Electrocatalytic Effect of Al_2O_3 Supported on Clay in Oxidizing of Ibuprofen at Graphite Electrode

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In this work, the electro-catalytic oxidation of ibuprofen was studied using aluminum oxide supported on clay (Clay/Al_2O_3). The latter has been successfully prepared by impregnating aluminum particles in the clay by heat treatment. The electro-catalytic performances of Clay/Al_2O_3 for the oxidation of ibuprofen were studied using cyclic voltammetry (CV), chronoamperometry, and differential pulse voltammetry (DPV) in 0.1 mol L^{-1} of the phosphate buffer (pH = 7). It has been shown that the proposed catalyst exhibits remarkably an electro-catalytic effect performance vis-a-vis the oxidation of ibuprofen. In addition, the peak oxidation currents depend linearly on the ibuprofen concentration in the wide ranges from $1.0 \cdot 10^{-3}$ mol L^{-1} to $1.0 \cdot 10^{-6}$ mol L^{-1} with a detection limit of $1.95 \cdot 10^{-8}$ mol L^{-1} and response time of 30 second. Possible interferences were evaluated in $1.0 \cdot 10^{-5}$ mol L^{-1} ibuprofen. The proposed catalyst also indicated suitable repeatability and stability. Besides, the proposed CPE-Clay/Al_2O_3 has been successfully applied for ibuprofen analysis in human blood with good recoveries.

Keywords: Ibuprofen, Clay, Al_2O_3, human blood, electrocatalysis

Electrochemical sensors have grown in popularity over the past decades and widely used in electroanalytical applications. Electrochemical sensors integrate the sensitivity of electroanalytical methods with the inherent selectivity of the sensing or identifying element [1]. Ibuprofen (IBU) is widely used as a nonsteroidal anti-inflammatory drug for the treatment of a variety of symptoms. Ibuprofen is the international non-proprietary name for 2-[4-phenyl] propionic acid. This is the active substance of an NSAID medicine used to relieve symptoms of arthritis, primary dysmenorrhea, pyrexia, and as a pain reliever, especially in inflammation. Be the main constituent of the landfill of pharmaceuticals industrial, domestic, and hospital wastes numerous reports have been published concerning the detection and analytical control of ibuprofen. Some other approaches are based on the derivatization process [2].

The increasing production and intensive use of pharmaceuticals products have led to the entry of these products into the environment and possible pollution of soil, groundwater, and surface water. Pharmaceutical residues are released to surface water, groundwater and may enter drinking water sources [3, 4]. Several analytical methods have been developed for ibuprofen determination in pharmaceutical samples including spectrophotometry [5, 6], spectrofluorimetry [7, 8], conductometry [9], potentiometry [10-12], high-performance liquid-chromatography (HPLC), with UV detection [13-15] and with amperometric detection [16, 17], and capillary electrophoresis [18, 19]. Ibuprofen is considered one of the most important Pharmaceutical contaminants in the sewage treatment plant (STP) influencing. Although 90% is lost during the passage of wastewater through a PBS, Ibu and its early biotics (hydroxy- and carboxy-ibuprofen) have been detected, among other pharmaceutical residues, in wastewater and effluents as well as in surface water [20-23]. Electrochemical techniques use carbon modified electrodes, such as Carbon Paste Electrode Modified with Heavy Metals [24], Carbon Paste Electrode Modified with clay [25], Natural Phosphate Modified Carbon Paste Electrode [26]. The aim of this work is to study the efficiency of cyclic voltammetry (CV) and the differential pulse voltammetry (DPV), on a carbon paste electrode modified by Clay/Al_2O_3, for the electroanalytical detection of ibuprofen. So, the electrode has been applied to the detection of AA concentrations in human blood using CV.

Experimental part

Reagents and chemicals. All of the chemicals used in this work were of analytical grade or the highest purity available. Sulfuric acid, ascorbic acid, and resorcinol were obtained from Merck (Darmstadt, Germany) and Fluka (St. Gallen, Switzerland). Ibuprofen purchased from Sigma-Aldrich are dissolved in 0.1 mol L^{-1} phosphate buffer (PBS; pH=7) to prepare a stock solution of $1.0 \cdot 10^{-3}$ mol L^{-1}. By diluting the stock solutions,

standard working solutions have been prepared. Paraffin was used as a sizing liquid for the carbon paste electrode (CPE). The carbon paste was supplied by Carbone Lorraine (Lorraine, France; ref. 9900). The pH was adjusted with sulfuric acid or potassium hydroxide. The clay used in the present work was obtained in the region of Beni Mellal (Morocco). All of these experiments were performed using distilled water and at room temperature. The electrochemical experiments were carried out by a voltalab potentiostat (PGSTAT 100 model, Eco Chemie B.V., Utrecht, The Netherlands) controlled by the voltalab master 4 software. The clay modified carbon paste electrode was used as a working electrode, the saturated calomel electrode as the reference electrode, and a platinum plate was used as the counter electrode. The pH meter (Copenhagen, PHM210, Tacussel, French) was used to adjust the pH values. The CV investigated the electroanalysis activity of CPE-Clay/Al_2O_3 towards the oxidation of ibuprofen and DPV connected to a computer for control, data acquisition and storage.

Electrodes preparation. The modified carbon paste electrode was prepared by thoroughly mixing the clay with graphite powder and Al_2O_3 using paraffin oil as a binder in a small mortar until a smooth paste was obtained. Subsequently, the dough is manually inserted into the cylindrical cavity of the electrode body (geometric surface area of approximately 0.1256 cm²). Electrical contact is made with a carbon bar. This is because it possesses various advantages e.g. a wide potential range, simple and fast preparation, convenient surface renewal, porous surface and low residual current, besides it is inexpensive.

Procedure. Different supporting electrolytes were tested such as acetate buffer, phosphate buffer and Britton Robinson buffer. The phosphate buffer (pH=7) obtained the excellent electrochemical response. The working procedure consists of measuring the electrochemical responses at the surface of the CPE-Clay/Al_2O_3 to a concentration of ibuprofen. A known concentration of IBU solution was prepared in 0.1 mol L^{-1} of phosphate buffer solution (pH=7) and 20 ml of the prepared solution was transferred to an electrochemical cell. The cyclic and differential voltamogramme were obtained between 0.5 and 1.4 V at 100 mV s^{-1}. Optimal conditions were determined by measuring the currents as a function of all parameters.

Results and discussion

Electrochemical behavior of IBU. In order to study the electro-catalytic behavior of CPE-Clay/Al_2O_3 vis-a-vis ibuprofen oxidation, cyclic voltammograms, CPE, CPE-Clay, and CPE-Clay/Al_2O_3 were recorded in 0.1 mol L^{-1} of buffer solution of phosphate (PBS) in the presence of ibuprofen, as indicated. Fig. 1A (DPV) and Fig. 1B (CV) respectively show, it demonstrates that ibuprofen has only one peak oxidation in the potential range of 0.5-1.4 V, suggesting that the electrochemical process of ibuprofen is completely irreversible. In addition, the experimental result shows that the peak current of IBU on the CPE-Clay/Al_2O_3 curve increased sharply compared to the CPE and CPE/Clay curves. The presence of Al_2O_3 also resulted in a decrease in peak potential. The above results indicated that CPE-Clay/Al_2O_3 exhibited improved electro-catalytic performance with a sensitivity suitable for IBU analysis.

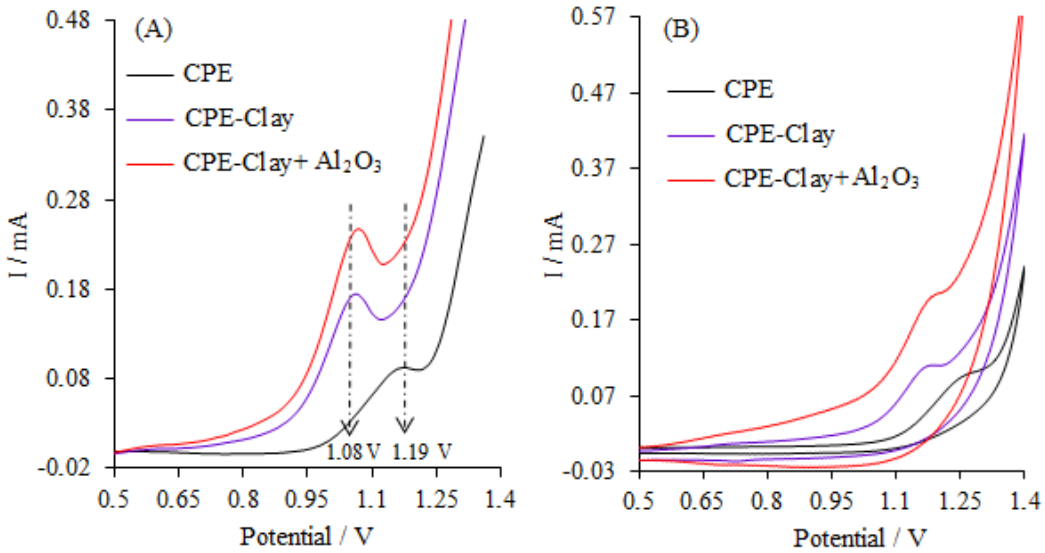

Fig. 1. (A) DPV, (B) CV (100 mV s^{-1}), obtained for CPE, CPE-Clay and CPE-Clay/Al_2O_3, 1.0 × 10^{-3} mol L^{-1} IBU in 0.1 mol L^{-1} phosphate buffer (pH=7).

Optimization of experimental variables. In order to obtain the response of the electroanalysis of ibuprofen with the highest magnitude. The transformation of ibuprofen is influenced by several electrochemical and chemical parameters such as the height and width of the pulse, the amplitude, the amount of clay inserted into the carbon electrode and the pH. Indeed, the best electrochemical response in terms of signal intensity and shape is obtained in Table 1.

Table 1. The electrochemical and chemical parameters such as the height and width of the pulse, the walking width, step height, the amount of clay inserted into the carbon and aluminum electrode and the pH.

Settings	Optimization range	Optimum value
Walking width (mS)	40-1000	900
Pulse width (mS)	40-180	160
Step height (mV)	1-40	20
Pulse height (mV)	40-180	120
Clay content (%)	1-20	4
pH	2-11	7

In addition to its electrochemical properties, CPE-Clay/Al_2O_3 shows a great capacity for the electroanalysis of ibuprofen. This electroanalysis was carried out by the DPV method. First, all electroanalysis parameters were optimized in a PBS solution (pH=7) containing $1.0 \cdot 10^{-3}$ mol L^{-1} of IBU. The effect of accumulation time on voltammetric responses was investigated. Fig. 2 shows an increase in current intensity as a function of preconcentration time during the first 30 seconds. After 30 seconds, the maximum intensity decreases with a marked increase in the accumulation time. Therefore, 30 seconds was used in all experiments.

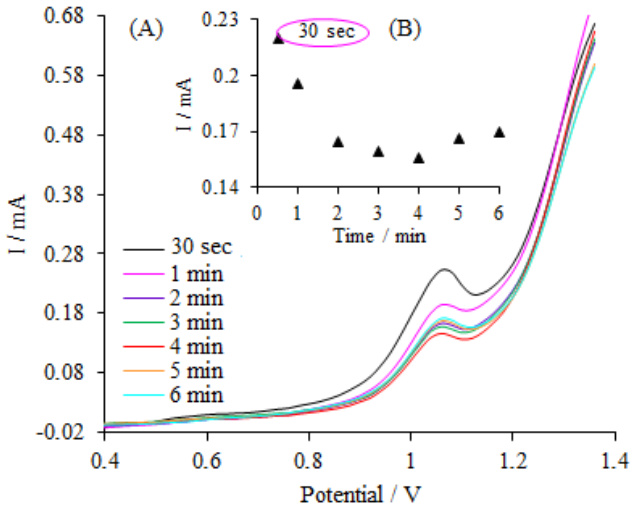

Fig. 2. Influence of the experimental variables ((A) and (B) accumulation time, involved in the DPV method, $1.0 \cdot 10^{-3}$ mol L^{-1} IBU in PBS solution (pH=7) at CPE-Clay/Al_2O_3.

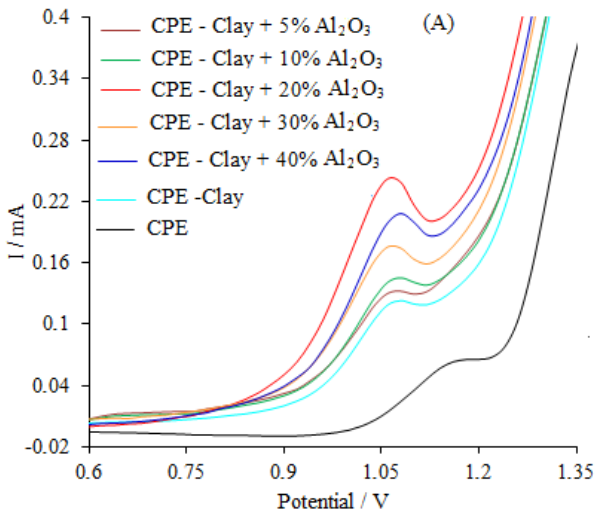

Fig. 3. Influence of the experimental variables ((A) % of Clay/Al_2O_3) involved in the DPV method, $1.0 \cdot 10^{-3}$ mol L^{-1} IBU in PBS solution (pH=7).

Fig. 4 shows the evolution of the current density of the anode peak as a function of the treatment temperature of the clay, it has been confirmed that, at a temperature of 600 ^{0}C, the electrode has good sensitivity.

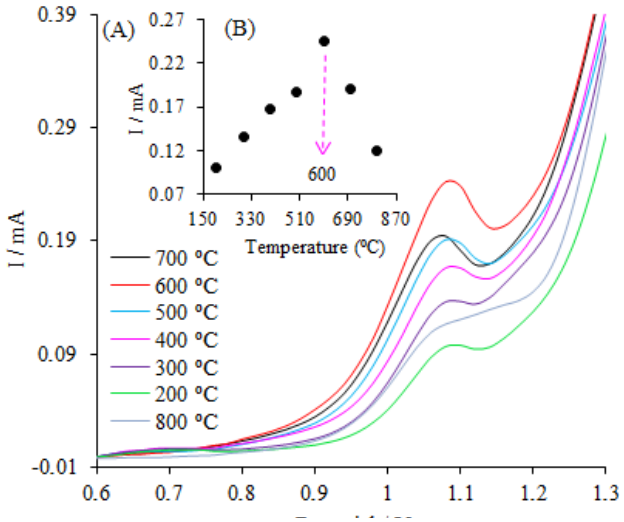

Fig. 4. Influence of the experimental variables ((A) and (B) temperature effect) involved in the DPV method, 1.0×10^{-3} mol L^{-1} IBU in PBS solution (pH=7) at CPE-Clay/Al_2O_3.

Influence of scanning rate. To further study the ibuprofen characteristics at the CPE-Clay/Al_2O_3, the influence of the scanning rates on the voltammetric behavior of IBU has been studied. Fig. 5A illustrates the cyclic voltammograms of ibuprofen ($1.0 \cdot 10^{-3}$ mol L^{-1}) in phosphate buffer at the CPE-Clay/Al_2O_3 surface with increasing scanning rates between 20 and 400 mV s^{-1}. The density of the peak current is proportional to the square root of the scanning rate ($v^{1/2}$) at the CPE-Clay/Al_2O_3 surface (Fig. 5B).

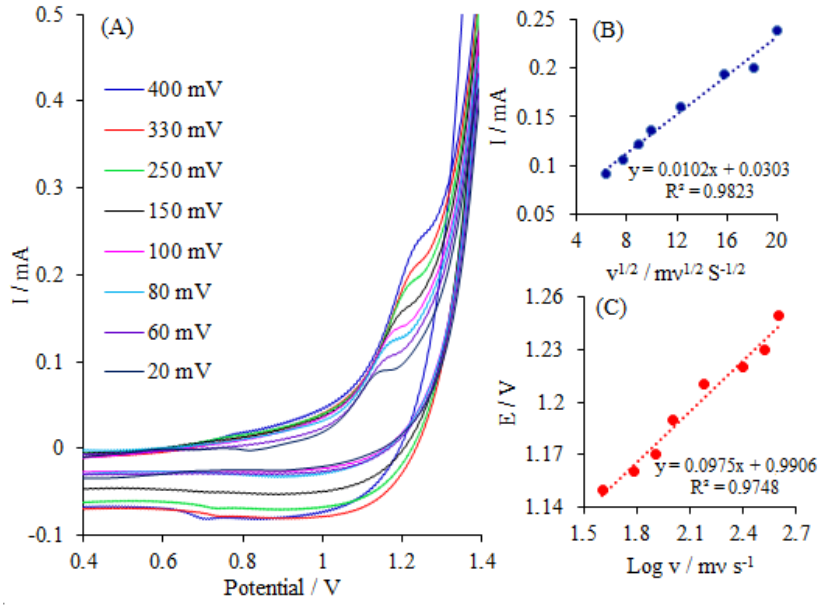

Fig. 5. CVs of $1.0 \cdot 10^{-3}$ mol L^{-1} IBU in 0.1 M phosphate buffer (pH=7); (A) CVs at different scanning rates; (B) variations of Ip with the $v^{1/2}$; (C) variations of Ep with log v.

This phenomenon proposed a diffusion-controlled mechanism at the CPE-Clay/Al_2O_3 [27]. In addition, the oxidation of IBU at the CPE-Clay/Al_2O_3 has been always irreversible, which can be appeared by the potential of IBU varied with the logarithm of scan rates. The oxidation peak potentials shifted regularly toward the positive direction with the scan rate varied from 20 to 400 mV s^{-1} (Fig. 5C).

Concentration effect of IBU. The influence of the IBU concentration was studied under the conditions optimized by DPV with CPE-Clay/Al_2O_3 (Fig. 6A). Fig. 6B shows the calibration curve for the oxidation of ibuprofen. The current density of the IBU oxidation peak increases with its concentration from 1.0×10^{-6} to $1.0 \cdot 10^{-3}$ mol L^{-1} of IBU. The detection limit calculated by the CPE-Clay/Al_2O_3 is $1.95 \cdot 10^{-8}$ mol L^{-1}. The repeatability of our analytical method was also studied as Relative Standard Deviation (RSD). Therefore, the calculated RSD is 3.4 % after nine measurements in solutions of $1.0 \cdot 10^{-5}$ mol L^{-1} IBU. The LD calculated by CPE-Clay/Al_2O_3 was compared with those obtained by other electrodes (Table 2) [28-30].

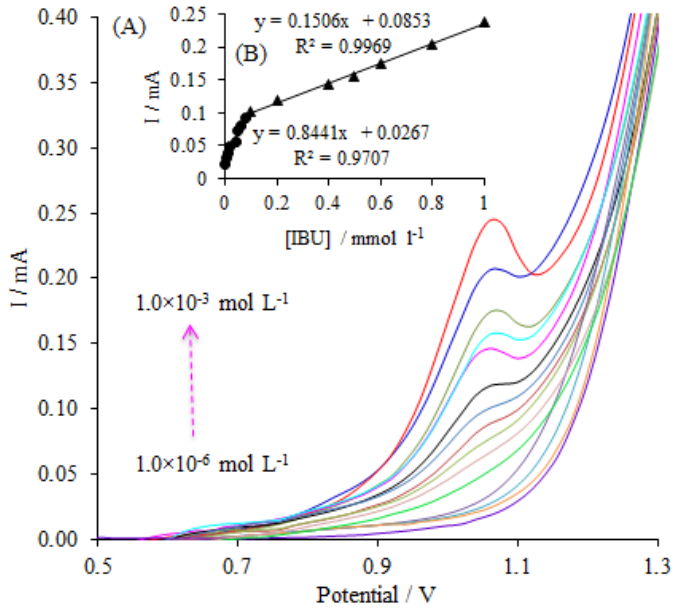

Fig. 6. (A) DPVs of IBU in 0.1 M PBS (pH=7) $1.0 \cdot 10^{-6}$ to $1.0 \cdot 10^{-3}$ mol L^{-1}. (B) Plots of electrocatalytic peak current versus IBU concentration.

Table 2. Limit detection obtained by several electrodes for the electroanalysis of IBU.

Modified electrode	Analytical technique	Detection limit	Ep (V)	pH	References
Carbon-epoxy nanotube multi-wall composite electrode	SQW	$1.50 \cdot 10^{-6}$ mol L^{-1}	1.10	8	[28]
Silver functionalized carbon nanofiber composite electrodes	CV	$1.45 \cdot 10^{-7}$ mol L^{-1}	1.29	7	[29]
HKUST-1 Metal-Organic Framework-Carbon Nanofiber composite electrode	CV	$1.05 \cdot 10^{-7}$ mol L^{-1}	1.25	7	[30]
CPE-Clay/Al_2O_3	DPV	$1.95 \cdot 10^{-8}$ mol L^{-1}	1.08	7	Present work

Electroanalysis of IBU in human blood. In order to verify the applicability and validity of the analytical method, the rock clay/Al_2O_3 modified carbon paste electrode was used for the detection of IBU in human blood samples. Human blood solutions were used without any pretreatment. The sample was prepared by adding 0.1 mol L^{-1} phosphate buffer (pH=7) to 20 ml of human blood, then enriched with appropriate amounts of ibuprofen. The electroanalytical curves were recorded by the pulse differential voltammetry method (Fig. 7A). Preliminary analysis indicates that this sample does not contain IBU. For this reason, we proceeded by contaminating this sample with ibuprofen at well-defined concentration levels. The IBU oxidation peak was well displayed. Then, the calibration curve of human blood samples using the optimal conditions is linear with a good correlation coefficient (R^2 = 0.91) (Fig. 7B). Therefore, the limit of detection obtained is $8.81 \cdot 10^{-8}$ mol L^{-1}. The calculated RSD is 4.08% after nine measurements in solutions of $1.0 \cdot 10^{-5}$ mol L^{-1} IBU. This shows the possibility of determining the IBU in human blood sample. Satisfactory results have previously been obtained for other molecules using other electrodes [31].

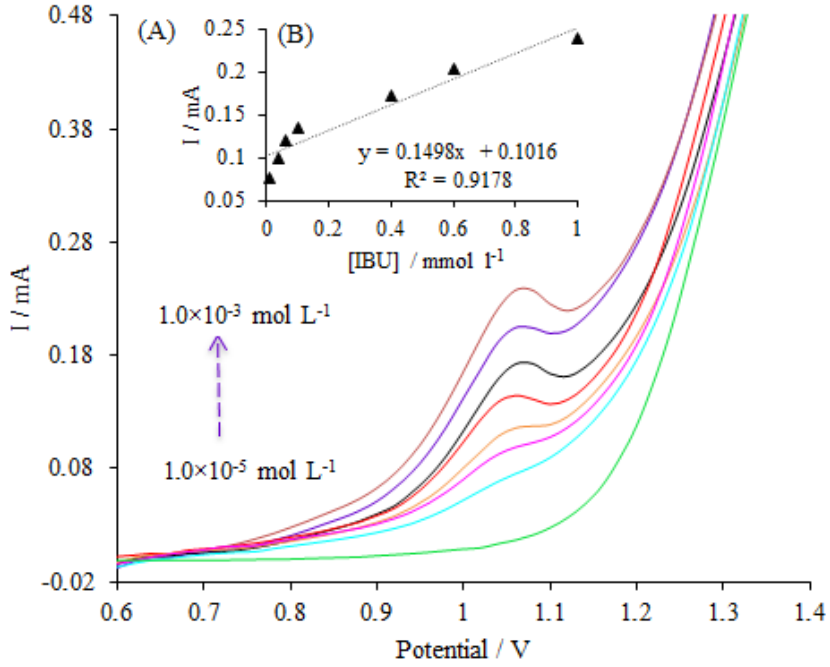

Fig. 7. (A) DPVs of IBU from 10^{-5} to 10^{-3} mol L^{-1} in 20 ml of human blood samples under optimized conditions, (B) plots of peak current versus IBU concentration.

Influence of interferences. The effect of interferents was also studied to determine the selectivity of CPE-Clay/Al_2O_3. These interferents are $1.0 \cdot 10^{-4}$ mol L^{-1} of ascorbic acid (AA), $1.0 \cdot 10^{-5}$ mol L^{-1} of resorcinol (RSC), $1.0 \cdot 10^{-5}$ mol L^{-1} of salicylic acid (As), in the solution containing $1.0 \cdot 10^{-4}$ mol L^{-1} of ibuprofen. Electrochemical measurements were studied to determine the influence of its interferents on the intensity of the oxidation currents of the compound examined (Fig. 8). The results obtained illustrate that the presence of interfering agents in a solution containing IBU does not influence the current density of the oxidation peak of IBU.

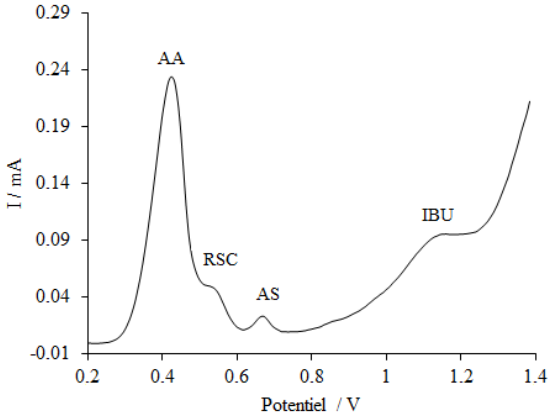

Fig. 8. DPV of a mixture of molecules containing ascorbic acid (AA), resorcinol (RSC), Salicylic acid (As) and ibuprofen (IBU).

Conclusion

Al_2O_3 supported on active clay was used as a modifier from carbon paste to oxidizing ibuprofen. The results showed that the peak potential of IBU goes in a negative direction. Therefore, the enhancing action in this case should be controlled by adsorption, which leads to an increase for IBU on the CPE-Clay/Al_2O_3 surface increases. Finally, the peak current of the IBU is also improved. The experimental conditions were optimized by varying the chemical and electrochemical parameters. the electro-catalytic behavior of the electrode with its long term stability, acceptable sensitivity, relatively low detection limit, wide dynamic range, easy preparation, relatively high selectivity, make it a useful device for the determination of ibuprofen in samples of human blood.

Conflicts of Interest

The authors declare no conflicts of interest.

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