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Novel multi walled carbon nanotubes/β-cyclodextrin based carbon paste electrode for flow injection potentiometric determination of piroxicam

Elmorsy Khaled [a],*, Manal S. Kamel [a], Hassan N.A. Hassan [a], Ahmed A. Haroun [b], Ahmed M. Youssef [c], Hassan Y. Aboul-Enein [d],**

[a] Microanalysis Laboratory, National Research Centre, Dokki, Giza, 12311, Egypt
[b] Chemical Industries Research Division, National Research Centre, Dokki, Giza, 12311, Egypt
[c] Packing and Packaging Materials Department, National Research Centre, Dokki, Giza, 12311, Egypt
[d] Pharmaceutical and Medicinal Chemistry Department, National Research Centre, Dokki, Giza, 12311, Egypt

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ABSTRACT

A novel carbon paste electrode based on functionlized multi-walled carbon nanotubes/β-cyclodextrin composite (FMWCNTs/β-CD-CPE) is described for potentiometric determination of piroxicam (PXM). Improved sensitivity and selectivity was achieved by application of CDs as molecular host–guest recognition elements and MWCNTs. The electrochemical performance of carbon paste electrodes incroporated with FMWCNTs/β-CD composite was compared to those incroporated with MWCNTs and free CDs. Matrices compositions of each electrode are optimized on the basis of nature and content of the modifier, ionic sites and selected plasticizer. CPEs containing FMWCNTs/β-CD composite, hyamine (Hy) and 2-fluorophenyl 2-nitrophenyl ether (*f*-NPE) as electrode plasticizer, work satisfactory in the concentration range from 10^{-6} to 10^{-2} mol L^{-1} with Nernstain compliance (58.7 ± 0.9 mV decade^{-1} activity) with fast response time of about 2 s and exhibit adequate operational lifetime (16 weeks). The developed electrodes have been applied for the potentiometric determination of PXM in pharmaceutical formulation under batch and flow injection analysis (FIA). FIA allows the analysis of 120 samples h^{-1} with the advantage of simplicity, accuracy and automation feasibility.

1. Introduction

Piroxicam (PXM, 4-hydroxy-2-methyl-N-(pyridine-2-yl)-2H-1, 2-benzo-thiazine-3-carboxamide-1,2-dioxide) is a well-known non-steroidal anti-inflammatory and analgesic drug (NSAIDs) for treatment of rheumatoid arthritis, osteoarthritis, ankylosing spondylitis and acute pain [1,2]. Data on reported techniques [3] for PXM determination in various objects are mainly based on chromatographic and spectrophotometric techniques, though voltamperometric and electrophoretic methods were also encountered. Nevertheless, most of these methods require expensive apparatus or involve several manipulation steps before the final result of analysis. An interest has been increased for developing reliable rapid and accurate procedures for PXM quantification.

Potentiometric methods are of choice since they possess the advantages of simplicity, accuracy without the need of separation or pretreatment procedures and the common availability of the instrumentation. Although a considerable attention has been given for drug analysis using ion-selective electrodes (ISEs) [4,5]; only a polyvinyl chloride (PVC) sensors based on ion-pair associates of PXM with tricaprylmethylammonium chloride [6] or Rhodamine 6 G [7] were found in literature. Potentiometric sensors based on ion-pairs are generally plagued by limited selectivity and their applications are restricted to more challenging matrices; therefore more selective molecular recognition component is clearly required. The beauty of electrochemical techniques is to utilize tailor made chemically modified electrodes (CMEs) for improved sensitivity and selectivity of the analytical applications [8,9]. Different types of molecular recognition elements have been proposed including; crown ethers, calixarenes, cyclodextrins (CDs) or porphyrins, and CDs were by far the most commonly used. Cyclodextrins are naturally occurring macrocyclic oligosaccharides formed of 1,4-glucosidic bond linked D (+) glucopyranose oligomers of 6, 7, and 8 glucose units yielding α-, β-, and γ-CDs, respectively [10]. CDs can form inclusion complexes with different types of guests without the formation of chemical bonds or changing their structure, where the binding forces are attributed to number of factors, such as hydrophobic forces, hydrogen bonding, size of the cavity and shape of the guest molecule [11,12]. Such unique properties introduced CDs as a sensing material in potentiometric sensors for many pharmaceutically important drugs [13–15].

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* Corresponding author. Tel.: +201003781777; fax: +20233370931.
** Corresponding author. Tel.:+201003678948.
E-mail addresses: elmorsykhaled@yahoo.com (E. Khaled), haboulenein@yahoo.com (H.Y. Aboul-Enein).

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PVC membrane sensors still have certain inherent limitations as they are mechanically complicated, have short lifetime and difficult to be miniaturized. To overcome the aforementioned limitations, carbon paste electrodes (CPEs); mixture of carbon powder and a suitable binder, have been developed and introduced as an alternative to PVC sensors. CPEs possess the advantages of simple fabrication and regeneration process, fast response time and low Ohmic resistance [16]. The feasibility of sensing materials incorporation during mixing of paste results in the so-called modified carbon paste electrode (CMCPEs) with desired composition and pre-determined properties [17–19].

An important milestone in the history of carbon is the discovery of carbon nanotubes (CNTs) as one of the most important materials of the 21st century [20]. CNTs represent a novel class of carbon family with superior in terms of reaction rates and reversibility. The research in the field of sensors based on CNTs is still a hot topic and a number of excellent review articles have been published [21–26]. Concerning CPEs, many reports indicated that addition of CNTs to the electrode matrix improves the conductivity and, therefore, conversion of the chemical signal to an electrical signal [27–30].

Furthermore, defects in the graphite structure, at both end and side walls of CNTs, enables the functionalization via either covalent or noncovalent modifications. Functionalization of CNTs with macromolecular structures will lead to new composite materials possessing the properties of each component, or even with a synergistic effect, which would be useful in the fields of electrometric sensing [30–32].

To the best of our knowledge, no potentiometric CPEs incorporated with MWCNT/CD composite and PVC membrane plasticizers as binding material were found in literature. Taking into consideration the electrochemical properties of both CNTs and CDs, this work suggested a novel strategy for fabrication of potentiometric sensors for various analytical applications.

2. Experimental

2.1. Reagents

All reagents were of the analytical grade and double distilled water was used throughout the experiments. Cyclodextrin derivatives including, heptakis (2,6-di-O-methyl)-β-CD (**I**, Aldrich), heptakis (2,3,6-tri-O-methyl)-β-CD (**II**, Aldrich), 2-hydroxypropyl-β-CD (**III**, Aldrich), β-CD (**IV**, Sigma), α-CD (**V**, Aldrich) and γ-CD (**VI**, Aldrich) were tested as sensing ionophores.

Different ionic sites were incorporated in the electrode matrices namely; hyamine®1622 (Hy, Fluka), cetylpyridinium chloride (CPCl, Fluka), hexadecyltrimethylammonium bromide (HTMABr, Fluka), tri-dodecyltrimethylammonium bromide (TDTMABr, Sigma), didodecyl-dimethylammonium bromide (DDMABr, Fluka) and Septonex (Hlohovec, CZ).

2-nitrophenyl octyl ether (NPOE, Fluka), 2-fluorophenyl 2-nitrophenyl ether (*f*-NPE, Fluka), dioctylphthalate (DOP, BDH), dioctylsebacate (DOS, Avocado), tricresylphosphate (TCP, Fluka), and paraffin oil (Fluka) were used as paste binder. Graphite powder (synthetic 1–2 μm, Aldrich) and multiwall carbon nanotube (Aldrich) were applied as electrode materials.

2.2. Authentic samples

Authentic piroxicam sample, assigned to be 99%, was obtained from National Organization of Drug Control and Research, Giza, Egypt. Stock solution (10^{-2} molL^{-1}) was prepared by dissolving a weighed amount of PXM in 5×10^{-2} molL^{-1} sodium hydroxide solution and kept at 4 °C.

2.3. Pharmaceutical preparations

Dispercam® tablets (MUP, Cairo, Egypt, 20 mg/tablet) were purchased from local drug stores. Ten tablets were weighed, grinded, dissolved in 5×10^{-2} molL^{-1} sodium hydroxide solution, filtered off and completed to 50 mL with the same solution.

2.4. Apparatus

Potentiometric measurements were carried out using a 692-pH meter (Metrohm, Herisau, Switzerland, Art.no. 1.691.00100) with Ag/AgCl double-junction reference electrode (Metrohm, Art.no. 6.0726.100) and combined pH glass electrode (Metrohm, Art.no. 6.0202.100). Single line flow injection system was composed of four channel peristaltic pump (MCP Ismatec, Zurich, Switzerland), sample injection valve (ECOM, Ventil C, Czech Republic) and wall jet flow cells adapted for CPEs [33]. The change of electrode potential was monitored using 46-Range Digital Multimeter (Radioshack) with PC interface. Surface structure and FTIR studies were performed using JXA-840A electron probe microanalyzer (JEO-Japan) and Jasco FT/IR-6100 type A spectrophotometer (Tokyo, Japan), respectively.

2.5. Procedures

2.5.1. Preparation of FMWCNT/β-CD composite

MWCNTs were functionalized prior to composite preparation via introducing of carboxylic acid moieties onto its surface through oxidation in acidic medium. Carbon nanotubes were dispersed in 2.0 mol L^{-1} nitric acid solution for 24 h at 25 °C, washed afterwards with deionized water and dried at 75 °C [34]. The obtained functionalized carbon nanotube (FMWCNTs) were grinded with β-CD in agate mortar and pestle with the dropwise addition of ethanol over the first 10 min, followed by further grinding for 3 h. After drying, a black product was obtained and characterized via FTIR and electronic microscope.

2.5.2. Sensor construction

Carbon paste electrodes were fabricated by hand mixing of defined amounts of graphite powder, binder and modifier (Table 1), and the paste matrices were packed into a piston driven Teflon holder [18]. The resulting CPEs were conditioned in 10^{-3} mol L^{-1} PXM solution for 2 h before measurements and electrode surface regeneration was performed by screwing the piston and polishing with a wet smooth paper.

Table 1
Optimal composition of PXM carbon paste electrodes.

Electrode	Matrix composition
FMWCNT/ β-CD-CPE	2.50 mg FMWCNT/β-CD + 1.25 mg Hy + 97.5 mg graphite powder + 60.0 μ L *f*-NPE
MWCNT-CPE	1.25 mg β-CD (**II**) + 1.25 mg Hy + 25.0 mg MWCNTs + 75.0 mg graphite powder + 90.0 μ L *f*-NPE
Graphite-CPE	1.25 mg β-CD (**II**) + 1.25 mg Hy + 100.0 mg graphite powder + 40.0 μ L *f*-NPE

2.5.3. Sensor calibration

Under batch measurements, sensors were calibrated by immersing the working and reference electrodes in 25 mL PXM solutions covering the concentration range from 10^{-7} to 10^{-2} mol L^{-1} at 25 °C. The electrode potentials were recorded and plotted against drug concentration in logarithmic scale [35].

For FIA measurements, 200 μL of freshly prepared PXM solutions were injected in the flowing stream (5×10^{-2} mol L^{-1} sodium hydroxide solution) at flow rate of 45 mL min^{-1}. The corresponding peak heights were recorded and used to draw the calibration graphs.

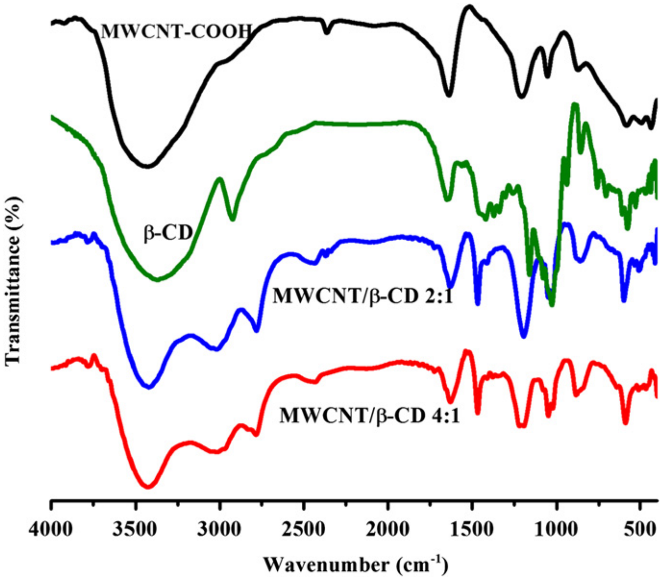

Fig. 1. FT-IR spectrum of β-CD, FMWCNT and FMWCNT/β-CD composites.

2.6. Potentiometric determination of PXM in pharmaceutical preparations

The developed electrodes were applied for potentiometric determination of PXM under potentiometric titration and FIA. Aliquots of the sample solutions, containing 0.99–3.3 mg PXM, were titrated by standardized Hy solution [36] using the fabricated PXM sensor as indicator electrode. Potential values were plotted against the titrant volume to estimate the end point.

For FIA, 200 μL of sample solutions were injected in the flowing stream (flow rate was 45 mL min^{-1}), and the peak heights were compared to those obtained from injecting standard solutions of the same concentration. The obtained recoveries were compared with the official method [37].

3. Results and discussion

3.1. MWCNT/β-CD composite as sensing material

Functionalized multiwall/β-CD composites were prepared and characterized by FTIR and SEM electronic microscope. Fig. 1 demonstrates the FTIR spectrum of the two composites compared with the FMWCNTs and β-CD. FMWNTs showed characteristic peaks at 3442, 1637 and 1062 cm^{-1}, actually corresponding to the stretching modes of the carboxylic acid groups [38]. β-CD showed specific absorption peaks at 3387 cm^{-1} (OH stretching

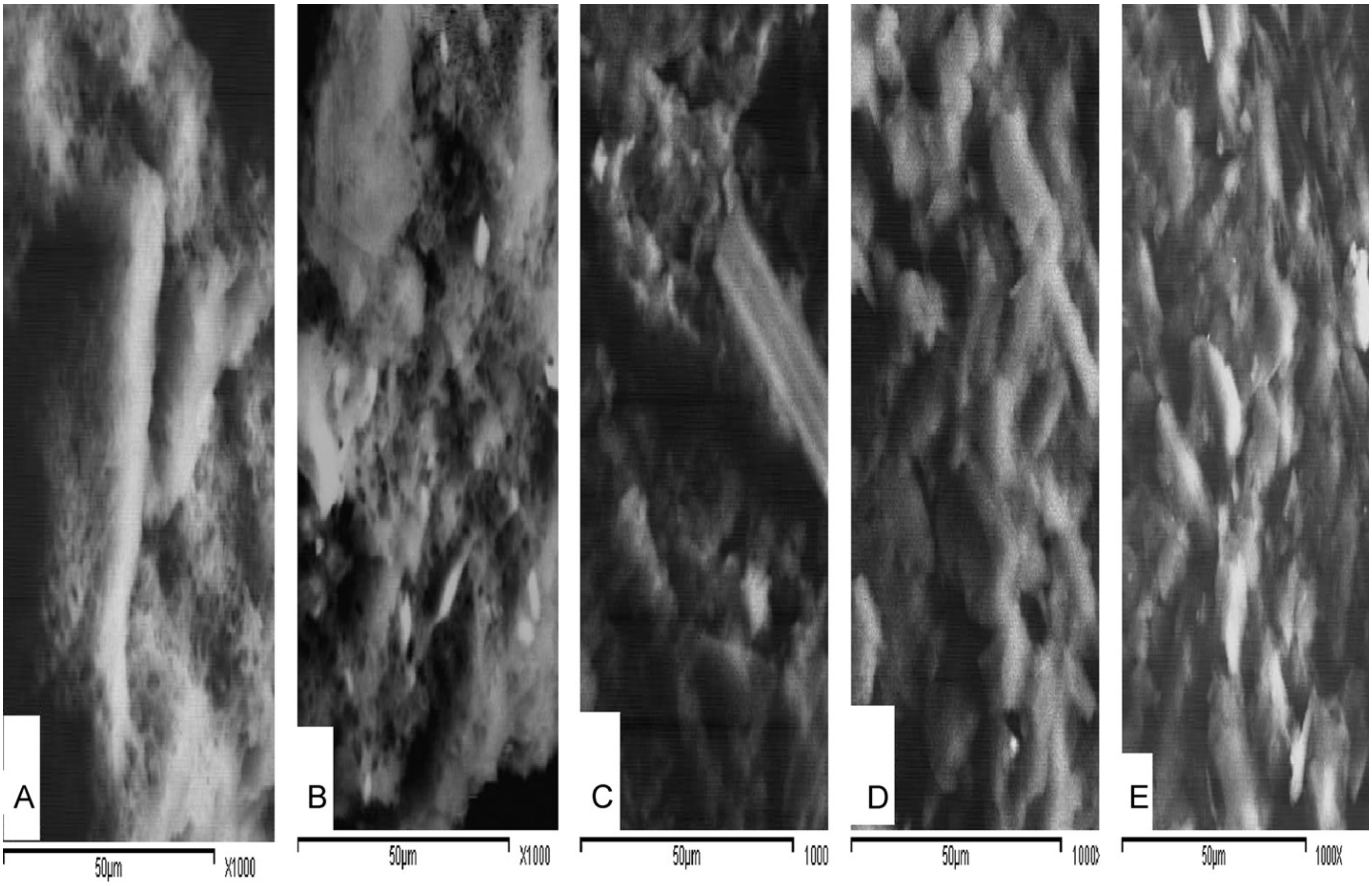

Fig. 2. SEM images of; (A) FMWCNT/β-CD 2:1, (B) FMWCNT/β-CD 4:1, (C) MWCNT based CPE, (D) FMWCNT/β-CD-CPE, and (E) graphite based CPE.

H-band), 2908 cm^{-1} (OH stretching), 1637 cm^{-1} (OH bending), 1475 cm^{-1} (OH deformation) and 1243 cm^{-1} (CH bending). The formed FMWCNT/β-CD composite showed new characteristic bands at 3021, 2778 and 2442 cm^{-1} indicating the interaction between β-CD and FMWCNTs.

Furthermore, SEM studies of the FMWCNT/β-CD agglomerates showed the disappearance of the tube morphology of MWCNTs and the small sheets/layers of β-CD [39]; as MWCNTs have been covered by β-CD due to electrostatic interactions. Carbon paste matrices incorporated with MWCNTs or FMWCNT/β-CD composite showed homogenous surface and the modifiers appear to be embedded inside the matrix (Fig. 2c and d). Graphite based carbon paste (Fig. 2e) is characterized by a surface formed by irregularly shaped micrometer-sized (1–2 μm) flakes of graphite.

3.2. Optimal sensor matrices compositions

Due to the critical role of the matrix composition on the electrode performance, parallel studies were carried out on the three electrode matrices including influence of the modifier, ionic sites and plasticizer to select the optimal sensor possessing the best sensitivity and selectivity.

3.2.1. CPEs modified with free β-CD as sensing ionophore

Preliminary experiment declared that CPEs fabricated without incorporation of sensing ionophore showed non-significant response towards PXM, while those modified with different CDs showed different sensitivities depending on the incorporated ionophore. Electrodes modified with α- or γ-CDs showed low Nernstain slope values due to the incompatible cavity size for complexation [40]; while application of containing different β-CDs derivatives showed reasonable responses (Nernstain slope was 66.2 ± 1.5 mV decade^{-1} for β-CDs **(II)**). On constructing an ISE, the amount of the sensing material in the electrode matrix should be sufficient to obtain reasonable complexation at the electrode surface that is responsible for the electrode response. If such ionophore is present in excess, over-saturation occurs in the network hindering the complexation process and lead to unsatisfactory measurements. Thus, β-CD **(II)** content within the electrode matrices (containing 1.0 mg Hy, 100.0 mg graphite powder and 40.0 μ L *f*-NPE), was varied from 1.0 to 10.0 mg, and incorporation of 1.25 mg of the aforementioned ionophore was sufficient to reach the proper electrode performance of PXM-CPE.

Lipophilic ionic additives promote the interfacial ion exchange kinetics at the electrode surface and enhance the ionic mobility in the electrode matrix [41,42]. The response of ISEs containing ionic sites can distinguish whether the incorporated ionophore acts as an electrically charged or neutral carrier [43]. Cyclodextrins behave as neutral carrier ionophores and their ISEs function only in presence of anionic sites, from different ionic sites tested, Hy exhibited the highest slope value compared with CPCl, DDMABr, HTMABr, TDMABr or septonex. Such difference in the electrode performances may be attributed to the difference in lipophilicities of the tested compounds. Furthermore, addition of 1.25 mg Hy to carbon paste matrix (1.25 mg β-CD **(II)**, 100.0 mg graphite powder and 40.0 μ L *f*-NPE) was selected.

Sensitivity and selectivity obtained for a given ionophore based ion-selective electrode are greatly influenced by the polarity of the electrode matrix, which is defined by the dielectrical constant of the used plasticizer [43]. It should be noted that the plasticizer nature not only affects the polarity of the electrode phase, but also the mobility of ionophore and the state of the formed inclusion complexes. Typical carbon paste usually consists of graphite powder dispersed in a non-conductive mineral oil. In addition, PVC membrane plasticizers were suggested for fabrication of CPEs [44].

In the present investigation, seven different binders having different dielectric constant were tested namely; *f*-NPE, NPOE, TCP, DOS, DOP and paraffin oil (ε = 50, 24, 17.6, 5.2, 3.8 and zero, respectively). Plasticizer selection was crucial for appropriate sensor performance as application of the less polar plasticizers decreased the sensitivity, while higher sensitivity was achieved with electrodes containing high polar plasticizer such as *f*-NPE and NPOE (slope values were 61.7 ± 0.8 and 54 ± 0.8 mV decade^{-1}, respectively), while less polar plasticizer gave less sensitive electrodes with lower Nernstain slopes.

3.2.2. CPEs modified with MWCNTs

Incorporation of CNTs in the composition of the carbon paste will improve the conductivity and transduction of the chemical signal to electrical signal, which in turn improved the dynamic working range and response time. Different amounts of MWCNTs ranging from 0 to 50% (w/w relative to carbon powder) were added to the paste matrix containing 1.25 mg β-CD **(II)**, 1.25 mg Hy and graphite powder. However, the consistence of pastes containing more than 25% MWCNTs was difficult to be mixed and the result electrodes showed lower Nernstian slopes with long response time. This may be due to the high surface area on the electrode surface and capturing ions on the surface of the paste. The effect of the plasticizer content within the electrode matrix was also studied and 90 μL of *f*-NPE was selected.

3.2.3. CPEs modified with FMWCNTs/β-CD composite

The prepared FMWCNT/β-CD composites were incorporated as sensing material in the carbon paste matrix instead of the free β-CD ionophore or MWCNTs. The contents of both composites (2:1 and 4:1) were varied from 1.25 to 20.0 mg. Addition of 2.5 mg of the 2:1 composite was sufficient to get the proper performance, while 7.5 mg of 4:1 composite was selected. It is noteworthy to mention that CPEs based on FMWCNT-β-CD (2:1) composite gave more stable and reproducible potentiometric measurements than that for 4:1 composite.

As the present composition of composite-paste matrix was not investigated before, the influence of the plasticizer was studied using five polar plasticizers (*f*-NPE, *o*-NPOE, TCP, DOS or DOP) and non polar binder (paraffin oil); higher sensitivity was observed for electrodes containing high polar plasticizer (Fig. 3a) and *f*-NPE showed the proper sensitivity. Different *f*-NPE contents were added to the electrode matrix, containing 2.5 mg composite, 97.5 mg graphite powder, and 60 μL was the selected (Fig. 3b).

3.3. Performance characteristics of different PXM-CPEs

The final performances of the three fabricated sensors were evaluated according to the IUPAC recommendation [35]. The fabricated sensors displayed Nernstian anionic responses towards PXM with sensitivities depending on the electrode composition (Table 2). Electrode modified with FMWCNT/β-CD composite was the most sensitive with other tested electrodes (Nernstain slope and detection limit values were 58.7 ± 0.9 mV decade^{-1} and 7.0×10^{-7} mol L^{-1}). Generally, the presented sensors, based on β-CD as sensing material, were more sensitive than that incorporated with PXM-ion pairs [6,7], which may be attributed to the encapsulation of PXM molecule into the CDs toroidal cavity (host–guest interaction).

The dynamic response times of the fabricated sensors were tested by measuring the time required to achieve a steady state potential (within ± 1 mV) after sudden increase in the PXM concentration from 1×10^{-6} to 1×10^{-3} mol L^{-1} (Fig. 4).

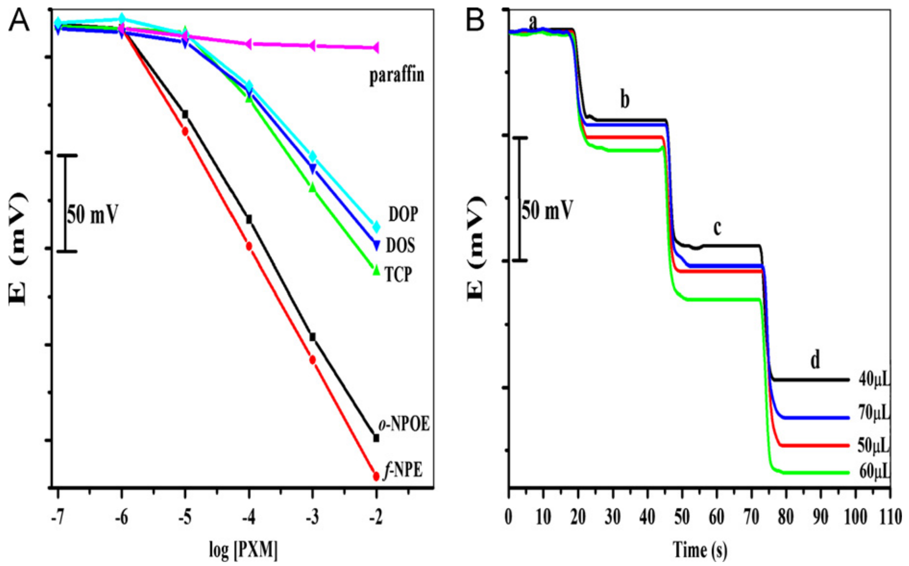

Fig. 3. Electrochemical performances of FMWCNT/β-CD based CPE containing; (A) different plasticizers and, (B) different *f*-NPE contents: (a) 1×10^{-6}, (b) 1×10^{-5}, (c) 1×10^{-4}, (d) 1×10^{-3}, and (e) 1×10^{-2} mol L^{-1}.

Table 2
Analytical performances[a] of various PXM sensors.

Sensors	FMWCNT/β-CD	MWCNT-CPE	Graphite-CPE
Concentration range (mol L^{-1})	10^{-6}–10^{-2}	10^{-6}–10^{-2}	10^{-5}–10^{-2}
Slope (mV decade^{-1})	58.7 ± 0.9	51.1 ± 1.9	61.7 ± 0.8
R	0.99967	0.99801	0.99983
LOD (mol L^{-1})	7.0×10^{-7}	1.0×10^{-6}	1.0×10^{-5}
Response time (s)	2	3	4
Lifetime (week)	16	4	4

[a] Results are average of five different calibrations.

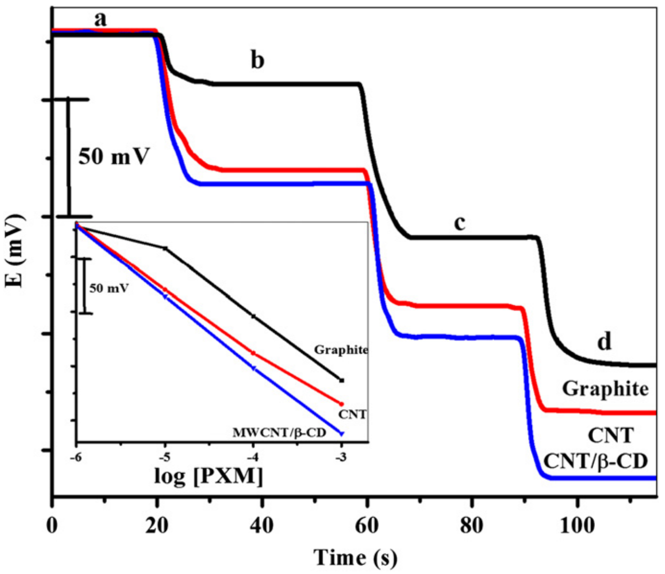

Fig. 4. Dynamic response of different PXM sensors: (a) 1×10^{-6}, (b) 1×10^{-5}, (c) 1×10^{-4} and (d) 1×10^{-3} mol L^{-1} PXM solutions.

The composite based electrode showed fast response (less than 2 s) compared with other electrodes which can be explained on the basis of the synergistic effect between MWCNT and β-CD within the composite structure.

Operational lifetimes of the fabricated electrodes were tested by performing day-to-day calibration. CPEs modified with either free β-CD (**II**) or MWCNTs showed useful lifetime of 4 weeks during which the Nernstian slopes did not change significantly (±2 mV decade^{-1}). Contrary, CPEs incorporated with nanocomposite can be used for at least 16 weeks without significant changes in the electrode performance. Such longer lifetime may be attributed to the formation of CNTs-CD net which diminishes ionophore leaching into soaking solution.

Table 3
Potentiometric selectivity coefficient for PXM-FMWCNT/β-CD based CPE under batch and FIA conditions.

Interferent	$-\log K_{A,B}$				
	Batch	FIA		Batch	FIA
Na^+	4.3	4.5	Maltose	3.30	3.5
K^+	3.8	4.0	Starch	3.9	4.1
Ca^{2+}	4.2	4.3	Sucrose	3.4	3.7
Mg^{2+}	4.7	4.9	Glucose	3.1	3.3
Oxalate	3.2	3.7	Fractose	2.0	2.7
Tartarate	2.9	3.1	Glycine	2.6	2.8
Bezoate	2.8	2.9	Caffeine	2.8	3.2
Phosphate	3.0	3.2	Cysteine	2.7	3.0
Citrate	2.7	3.0			

[a] Average of five measurements.

The selectivity of the prepared PXM sensors was tested applying Matched Potential Method (MPM) as recommended by IUPAC [45]. Results revealed a high selectivity toward PXM in the presence of other interferents, additives and fillers commonly introduced in pharmaceutical formulations (such as glycine, caffeine, citrate, maltose, sucrose, and starch) as well as inorganic cations (Table 3).

3.4. Potentiometric titration

In contrast to direct potentiometric measurements requiring careful calibrations of the measuring cells, potentiometric titration techniques offer the advantage of high accuracy and precision; in spite of the cost of increased time and consumption of reagents used as titrants [46]. In addition to the direct potentiometric determination of PXM reported before [6,7], the present electrodes can be also applied as indicator electrodes for potentiometric titration of PXM by standardized Hy solution. Under the optimum

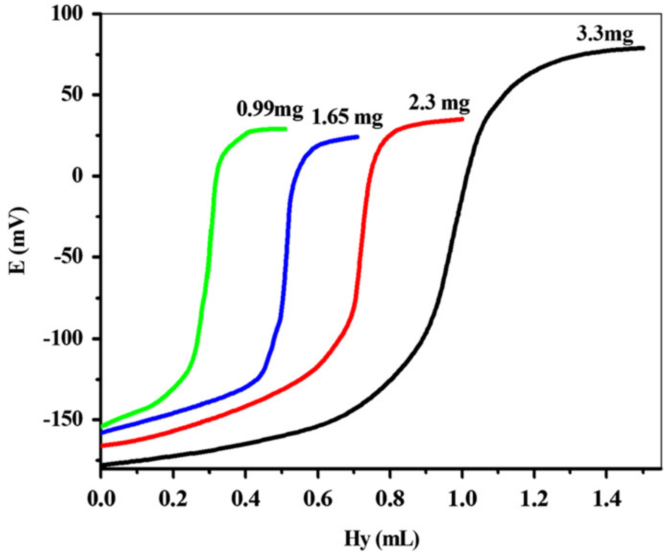

Fig. 5. Potentiometric titration of PXM by 10^{-2} mol L^{-1} Hy using FMWCNT/β-CD based CPE.

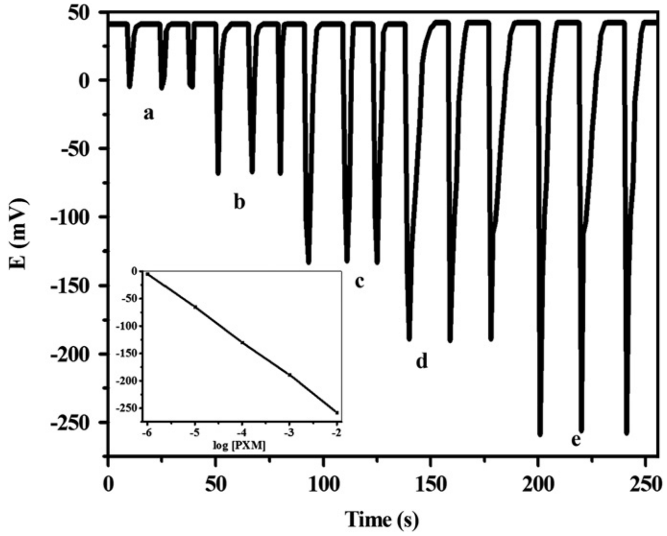

Fig. 6. FIA potentiometric determination of PXM using MWCNT/β-CD based CPE: (a) 1×10^{-6}, (b) 1×10^{-5}, (c) 1×10^{-4}, (d) 1×10^{-3}, and (e) 1×10^{-2} mol L^{-1}; injected volume 200 μL and flow rate 45 mL min^{-1}.

conditions, titration curves were symmetrical with well-defined potential jumps (Δ*E* ranged from 170 to 276 mV) allowing the determination of less 0.99 mg PXM (Fig. 5).

3.5. Electrode response under FIA conditions

Incorporation of ISEs in flow injection systems has the advantages of automation with high sampling frequency [47]. The system performance and analytical throughput is controlled by the electrode performance, which mainly depends on the sensitivity and the response time of the electrode used. CPEs fabricated at optimum matrix composition showed different performances under FIA conditions related to their sensitivities and response times. By injection of 200 μL 10^{-4} mol L^{-1} PXM solution, at flow rate 45 mL min^{-1}, the peak residence times were 12, 15 and 18 s for FMWCNT/β-CD, MWCNT-CPE and graphite-CPEs, respectively.

Fig. 6 showed peaks from the FMWCNT/β-CD-CPE system when 200 μL of PXM solutions at various concentrations were injected in the flowing stream (45 mL min^{-1}). Calibration graphs were linear in the concentration range from 10^{-6} to 10^{-2} mol L^{-1} with Nernstian slopes of 57.8 ± 0.5 mV $decade^{-1}$ and sampling output 120 sample h^{-1}. Reproducibility was evaluated from repeated 10 injections of 200 μL of 10^{-3} mol L^{-1} PXM solution; the average peak heights were found to be −189 ± 2.0 mV.

Table 4
Potentiometric determination of PXM in pharmaceutical preparations.

	Taken	Found			
		Pure solution		Dispercam®	
		Recovery [a]	RSD [a]	Recovery	RSD
Titration	0.99 (mg)	98.4	1.3	98.0	1.5
	1.65 (mg)	99.8	1.0	98.6	1.0
	3.3 (mg)	101.4	1.1	99.0	1.3
FIA [b]	0.66 (μg)	98.0	1.2	98.1	1.2
	6.6 (μg)	102.0	0.9	99.7	1.1
	66.0 (μg)	100.0	0.7	101.5	0.8

[a] Mean recovery and relative standard deviations of five determinations.
[b] FIA measuring was performed using MWCNT/β-CD based electrode.

3.6. Analytical applications

The proposed sensors were successfully employed for PXM assaying in authentic samples and pharmaceutical formulations under FIA and potentiometric titration modes. Results clearly indicated satisfactory agreement between the PXM contents in pharmaceutical samples determined by the developed sensor and official method (Table 4). The time required for sample analysis time was short in case of FIA (about 1 min) compared with about 10 min for potentiometric titration method.

4. Conclusion

The present work demonstrates the fabrication of novel FMWCNT/β-CD-CPEs for potentiometric determination of piroxicam. The proposed electrodes showed Nernstian slopes in the concentration range 10^{-6} to 10^{-2} mol L^{-1} with fast response time (2 s) and long operational lifetime. The sensitivity and operational lifetime of the suggested electrode were improved compared with those based on PXM-ion pairs as sensing material [6,7]. PXM was potentiometrically determined in pure and pharmaceutical forms under FIA and potentiometric titration, with average recoveries comparable to the official methods. FIA allows high sampling output with the possibility for incorporation in routine analysis.

The present investigation may be the base for further research (preparation of CNT-composites with different molecular recognition elements such as calixarenes, porphyrins and crown ethers) leading to improvement of the analytical parameters and expanding of the spectrum of analytes under potentiometric and voltammetric techniques.

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