteoarthritis, nonarticular rheumatism, sport injuries and other painful musculoskeletal illnesses.^{1,2} However, the excess of MFA leads to the production of toxic metabolite accumulation which can cause acute hepatic necrosis, inducing morb-

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idity and mortality in humans. So, according to the importance of MFA determination in biological fluids such as serum solution, some analytical methods such as spectrophotometry,^{3,4} chromatography,⁵ chemiluminescence,⁶ capillary electrophoresis,^{7,8} potentiometry,^{9,10} polarography,¹¹⁻¹³ and voltammetry using molecularly imprinted film modified carbon electrode^{14,15} have been developed for the quantitative determination of MFA. The mentioned methods have some disadvantages such as being time consuming, expensive and having low sensitivity and selectivity in the corresponding determinations. The electrochemical methods using modified electrodes offer a powerful tool for environmental, clinical and food analysis because of their advantages like high sensitivity, good selectivity, simplicity and low-cost.¹⁶⁻¹⁸

The nanomaterials have recently received noticeable attention in the scientific and engineering fields due to their unique properties such as high conductivity, large surface/volume ratio, and extremely high mechanical strength.^{19,20} In the electrochemical field lots of nanomaterials have been applied as electrode materials to promote electron transfer reactions and to enhance electrode conductivity.²¹ Graphene nano sheets (Gr) as a monolayer of hexagonally configured sp^2 bonded carbon atoms, due to the specific properties such as suitable mechanical strength, large surface area, high conductivity and electron mobility at room temperature, is a nanomaterial which has attracted a considerable degree of attention in scientific and technological areas.²²

Another nanomaterial which has been widely used in the electrochemical field are the multi wall carbon nanotubes (MWCNTs). Carbon nanotubes are constructed from sp^2 carbon units with the structure of hexagonal honeycomb lattices which possess several nanometers in diameter and many microns in length which leads to an enhancement in surface area and consequently high conductivity.²³ Therefore, carbon nanotubes (CNT) and graphene nano sheets are widely used in the construction of modified electrodes and electrochemical sensors.^{24,25}

Up to now, a carbon paste electrode modified with multiwall carbon nanotubes (MWCNTPE) was applied to study the electrocatalytic activity of dopamine (DP) in the presence of homocysteine (HCy) and it was used for the determination of HCy.²⁶ Keshtkar group reported a novel electrochemical sensor for the selective and sensitive detection of carbidopa in the presence of a large excess of folic acid at physiological pH by the bulk modification of a carbon paste electrode (CPE) with carbon nanotubes (CNTs) and vinylferrocene. Using square wave voltammetry (SWV), a linear dynamic range of 1.0×10^{-6} – 7.0×10^{-4} M with a detection limit of 2.0×10^{-7} M was obtained for carbidopa detection.²⁷ Lv group developed a new electrochemical sensing strategy for the quantitative monitoring of inorganic mercury(II) in the contaminated water by the immobilization of poly(*p*-aminobenzene sulfonic acid)-functionalized single-walled car-

bon nanotubes on a glassy carbon electrode.²⁸ Olana *et al.* reported a new method for the determination of ascorbic acid (AA) based on a glassy carbon electrode (GCE) modified with a perforated film produced by reduction of diazonium generated *in situ* from *p*-phenylenediamine (PD) while holes were intentionally created in the modifier film by stripping pre-deposited gold nanoparticles.²⁹ Also, Benvidi group developed a nanostructure electrochemical sensor for the simultaneous determination of cysteine and tryptophan with a low detection limit and applicable in real samples.³⁰

Following our previous works in electrocatalytic area,^{31,32} some modified electrodes were designed for the determination of various species such as hydrazine and hydroxyl amine with low detection limit and wide linear range. In the present study, a glassy carbon electrode modified with graphene oxide nano-sheets and multi-wall carbon nanotubes (MWCNT/Gr/GCE) was made. The modification of the electrode with nanomaterials of Gr and MWCNTs leads to the increasing of the surface area of the electrode and its catalytic properties.³³ Under the optimum conditions, some parameters of analyte (MFA) such as the diffusion coefficient of MFA in a 0.1 M NaOH solution (pH 13) were calculated. The obtained results revealed a linear dynamic range of 2–100 μM and the detection limit of 0.66 μM for MFA using the differential pulse voltammetric (DPV) technique. Also, the MWCNT/Gr/CPE sensor was used for rapid and sensitive electrocatalytic determination of MFA in drug samples and serum solutions.

EXPERIMENTAL

Apparatus and chemicals

Electrochemical measurements were performed by a potentiostat/galvanostat (SAMA 500, electroanalyzer system, Iran). All electrochemical measurements were carried out in a three electrode cell including a modified or bare GCE, an Ag/AgCl (KCl, sat.) and a platinum electrode as working, reference electrode (all potentials are referred to this reference electrode) and auxiliary electrodes, respectively. The pH values of solutions were adjusted using a Milwaukee pH meter.

All solutions were freshly prepared with deionized water. The graphite fine powder and paraffin oil (DC 350, 0.88 g cm⁻³), both from Merck (Germany), were used as received. MWCNT was purchased from Merck and all other reagents were from Sigma–Aldrich. All other reagents were of analytical grade.

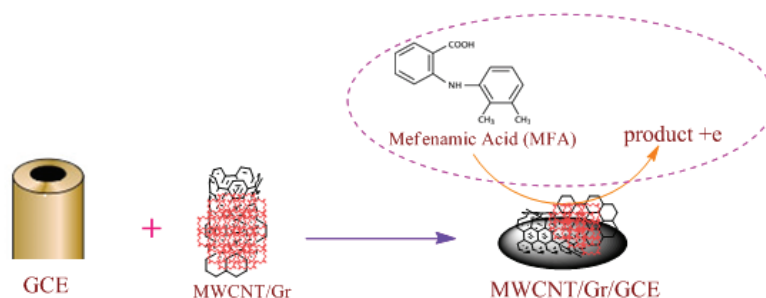
The synthesis process of reduced graphene oxide (Gr)

The graphene nano sheets were synthesized according to the procedure from the literature.³⁴ At first, a mixture of graphite/KMnO₄ (3:18 mass ratio) and a mixture of H₂SO₄/H₃PO₄ (360:40 volume ratio) were prepared at 50 °C. After that, two mixtures were added by shaking and then stirring for 12 h. The prepared product cooled down to 25 °C and was then transferred into ice bath containing 6 mL of H₂O₂ (30 %). The obtained solution was centrifuged and then filtered. After filtering, the obtained precipitate was washed with water, HCl (30 %), and finally washed twice with 200 mL of ethanol. After washing process the precipitate was sonicated for 3 h and consequently a colloidal suspension of graphene oxide nano sheets were obtained in purified water (150 mg/50 mL). Graphene oxide (GO) was reduced

using hydrazine and ammonia solutions to obtain reduced graphene oxide nano sheets (Gr). For the reducing process, 50 μL of hydrazine solution (98 %) with 200 μL of ammonia solution (30 % in water) were added to the graphene oxide suspension. The obtained solution was refluxed at 90 $^{\circ}\text{C}$ for 12 h and it was cooled down to room temperature. Finally, this solution was centrifuged, and the obtained precipitate (Gr) was washed with water and dried at 60 $^{\circ}\text{C}$ in vacuum for 24 h.

Fabrication of MWCNT/Gr/GCE sensor

The MWCNT/Gr/GCE sensor was prepared as follows. At first, the glassy carbon electrode was polished by 0.05 μm alumina slurry to mirror like, and then the mirror GCE was washed successively with anhydrous alcohol and water. Then, the ultra-sonication for 5 min was performed on the GCE. At the second step, 30 μL of composite of MWCNT/Gr (Gr (0.03 g mL^{-1}) and MWCNT (0.04 g mL^{-1}) in distilled water) the homogeneous suspension was pipetted onto the glassy carbon electrode surface and dried under ambient condition. At last, after drying of the modified electrode, it was washed with distilled water to prepare MWCNT/Gr/GCE sensor. The preparation of the MWCNT/Gr/GCE sensor is illustrated schematically in Scheme 1.



Scheme 1. The proposed electrochemical oxidation reaction mechanism of MFA.

Preparation of real samples for analytical performance

The solution of mefenamic acid (MFA) capsule (which were purchased from local sources (250 mg per capsule)) were prepared. After that, 20 mg of capsule powder was weighed and dissolved in a 50 mL distilled water solution by ultra-sonication, and the mixture was filtered with a filter paper. After filtering and adjusting the pH using a NaOH solution (pH 13.0), further dilution was performed to reach the calibration range of MFA. The blood serum sample was centrifuged for 10 min, filtered and diluted with a NaOH solution (pH 13.0) without any further treatment. Finally, 10 mL of obtained solution was transferred into the voltammetric cell to be analyzed without any further pre-treatment.

RESULTS AND DISCUSSION

The morphology investigation of MWCNT/Gr/GCE sensor

The morphology of bare GCE, and the modified electrodes was examined by the scanning electron microscopy (SEM). Fig. 1 reveals the SEM images of bare GCE, Gr/GCE, MWCNT/GCE and MWCNT/Gr/GCE electrodes, respectively. As shown in this figure, the bare glassy carbon electrode has a smooth surface

while Gr/GCE indicates petal-like graphene nanosheets with sharp edges, and random directions which make the nest-like structure with a large surface area (Fig. 1A and B). The SEM image of MWCNT/GCE indicates a surface which is covered uniformly with nanotubes of carbon and causes the rougher irregular surface than bare GCE surface (Fig. 1C). Fig. 1D shows the SEM image of MWCNT/Gr/CPE with more surface area than Gr and MWCNT, individually. So, according to the SEM images the modification of GCE with nanomaterials of Gr and MWCNT has been done well and led to the enhancement of the surface area.

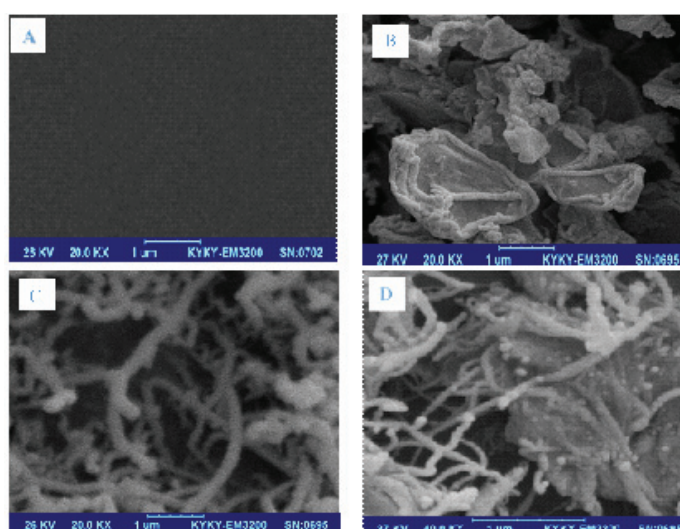


Fig. 1. The SEM images of GCE, Gr/GCE, MWCNT/GCE and MWCNT/Gr/GCE electrodes.

The electrochemical oxidation of MFA at the designed sensor

The electrooxidation of MFA at modified and non-modified electrodes was investigated by the cyclic voltammetry (CV) technique. The curves in Fig. 2 are related to the cyclic voltammogram of bare GCE (a), MWCNT/GCE (b), Gr/GCE (c), and MWCNT/Gr/GCE (d) in the absence of MFA and GCE (e), MWCNT/GCE (f), Gr/GCE (g) and MWCNT/Gr/GCE (h) in the presence of MFA (1.0 mM) in a NaOH solution pH 13.0 at the scan rate of 30 mV s^{-1} . The anodic peak potential of MFA is higher than 480 mV at bare GCE (curve e), while it is decreased to the potential of less than 350 mV at modified glassy carbon electrodes with MWCNT, Gr and MWCNT/Gr electrodes. Therefore, using the graphene nano-sheets and carbon nanotubes shows the noticeable catalytic effect on the oxidation of MFA. Also, the anodic peak current of MFA is significantly improved at the modified glassy carbon electrodes, which indicates the large surface area of the modified electrode. The observations reveal that the presence of graphene nano sheets and multi wall carbon nanotubes at the electrode

surface leads to the great improvement of the electrochemical responses, which can decrease the overpotential and increase the peak current for MFA oxidation. Therefore, MWCNT/Gr/GCE sensor offers a favourite electrode for the oxidation and the electroanalysis of MFA due to the low resistance, the catalytic effect and the large accessible surface area.

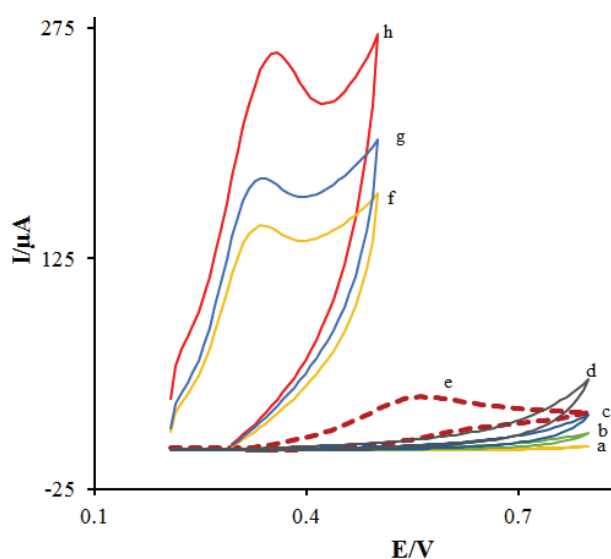


Fig. 2. Cyclic voltammograms of bare GCE (a), MWCNT/GCE (b), Gr/GCE (c) and MWCNT/Gr/GCE (d) in the absence of MFA and GCE (e), MWCNT/GCE (f), Gr/GCE (g), and MWCNT/Gr/GCE (h) in the presence of MFA (1.0 mM) in a NaOH solution pH 13.0 at the scan rate of 30 mV s⁻¹.

The effect of the potential scan rate was investigated on the oxidation of MFA using MWCNT/Gr/GCE sensor. Fig. 3 displays the cyclic voltammograms of MFA at different scan rates on the surface of the fabricated sensor. As observed in Fig. 3, the peak potentials are shifted slightly toward positive direction by increasing the scan rate. As shown in inset of this figure, the plot of the anodic peak current of MFA *versus* the square root of scan rate ($v^{1/2}$) is linear in the range of 10–100 mV s⁻¹. This linear behaviour indicates that the electrochemical oxidation of MFA at the MWCNT/Gr/GCE sensor is controlled by diffusion effect.³⁵

The surface coverage investigation

An approximate estimate of the surface coverage of the electrode was made by adopting the method used by the Randles–Sevcik equation:³⁶

$$I_{\text{peak}} = 2.69 \times 10^5 n^{2/3} AD^{1/2} C v^{1/2} \quad (1)$$

where I_{peak} is the anodic peak current, A is the surface area (cm^2), $n = 1$ and $D = 2.88 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$, and the other symbols have their usual meanings. Using the Randles–Sevcik equation and the slope of the I_p versus $v^{1/2}$ plot for a known concentration of $\text{K}_4[\text{Fe}(\text{CN})_6]$ (0.5 mM), microscopic areas for GCE, MWCNT/GCE, Gr/GCE and MWCNT/Gr/GCE were calculated to be 0.068, 0.1010, 0.1294 and 0.1512 cm^2 , respectively (while the geometric area for GCE was 0.07 cm^2).

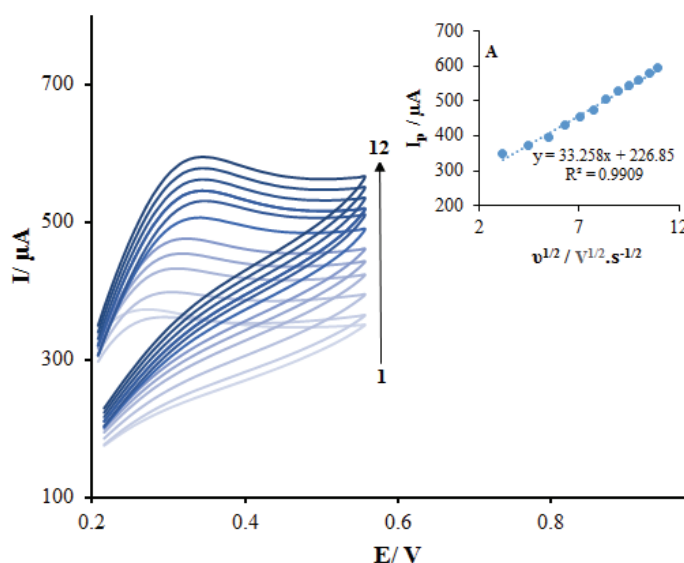


Fig. 3. Cyclic voltammograms of 1.0 mM MFA at different scan rates ($10\text{--}100 \text{ mV s}^{-1}$) on MWCNT/Gr/GCE sensor; inset: plot of anodic peak current (I_{pa}) versus the square root of scan rate ($v^{1/2}$).

The obtained results show that the presence of nanomaterials in MWCNT and Gr ion in the composite of MWCNT/Gr makes an increase of the active surface of the modified electrode, compared to the bare GCE and modified electrodes with Gr and MWCNT individually. The observation obtained for the active surface area confirms that using the nanomaterials in the structure of the designed sensor leads to the increasing of the peak current oxidation of MFA.

The optimization of experimental conditions

For the increasing of the sensitivity of MWCNT/Gr/GCE sensor, some experimental parameters such as the percentages of Gr and MWCNT in the composite of MWCNT/Gr and the pH of solution were optimized. The percentage of Gr in the composite of MWCNT/Gr was analysed in the range of 0.5 to 5.0 % at the scan rate of 30 mV s^{-1} . According to Fig. 4A, the optimum obtained percentage of Gr in the composite of MWCNT/Gr was 3.0 % and this value was selected for the preparation of the sensor. The percentages of MWCNT in the composite of

MWCNT/Gr were analysed in the range of 1.0 to 6.0 % at the scan rate of 30 mV s^{-1} . According to Fig. 4B, the optimum percentage of MWCNT in the composite of MWCNT/Gr was found to be 4.0 % and this value was chosen as an optimum value. The effect of pH on the oxidation of MFA was examined using cyclic voltammetry. The results revealed that the calculated half-wave potential of MWCNT/Gr composite as a modifier is pH-dependent, according to $E_p (\text{V}) = -0.0562\text{pH} + 0.9881$ ($R^2 = 0.9839$) with the slope of 56.2 mV/pH unit in a range of 10.0 to 13.5, and this value is close to the Nernstian value of $59/n \text{ mV}$. Therefore, it suggested that the number of electron transfers is equal to that of hydrogen ions taking part in the electrode reaction. The oxidative reaction of MFA is a one electron, one-proton transfer process³⁷ (see Scheme 1). As shown in Fig. 4C, it was observed that the peak potentials of MWCNT/Gr/GCE sensor shifted to negative values with the increase of pH (from 0.5 V to 0.2 V). Hence, the electrocatalytic oxidation of MWCNT/Gr composite was affected by pH parameter in the presence of MFA.

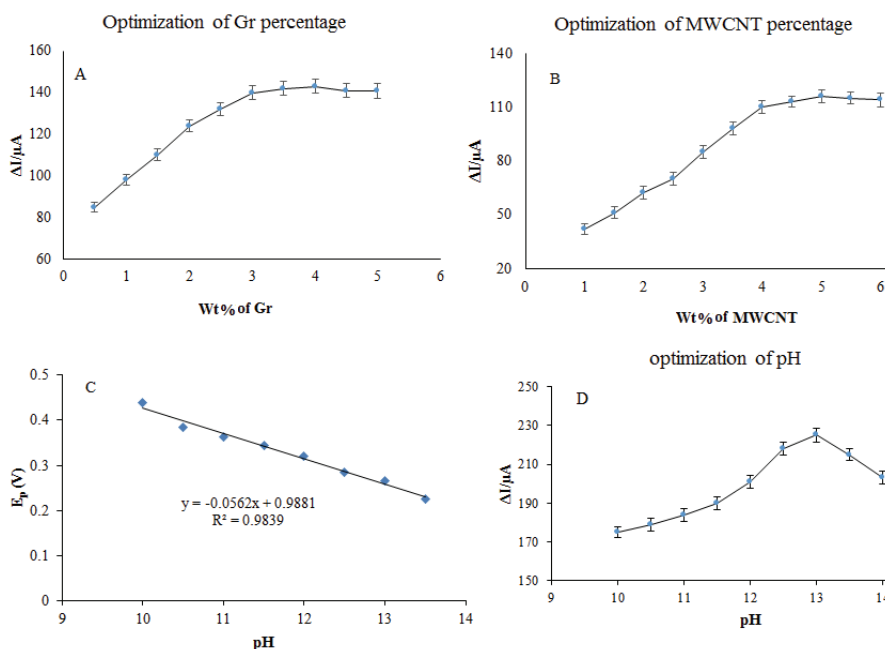


Fig. 4. The optimization of experimental conditions: A) optimization of Gr percentages, B) optimization of MWCNT percentages, C) E_p vs. pH and D) optimization of pH.

As shown in the Fig. 4D, the pH optimization was investigated in the range of 10.0 to 14.0. By increasing of the pH values up to 13.0, the oxidation peak currents were increased and then the values of the peak current were decreased. So, the value of pH 13.0 was selected as an optimum pH for further experiments.

Chronoamperometric measurements

Chronoamperometry also was used for the electrochemical study of MFA oxidation at MWCNT/Gr/GCE sensor for different concentrations of MFA while the potential of working electrode was adjusted to be 0.45 V. The current was controlled by diffusion of MFA from the bulk solution towards the surface of the MWCNT/Gr/GCE sensor (a near-Cottrellian behaviour) because there was a linear relationship between electrocatalytic current and $t^{-1/2}$ (see inset A of Fig. 5). The slopes of the resulting straight lines were plotted versus the various concentrations of MFA (inset B of Fig. 5), from the obtained slope and applying the Cottrell equation, the mean value of D was found to be $(2.88 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1})$, and this calculated diffusion coefficient for MFA is comparable with the values reported in the previous researches.^{38,39}

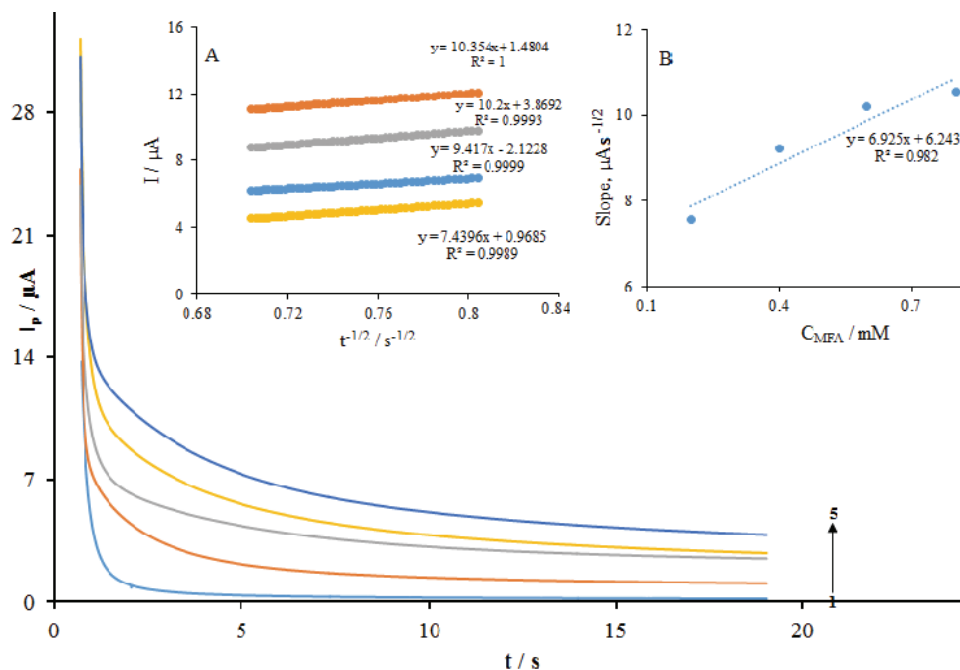


Fig. 5. Chronoamperograms obtained at MWCNT/Gr/GCE sensor in a NaOH solution pH 13.0 for MFA concentrations of 0.0, 0.1, 0.2, 0.4, 0.6 and 0.8 mM. Insets: (A) plots of I vs. $t^{-1/2}$ obtained from the chronoamperogram data, (B) plot of the slope of the straight lines against the MFA concentration.

Calibration by using differential pulse voltammetry technique

The technique of differential pulse voltammetry (DPV) was used to obtain the calibration plots of MFA using the fabricated sensor (MWCNT/Gr/GCE). For this purpose, the differential pulse voltammograms of different concentrations of

MFA were recorded in the potential window of 0.2 to 0.4 V (Fig. 6). According to Fig. 6, there is a linear relationship between the changes of DPV peak currents of MFA and various concentration of MFA in the range of 2–100 μM . The obtained calibration plot contained a calibration equation of $I / \mu\text{A} = 0.5112C_{\text{MFA}} / \mu\text{M} + 31.287$ and regression coefficient of $r^2 = 0.9902$. The detection limit was calculated as 0.66 μM for MFA by the slope of the calibration plot at 3σ level. As shown in Table I, the detection limit and linear range for MFA determination is acceptable.

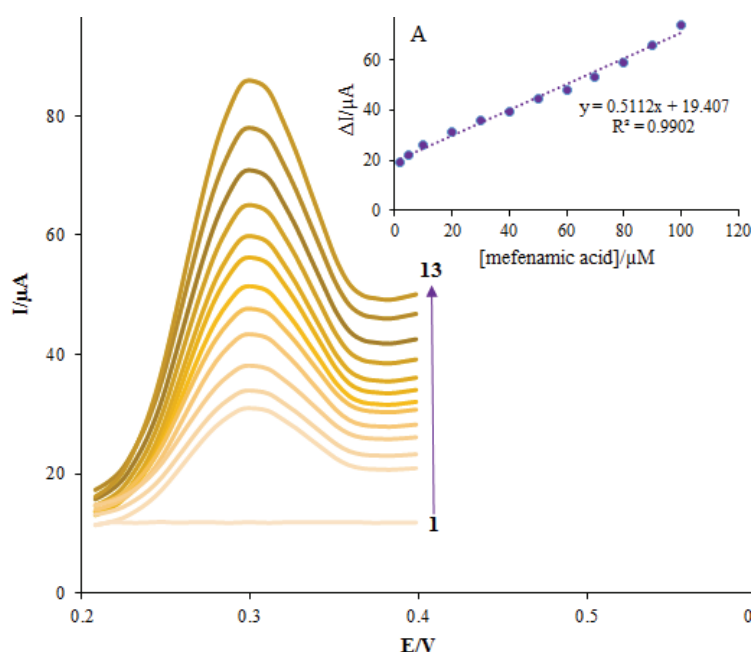


Fig. 6. The DP voltammograms of different concentrations of MFA on the modified electrode; Inset: the obtained calibration plot of MFA.

The selectivity investigation of MWCNT/Gr/GCE sensor by interference effect

To investigate the selectivity of MWCNT/Gr/GCE sensor, the effect of increasing concentrations of different species on the oxidation peak current of MFA (90 μM) was examined. As it is known, the tolerance limit is explained as the maximum concentration of foreign substances that caused an error of less than $\pm 5\%$ for the determination of MFA (90 μM) as analyte. The observations indicated that the peak current of MFA was not affected by a 100-fold increase in the concentration of some materials such as acetaminophen, folic acid, penicillamine, levodopa, carbidopa, hyosine, cysteine and glycine compound.

TABLE I. Comparison of the efficiency of some modified electrodes used in the determination of MFA

Electrode	Detection technique	Detection limit M	Linear range M	Ref.
CPE/Magnetic molecularly imprinted polymer nanoparticles (MMIPNPs)	DPV	1.2×10^{-9}	2.0×10^{-9} – 1.0×10^{-6}	38
Nickel hydroxide modified nickel (NHMNi) electrode	Amperometry	4.96×10^{-6}	2.5×10^{-5} – 4.76×10^{-4}	39
Ion-pair Brilliant Green mefenamate	Potentiometric	4.5×10^{-5}	9.0×10^{-5} – 1.0×10^{-2}	41
CPE/Fe (III) schiff base (Fe (III)-SBMCP)	DPV	2.0×10^{-8}	2.0×10^{-7} – 1.5×10^{-5}	42
Pt/Hg/Hg ₂ (MF) ₂ /Graphite	Potentiometric	6.2×10^{-7}	1.0×10^{-6} – 1.0×10^{-2}	43
MWCNT/Gr/GCE	DPV	6.6×10^{-7}	2.0×10^{-6} – 1.0×10^{-4}	This work

The investigation of repeatability, reproducibility and stability of the designed sensor

The repeatability of the proposed sensor was investigated by recording the differential pulse voltammograms of MFA (90 μ M) for 10 measurements. The relative standard deviations (RSD) of the anodic currents were calculated to be 3.8 % which indicated the suitable repeatability of MWCNT/Gr/GCE sensor for the determination of MFA. For the investigation of reproducibility of MWCNT/Gr/GCE sensor, the generation of a reproducible surface was examined by DPV technique. Five separately MWCNT/Gr/GCE sensors were prepared under the optimum conditions (pH 13.0). The differential pulse voltammograms of the MWCNT/Gr/GCE sensors for MFA (90 μ M) were obtained and a RSD of 4.9 % was calculated, which indicated that the reproducibility of MWCNT/Gr/GCE sensor is suitable. For the stability investigation of MWCNT/Gr/GCE sensor, the fabricated sensor was stored at room temperature and after 3 days, 1 week and 2 weeks the recorded current of DPVs for oxidation peak currents of MFA were obtained, with values of 97.1, 96.9 and 95.0 % of the initial response respectively. The obtained results revealed the high stability of the designed sensor.

Analytical performance of MWCNT/Gr/GCE sensor

To investigate the analytical performance of MWCNT/Gr/GCE sensor, the MFA capsule solution and diluted serum solution which were prepared according to the experimental section, were used. The MWCNT/Gr/GCE sensor was used for the determination of MFA in the different concentrations of drug solutions. According to Table II, in the confidence level of 95 % the calculated t_{exp} values (2.66, 2.30 and 2.40) are less than the t value from literature (2.78)⁴⁰ which indicated the applicability of MWCNT/Gr/GCE sensor for the determination of MFA in the drug solution.

TABLE II. Determination of MFA in the MFA capsule using MWCNT/Gr/GCE sensor at the confidence limit of 95 % ($n = 5$); t_{cri} : 2.78

Sample number	MFA value in capsule, μM	Found MFA value, μM	RSD / %	t_{exp}
1	30	28.40	4.20	2.66
2	50	51.50	2.52	2.30
3	80	78.20	3.10	2.40

Also, for the investigation of the applicability of MWCNT/Gr/GCE sensor for the determination of MFA in real samples, this designed sensor was applied for serum solutions. The specific concentrations (concentrations in the linear range of the fabricated sensor which are listed in Table III) were added to the diluted serum solutions, preparation of which were described in the experimental section. The quantitative determination of MFA in blood serum samples was performed and the recovery percentages were obtained (see Table III). As shown in Table III, the obtained recovery percentages are suitable and these observations indicate that the MWCNT/Gr/GCE sensor is applicable for the determination of MFA in real biological samples.

TABLE III. Determination of MFA concentration in the serum solutions by using MWCNT/Gr/GCE sensor ($n = 3$)

Serum solution	Spiking value, μM	Assayed value, μM	Recovery value, %
1	20	21 (± 0.5)	105.0
2	40	38 (± 0.4)	95.0
3	60	58 (± 0.6)	96.6

CONCLUSION

In the present research, an electrochemical sensor was prepared by the modification of a glassy carbon electrode (GCE) with graphene nano-sheets (Gr) and multi wall carbon nanotubes (MWCNT). The MWCNT/Gr/GCE sensor displayed electrocatalytic behaviour, when applied for mefenamic acid (MFA) oxidation, using Gr and MWCNT (possessing good conductivity, low electron transfer resistance and catalytic effect of Gr and MWCNT). Under the optimum conditions, some parameters such as diffusion coefficient were obtained by the electrochemical method. The MWCNT/Gr/GCE sensor displayed a linear dynamic range for MA (2–100 μM) with a detection limit of 0.66 μM by the differential pulse voltammetry technique. Also, this sensor showed a suitable applicability for the determination of MFA in real samples (drug samples and serum solutions).

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ИЗВОД
ПОГОДНА НАНОСТРУКТУРИРАНА ОСНОВА БАЗИРАНА НА ВИШЕСЛОЈНИМ
УГЉЕНИЧНИМ НАНОТУБАМА И НАНОПЛОЧАМА ГРАФЕНА ЗА ОДРЕЂИВАЊЕ
МЕФЕНАМИНСКЕ КИСЕЛИНЕ

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Сензор за мефенаминску киселину је припремљен модификацијом електроде од стакластог угљеника (GCE) са графеном (Gr) и вишеслојним угљеничним нанотубама (MWCNT). Дизајниран сензор (MWCNT/Gr/GCE) показује електрокаталитичко понашање према оксидацији мефенаминске киселине (MFA) захваљујући доброј проводљивости, ниском отпору преносу наелектрисања и каталитичком ефекту. Предложени сензор остварује нижу пренапетост и већу струју у поређењу са класичном GCE за оксидацију MFA. Посматрања указују да је потенцијал оксидације MFA смањен за више од 200 mV коришћењем дизајнираног сензора. Оптимизован је проценат MWCNT и Gr нано материјала, као и pH раствора. Под оптималним условима, неки кинетички параметри као што су површинска покривеност у раствору 0,5 mM $[\text{Fe}(\text{CN})_6]^{3-/4-}$, добијени су методом цикличне волтаметрије. Израчунат дифузиони коефицијент MFA (D) хроноамперометријском техником износи $2,88 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$. Сензор MWCNT/Gr/GCE показује линеарност у опсегу MFA 2–100 μM са детекционом границом од 0,66 μM диференцијално пулсном волтаметријом (DPV). Сензор остварује погодну применљивост за одређивање MFA у реалним узорцима (узорци лекова и серума).

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REFERENCES

1. J. R. Vane, *Nat. New Biol.* **23** (1971) 232
2. S. Muraoka, T. Miura, *Life Sci.* **72** (2003) 1897
3. T. P. Ruiz, C.M. Lozano, T. Virginia, J. Carpena, *Talanta* **47** (1998) 537
4. J. C. Botello, C.G. Perez, *Talanta*, **42** (1995) 105
5. M. R. Rouini, A. Asadipour, Y.H. Ardakani, F. Aghdasi, *J. Chromatogr., B* **800** (2004) 189
6. F. A. Aly, S. A. Tamimia, A. A. Alwarthan, *Anal. Chim. Acta* **416** (2000) 87
7. T. P. Ruiz, C. M. Lozano, A. Sanz, E. Bravo, *J. Chromatogr., B* **708** (1998) 249
8. P. Miroslav, P. Marie, U. Marek, *J. Pharm. Biomed. Anal.* **23** (2000) 135
9. M. Shamsipur, F. Jalali, S. Ershad, *J. Pharm. Biomed. Anal.* **37** (2005) 943
10. S. S. M. Hassan, W. H. Mahmoud, M. A. F. Elmosallamy, M. H. Almarzooqi, *J. Pharm. Biomed. Anal.* **39** (2005) 315
11. M. T. Xu, L. F. Chen, J. F. Song, *Anal. Biochem.* **329** (2004) 21
12. J.-F. Song, W. Guo, X. F. Kang, Y. H. Hu, *Sci. China, B* **36** (1993) 906
13. J. F. Song, W. Guo, *Chin. J. Pharm.* **24** (1993) 24
14. M. C. Blanco-Lopez, M. J. Lobo-Castanon, A. J. Miranda-Ordieres, P. T. Blanco, *Anal. Bioanal. Chem.* **377** (2003) 257
15. M. C. B. Lopez, L. F. Lano, M. J. L. Castanon, A. J. M. Ordieres, P. T. Blanco, *Anal. Lett.* **5** (2004) 915
16. M. Mazloum-Ardakani, M. A. Sheikh-Mohseni, M. Abdollahi-Alibeik, A. Benvidi, *Analyst* **137** (2012) 1950
17. M. Noroozifar, M. Khorasani Motlagh, R. Akbari, M. Bemanadi Parizi, *Anal. Bioanal. Chem. Res.* **1** (2014) 62

18. M. Mazloun-Ardakani, M. A. Sheikh-Mohseni, B. F. Mirjalili, *Electroanalysis* **25** (2013) 2021
19. X. Wang, Y. D. Li, *Nature* **437** (2005) 121
20. J. J. Urban, W. S. Yun, Q. Gu, H. K. Park, *J. Am. Chem. Soc.* **124** (2002) 1186
21. J. J. Gooding, *Electrochim. Acta* **50** (2005) 3049
22. Y. Zhu, S. Murali, W. Cai, X. Li, J. W. Suk, J. R. Potts, R. S. Ruoff, *Adv. Mater.* **22** (2010) 3906
23. Q. Zhao, Z. Gan, Q. Zhuang, *Electroanalysis* **14** (2002) 1609
24. H. Beitollahi, H. Karimi-Maleh, H. Khabazzadeh, *Anal. Chem.* **80** (2008) 9848
25. A. Afkhami, H. Khoshsafar, H. Bagheri, T. Madrakian, *Sensors Actuators, B: Chem.* **203** (2014) 909
26. S. Mohammadzadeh, M. Fouladgar, *J. Serb. Chem. Soc.* **78** (2013) 1595
27. N. Keshkar, M. A. Taher, H. Beitollahi, *J. Serb. Chem. Soc.* **80** (2015) 789
28. J. Lv, Y. Tang, L. Teng, D. Tang, J. Zhang, *J. Serb. Chem. Soc.* **82** (2016) 73
29. B. N. Olana, Sh. A. Kitte, T. R. Soreta, *J. Serb. Chem. Soc.* **80** (2015) 1161
30. A. Benvidi, M. M. Ansaripour, N. Rajabzadeh, H. R. Zare, B. B. F. Mirjalili, *Anal. Methods* **7** (2015) 3920
31. A. Benvidi, S. Jahanbani, A. Akbari, H. R. Zare, *J. Electroanal. Chem.* **758** (2015) 68
32. A. Benvidi, P. Kakoolaki, A. R. Gorji, M. Mazloun-Ardakani, H. R. Zare, R. Vafazadeh, *Anal. Methods* **5** (2013) 6649
33. F. Cui, X. Zhang, *J. Electroanal. Chem.* **669** (2012) 35
34. D. C. Marcano, D. V. Kosynkin, J. M. Berlin, A. Sinitskii, Z. Sun, A. Slesarev, L. B. Alemany, W. Lu, J. M. Tour, *ACS Nano* **4** (2010) 4806
35. A. J. Bard, L. R. Faulkner, *Electrochemical Methods Fundamentals and Applications*, Wiley, New York, 2001
36. N. Ramalakshmi, S. Muthukumar, B. Marichamy, *IJCPS* **2** (2013) 16
37. L. Liu, J. Song, *Anal. Biochem.* **354** (2006) 22
38. T. Madrakian, E. Haghshenas, M. Ahmadi, A. Afkhami, *Biosens. Bioelectron.* **68** (2015) 712
39. M. Hajjizadeh, A. Jabbari, H. Heli, A. A. Moosavi-Movahedi, S. Haghgoo, *Electrochim. Acta* **53** (2007) 1766
40. J. C. Miller, J. N. Miller, *Statistics for analytical chemistry*, 2nd ed., Wiley, New York, 1988
41. Zh. Kormosh, O. Matviychuk, *Chin. Chem. Lett.* **24** (2013) 315
42. M. Hasanzadeh, N. Shadjou, L. Saghatforoush, J. Ezzati N. Dolatabadi, *Colloids Surfaces, B* **92** (2012) 91
43. A. O. Santini, H. R. Pezza, L. Pezza, *Sensors Actuators B* **128** (2007) 117.