Research Paper

Optimization of the experimental parameters in the determination of fluoride in water by differential pulse voltammetry

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Abstract
Fluoride has a fundamental role in maintaining dental health, as it is essential in the formation of the mineral fluorapatite that makes up tooth enamel. On the other hand, excessive fluoride intake can result in dental fluoresis. Since water is the main source of fluoride for humans, knowledge of fluoride levels in drinking water is important knowledge. In this work, the differential pulse voltammetry methodology for fluoride quantification in aqueous samples was optimized. The methodology is based on the competitive reaction of the fluoride ion and alizarin red S by lanthanum (III), in which the current resulting from the reduction of the complex of alizarin S red with lanthanum (III) will be measured by the addition of fluoride using an HMDE electrode. After the complexation reaction, a voltammetric peak was observed, corresponding to the oxidation of the anthraquinone group at -0.556 V vs Ag/AgCl using a acetic acid/sodium acetate buffer 0.1 mol L^{-1} as support electrolyte pH 4.76. The instrumental factors, drop size, frequency, voltage increment and pulse amplitude, were studied using an exploratory Plackett-Burman design to screen the relevant factors and then, to optimize the factor levels, a central composite design was performed. The best voltammetric responses were obtained when using the factors voltage increment of 12 mV, pulse amplitude of 40 mV, frequency of 30 Hz and drop size of 0.7 mm^2. With the optimized parameters, the voltammetric signal of the complex was linearly dependent with the concentration of added fluoride. The relative error using the optimized parameters was 4.96%. This methodology was applied to determine fluoride in water, comparing it with potentiometric measurements with selective electrodes, and the results were statistically equivalent.
Keywords: *differential pulse voltammetry; optimization; Fluoride; water.*

I.   INTRODUCTION

The role of fluoride as an important trace element for the human body has been the subject of many studies, so there is a concern to monitor public water supplies and verify that they are in potable conditions so that they do not pose any risk to the population health (Moraes et al, 2009). Ordinance No. 36/1990 of the Ministry of Health of Brazil establishes the minimum acceptable parameters, which are achieved by various techniques and treatments, the most traditional being the one that basically includes the steps of coagulation, flocculation, decantation, filtration, disinfection and fluoridation. Federal law 6050/1974 of Brazil, with its regulatory decree 76.872/1975, establishes the norms for the fluoridation of public water supply.

The element fluorine, whose presence in the environment occurs mainly in the form of fluoride, constitutes approximately 0.06-0.09% of the earth's crust, being found mainly in the form of fluorite ore. Fluorine is the most electronegative and reactive of all the elements, and many fluorine compounds are insoluble, which causes them to accumulate in tissues and organs of animals and plants. Thus, the exact amount of fluoride in animal and vegetable tissues, soil, drinking water, food and beverages is of fundamental importance (Krawezyk-Coda & Stanisz, 2017).

Intake of water and foods containing fluorine are defined as the primary sources of fluoride incorporation in the body. In the case of fluoride ingestion from water, its presence is considered beneficial when in a concentration around 0.7 mg L^{-1}, according to the World Health Organization (WHO), and it can be harmful if it exceeds 1.5 mg L^{-1} (Krawezyk-Coda & Stanisz, 2017). Concentrations in the range between 1.5 and 4.0 mg L^{-1} can cause dental fluorosis, and values above these levels can even cause skeletal fluorosis. Fluoride can replace the hydroxide ion of hydroxyapatite ($Ca_5(PO_4)_3OH$), which is the main mineral constituent of tooth enamel, and form fluorapatite ($Ca_5(PO_4)_3F$). This replacement makes the bone structure harder, but consequently also makes it more brittle (Krawezyk-Coda & Stanisz, 2017), but this reaction makes the mineralized part of the tooth less soluble, making it more resistant to the action of bacteria such as Streptococcus mutans, which is the main microorganism responsible for initiating caries (Moraes et al., 2009)

The determination of fluoride in water samples is usually carried out using chromatographic methods such as ion chromatography and high performance liquid chromatography or else using voltammetric and potentiometric methods, in the latter case using ion selective electrodes (Katsuóka, 1996). Another applicable alternative is molecular absorption spectroscopy for the determination of fluorine (Krawezyk-Coda & Stanisz; 2017).

Alizarin red S (ASR), sodium 1,2-dihydroxyanthraquinone-3-sulfonate, has been widely used for analytical purposes for the determination of various organic and inorganic compounds (Cunha, 2010). The colorimetric method for the determination of fluoride using this reagent was proposed by Sanchis (1934), in this case an organometallic complex of zirconium with the ASR is formed, which in an acidic medium is discolored by the addition of fluoride to the system (Parissakis & Kontoyannakos, 1963).

This organic compound used in the complexation of metals consists of an anthraquinonic group, two phenolic groups and a sulfonic group, which gives it high solubility in water, in addition to a variable color depending on the pH at which it is found, as can be seen in Figure 1 (Cunha, 2010).
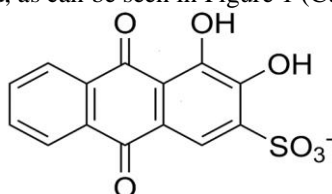

Figure 1: Molecular structure of Alizarin S Red dye.

In voltammetry, since fluoride is not electroactive, it can be determined by complexation between a metallic ion and alizarin red S and the precipitation reaction of the metallic ion with fluoride, taking advantage of the electroactivity of alizarin red S. Several are the voltammetric techniques for this analysis, highlighting the differential pulse voltammetry.

In an analysis, it is necessary to determine the values of the experimental parameters in which the response reaches its optimal value. This optimal value can be maximum or minimum depending on the parameters. One of the methodologies used to obtain these values is the Response Surface Methodology (Kalavathy et al., 2009). This methodology involves the use of experiments with reliable measures of the response of interest, to obtain an adequate mathematical model (Aslan, 2008).

Therefore, it is necessary to carry out experimental design, which are techniques that have been widely used in the most diverse branches of science, where first a series of experimental tests are established, and with that, changes in the input variables of a process are determined, so that it is possible to observe and identify the factors that modify the response (Ferreira et. al., 1999). Thus, it is possible to determine which variables exert the greatest influence so that a given result is achieved.

Experimental designs are effective when they provide a sufficient amount of information with less effort. After selecting the variables that can be studied and that probably interfere in the system, it is necessary to evaluate the experimental methodology (time, cost, etc.). The variables that were not selected must be fixed throughout the experiment (Teófilo & Ferreira, 2006).

II.   MATERIALS AND METHODS
Voltammetric measurement equipment

A voltametric analyzer model 797 VA Computrace from Metrohm® was used, managed by the 797 Computrace software version 1.2, via USB, using as working electrode a hanging drop mercury electrode (HMDE), an Ag/AgCl (KCl 3.0 mol L^{-1}) as reference electrode and a platinum wire as auxiliary electrode.

All data generated by the 797 VA Voltammetric Analyzer were treated using the Origin 9.1 and Statistica 7.0.

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pH and fluoride measurements with selective electrode

To measure the pH of the solutions, an Orion-Jundilab potentiometer, model 720A with a glass electrode, combined with a reference electrode of Ag/AgCl (KCl 3.0 mol L^{-1}) was used. For potentiometric measurements of fluoride concentration, the same potentiometer was used with a fluoride-selective electrode, combined with a double-walled Ag/AgCl (KCl 3.0 mol L^{-1}) reference electrode.

Reagents and Solutions

All reagents used were analytical grade and the water used to prepare the solutions was deionized (Milli-Q). All solutions were stored in polyethylene bottles.

The glassware and polyethylene bottles were washed and then immersed in a HNO_3 10% (v/v) (Quimex) solution for 24 hours and rinsed with deionized water.

The mercury used as the working electrode was purified by successive washings, at least three times, with HNO_3 0.01 mol L^{-1} and finally dried by filtration on filter paper.

A stock solution of alizarin red S (Vetec) 0.01 mol L^{-1} in deionized water was prepared, obtaining the working solutions by appropriate dilution of the stock solution in deionized water.

A stock solution of La(III) 0.0072 mol L^{-1} was prepared by digestion of lanthanum oxide (La_2O_3 – Scientific Exodus) by dripping with concentrated hydrochloric acid, until complete solubilization. Afterwards, the solution was transferred to a volumetric flask, completing the volume with deionized water.

The acetic acid/sodium acetate buffer solution 0.1 mol L^{-1} was prepared by dissolving, in deionized water, glacial acetic acid (CH_3COOH - Vetec) together with sodium acetate (CH_3COONa - Vetec). The solution was transferred to a volumetric flask, completing the volume with deionized water. The pH of this solution was adjusted to 4.75 with glacial acetic acid or concentrated sodium hydroxide solution.

The fluoride stock solution 0.0024 mol L^{-1} was prepared by dissolving sodium fluoride (NaF - Vetec), transferring the solution to a volumetric flask and completing the volume with deionized water.

For the interference study, solutions of $Fe(NO_3)_3$ 0.012 molL^{-1}, $Fe_2(SO_4)_3$ 0.012 mol L^{-1}, $Al(NO_3)_3$ 0.012 mol L^{-1} and $Al_2(SO_4)_3$ 0.012 mol L^{-1} were prepared, all in deionized water.

Voltammetric Analysis

The standard procedure performed for all voltammetric analyzes of the ASR-La complex was performed by adding 10.0 mL of acetic acid/sodium acetate buffer solution 0.1 mol L^{-1} (pH 4.75) to the voltammetric cell; 2.0 mL of alizarin red S solution 0.0015 mol L^{-1} (3.0 µmol) and 100 µL of La(III) solution 0.0072 mol L^{-1} (0.72 µmol). The solution was deoxygenated with ultrapure nitrogen for 240 seconds, under constant agitation. In the fluoride standard or sample addition procedures, the deoxygenation operation was carried out for 60 seconds. The techniques used were cyclic and differential pulse voltammetry, exploring the potential range between -0.150 and -0.700 V.

Preliminary Tests

Preliminary experiments by cyclic voltammetry were carried out to investigate the electrochemical behavior of the ASR and the ASR-La complex in the range of -0.150 to -0.700 V.

To verify the influence of process variables, voltage increment (VS), frequency (FR), amplitude (AM) and droplet size (TG) on the voltammetric response, a univariate screening was performed using the voltammetry of differential pulse, according to the values established in Table 1.

Table 1: Variables values for univariate screening.

Variables	Values				
VS (mV)	3	6	9	12	15
FR (Hz)	10	30	50	70	90
AM (mV)	10	20	30	40	50
TG (mm^2)	0.1	0.3	0.5	0.7	0.9

Factorial Design

After screening, a complete factorial design was performed to define which variables have a significant effect on the voltammetric response. The choice of values for the variables voltage increment (VS), pulse amplitude (AM), frequency (FR) and mercury droplet size (TG) (Table 2) was made according to the results of the preliminary tests.

Using the coded variables (Table 3), the 16 experiments were performed, whose current results were analyzed with the Statistica.

If the linear model does not satisfy the operating conditions of the system, in this case due to a curvature in the response surface, then the central composite design (Central Composite Design - CCD) is appropriate to fit the complete second order polynomial model (Teófilo & Ferreira, 2006).

Thus, after analyzing the data obtained with the complete factorial design, a central composite design was performed, keeping the less significant variables at a constant value and reassessing the significant variables from the previous design.

With the data obtained in the central composite design and using the Statistica, the response surface was generated as a function of the significant variables.

Interferences and samples

Possible interferences of Fe(III) and Al(III) ions were verified, with successive additions of increasing amounts of them, following the voltammetric analysis procedure of the Materials and Methods item.

Subsequently, the optimized methodology was applied for the analysis of fluoride in five water samples.

III. RESULTS AND DISCUSSION

The exploratory experiments by cyclic voltammetry were carried out with the aim of investigating the electrochemical behavior of the ASR ligand and the complex formed ASR-La, in the range of -0.150 to -0.700 V (Figure 2).
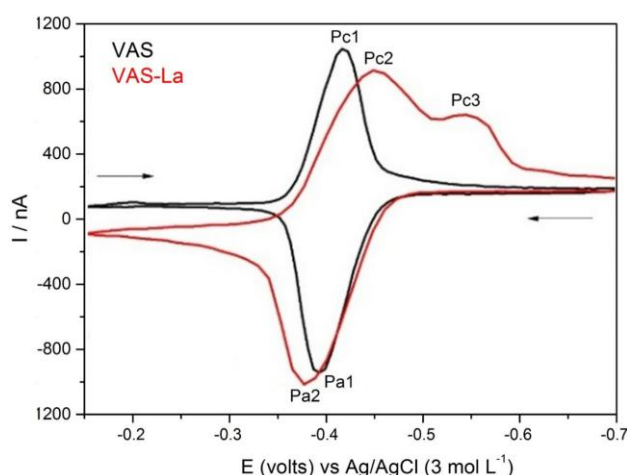

Figure 2: Cyclic voltammograms for pure ASR and for the ASR-La complex.

In the cyclic voltammogram, it is possible to observe that in the anodic scan for the ASR, the Pa1 peak (-0.390 V) appears related to its oxidation and the one related to its reduction can be associated with the Pc1 peak (-0.414 V) in the cathodic scan.

After the addition of lanthanum (III) to the system, it is observed that in the anodic scan there is a shift in the oxidation potential of the ASR peak, related to the Pa2 peak (-0.374 V), and the peak of its reduction in the Pc2 point is also shifted (- 0.447 V). In the cathodic sense, after the addition of La, the appearance of a new Pc3 peak (-0.543 V) is also observed, which is associated with the formation of the ASR-La complex. As this peak appears in only one direction of the cyclic sweep, it is concluded that the formation of this complex is not reversible.

The cyclic voltammogram obtained for pure ASR is in agreement with Heng Li et al. (2005), who used ASR as a complexing agent in the voltammetric adsorptive technique of redissolution with a carbon paste electrode. They concluded that the peaks, in the forward and in the reverse direction, come from the reduction and oxidation of the anthraquinonic group of the ASR molecule, as shown in Figure 3.
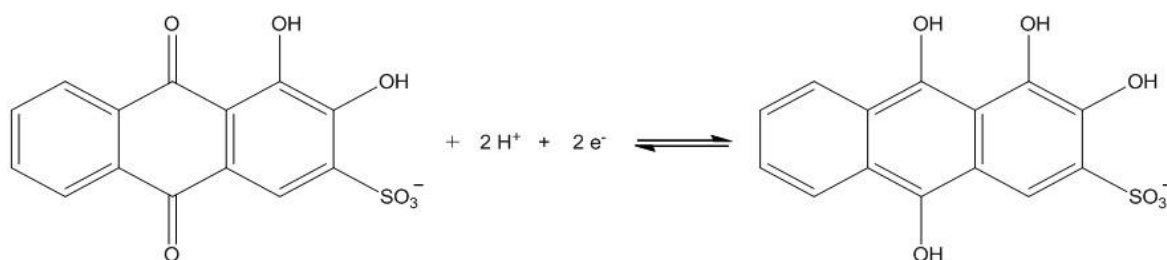

Figure 3: ASR reduction and oxidation reactions.

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Preliminary Studies

Preliminary experiments using differential pulse voltammetry, for the subsequent choice of values for the factorial designs, were based on the electrochemical behavior of the ASR ligand and the complex formed ASR-La, in the range of -0.150 to -0.700 V, in the experiments of cyclic voltammetry.

The variable voltage increment (VS) was studied by varying the values between 3, 6, 9, 12 and 15 mV in each experiment. The voltammograms obtained can be seen in figure 4A.

As can be seen in Figure 4A, the response to the peak of the complex increases proportionally with the increase in VS, but from the value of 15 mV onwards the response starts to appear with a lot of noise, choosing the value of 9 mV as the point central to factor design.
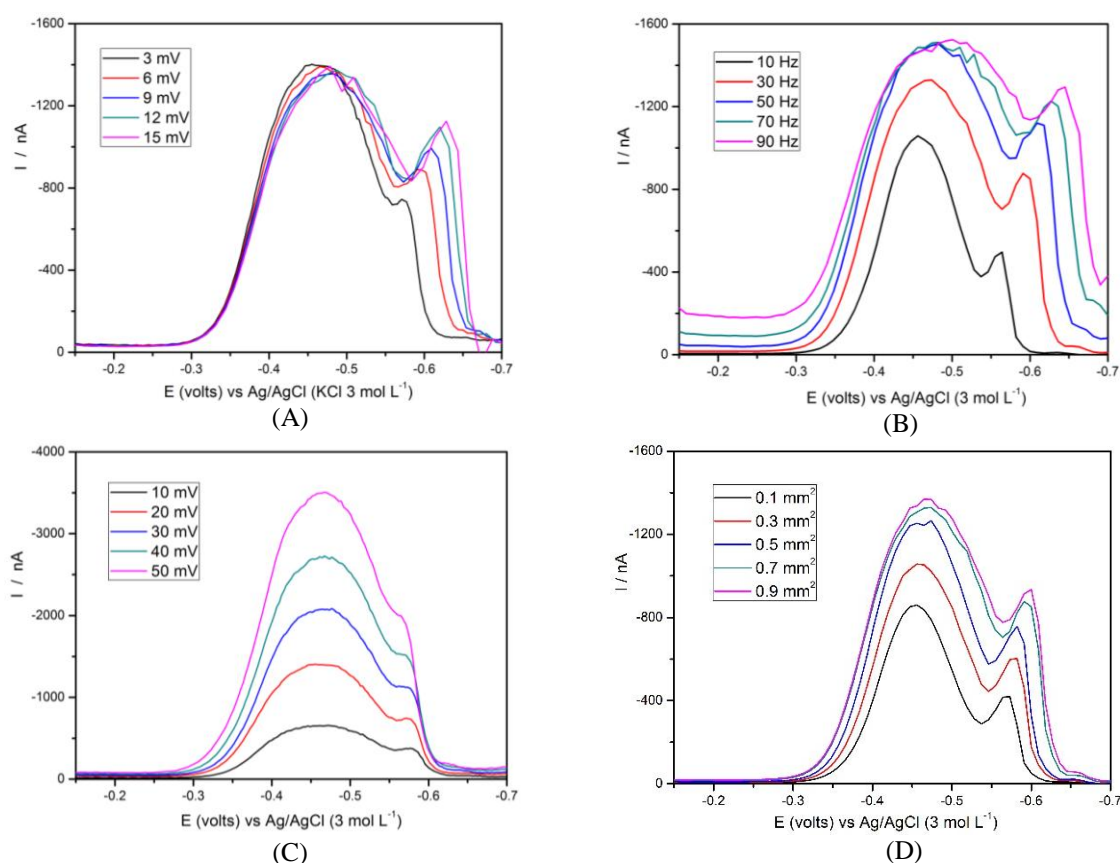

Figure 4: Variations of voltage increment (A), frequency (B), pulse amplitude (C) and mercury droplet size (D) in the preliminary experiments.

The frequency values (FR) studied were 10, 30, 50 70 and 90 Hz. As can be seen in Figure 4B, the increase in frequency in the experiment leads to an increase in the signal, but from 50 Hz the results show a lot of noise, being then chosen the value of 30 Hz as the central point in the factorial design.

The amplitude (AM) was evaluated at values of 10, 20, 30, 40 and 50 mV, and the responses obtained are shown in Figure 4C. As the value of 20 mV had the best resolution between the characteristic peak of alizarin in relation to the peak of the formed complex, this value was chosen as the central point in the factorial designs.

The hardware of the potentiostat used provides preset values for the size of the drop of mercury (TG) used in the HMDE technique, equal to 0.1, 0.3, 0.5, 0.7 and 0.9 mm^2. Figure 4D shows the results obtained in each configuration, and under these conditions the 0.7 mm^2 size presented better resolution with less signal noise, and for this reason it was chosen as the central point in the factorial designs.

Screening Experiments

As verified in the preliminary experiments, the alteration of the experimental parameters interferes with the voltammetric response given by the equipment. Thus, through the complete factorial design, a screening was carried out in order to identify which factors are important by choosing the variable levels (Table 2), considering the results of the preliminary experiments.

Table 2: Factorial design with the variables and levels established in the preliminary experiments.

Variables	Levels	
	-	+
VS (mV)	6	12
FR (Hz)	10	50
AM (mV)	10	30
TG (mm^2)	0.5	0.9

Table 3: Complete factorial design with current results, for definition of significant variables.

Test	VS	AM	FR	TG	|Ip| (nA)
01	+	+	+	+	1003
02	-	+	+	+	936
03	+	-	+	+	341
04	-	-	+	+	284
05	+	+	-	+	364
06	-	+	-	+	275
07	+	-	-	+	121
08	-	-	-	+	108
09	+	+	+	-	808
10	-	+	+	-	623
11	+	-	+	-	269
12	-	-	+	-	235
13	+	+	-	-	283
14	-	+	-	-	203
15	+	-	-	-	103
16	-	-	-	-	86

The Pareto chart (Figure 5) shows the information generated by Tables 3 and 4. With this chart we can see that at a 99% confidence level, the effects of the frequency and amplitude variables were statistically significant, as well as their interaction. Two variables went far beyond the defined significance level and affected the current intensity of the ASR-La complex in the same proportion. The drop size variable was not as significant as the frequency and amplitude variables, thus it was fixed at the mean value of 0.7 mm^2.

Table 4: Estimates of main effects and interactions for the full factorial.

Estimate of effects ± error (*)	
Average	378.25 ± 9.75
Main effects	
VS	66.50 ± 19.50
AM	367.25 ± 19.50
FR	368.25 ± 19.50
TG	101.50 ± 19.50
Second order interaction	
AMxFR	193.00 ± 19.50
AMxTG	63.75 ± 19.50
FRxTG	55.75 ± 19.50

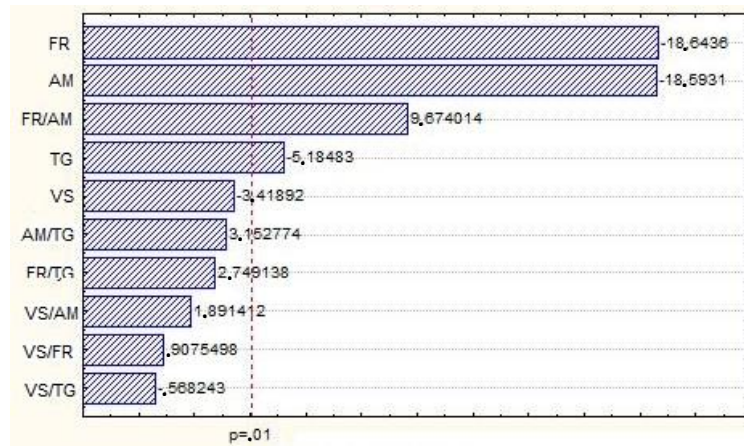(*) Estimates of effects in bold are the most significant.

Figure 5: Pareto chart with estimated effect (absolute value)
of the variables tested in the complete factorial design.

Table 5: Central composite design, with decoded variables and levels.

Variables	Levels				
	$-\sqrt{2}$	-1	0	+1	$+\sqrt{2}$
AM (mV)	6.0	10	20	30	34.0
FR (Hz)	2.0	10	30	50	58.0
VS (mV)*	4.8	6	9	**12**	13.0
TG (mm^2)*	0.4	0.5	**0.7**	0.9	1.0

* Variables VS and TG were kept constant, in bold values.

After analyzing the data obtained with the complete factorial design, verifying the significance of the FR and AM variables and, to a lesser extent, for the TG (Table 4 and Figure 5), a central composite design was performed (Table 6), maintaining the less significant variables at constant values (Table 5) and reassessing the significant variables from the previous design.

Table 6: Central composite design and responses.

Ensaio	AM	FR	VS*	TG*	|Ip| (nA)
01	-1	-1	+1	0	308
02	+1	-1	+1	0	289
03	-1	+1	+1	0	489
04	+1	+1	+1	0	837
05	$-\sqrt{2}$	0	+1	0	807
06	0	$-\sqrt{2}$	+1	0	638
07	$+\sqrt{2}$	0	+1	0	1431
08	0	$+\sqrt{2}$	+1	0	895
09	0	0	+1	0	1103
10	0	0	+1	0	1297
11	0	0	+1	0	1396
12	0	0	+1	0	1392

* VS and TG – Less significant variables kept constant values, VS = 12 mV and TG = 0.7 mm^2.

Table 7: Result of central composite design.

Symbol	Coefficent (*)
Average	916.106 ± 141.143
Principal effects	
AM	151.556 ± 128.935
FR	136.828 ± 128.935
Second order interaction	
FRxFR	-196.243 ± 141.704

Response Surface Methodology

  With the data obtained from the central composite design in Table 6 and after verifying the significance of each effect and their interactions (Table 7), the equation that generates the response surface (Figure 6) with the coded variables was determined.

$$I(nA) = 916.106 + 151.556 \cdot AM + 136.828 \cdot FR - 196.243 \cdot FR^2$$
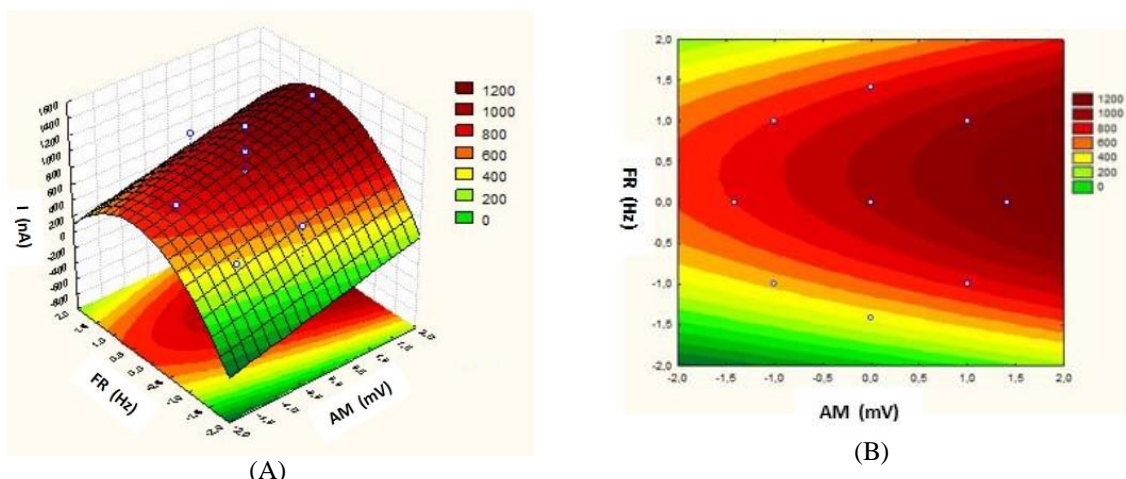

(A)   (B)

Figure 6: Response surface (A) and contour projection (B) of the current as a function of the coded variables AM and FR.

  Considering that the point referring to the values of the variable AM equal to 40 mV and the variable FR equal to 30 Hz, is in the maximum area of the surface, although AM extrapolates the values of the design data, applied in the equation, a current of 1143.4 nA. Using these values experimentally, the current obtained was 1203.1 nA, which gave a relative error of 4.96%, showing that the executed design is valid and applicable. After optimization, the parameters used in the subsequent analyzes were established as shown in Table 8.

Table 8: Optimized parameters for fluoride analysis by differential pulse voltammetry.

Parameters	Optimum values ótimos	Estimated current
Initial Potential	-0.15 V	1143.4 nA
Final Potential	-0.70 V	
Voltage increment	12 mV	
Amplitude	40 mV	Observed current
Frequency	30 Hz	1203.1 nA
Sweep speed	0.72 Vs^{-1}	
Drop size	0.70 mm^2	*Relative error: +4.96 %

  The molar ratio between La(III) and ASR is 1:2, according to Kawashima et al. (1961), so that the anionic complex formed has the formula $[La(ASR)_2]^-$ and the possible reactions between La(III), ASR and fluoride are shown in Figure 7.

  ASR is a diprotic acid, with values of pKa_1 (α-OH) = 5.39 and pKa_2 (ß-OH) = 10.72 (Cunha, 2010), which is why the experiments were planned in a system with a pH close to a 5, which promotes the ionization of the first hydroxyl and facilitates the formation of the complex.
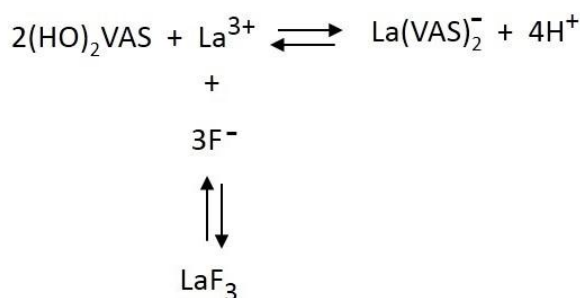
$$2(HO)_2VAS + La^{3+} \rightleftharpoons La(VAS)_2^- + 4H^+$$

$$+$$

$$3F^-$$

$$\updownarrow$$

$$LaF_3$$

Figure 7: Reaction between ASR, fluoride and La(III).

For the determination of fluoride in a solution, the ASR-La complex was used, considering the fact of the differences in the formation constants of the La(II) complex with the ASR complexant ($K_f = 4 \times 10^8$) and the formation of little salt soluble LaF_3 ($K_{PS} = 7 \times 10^{-17}$). Thus, when fluoride is added to the system containing La(III) and ASR, the peak referring to the ASR-La complex will decrease proportionally to the amount of fluoride added. In Figure 8, it is possible to observe the voltammogram referring to the entire extension of the potential scan and the enlarged detail of the Pc3 peak referring to the ASR-La complex after each fluoride addition.
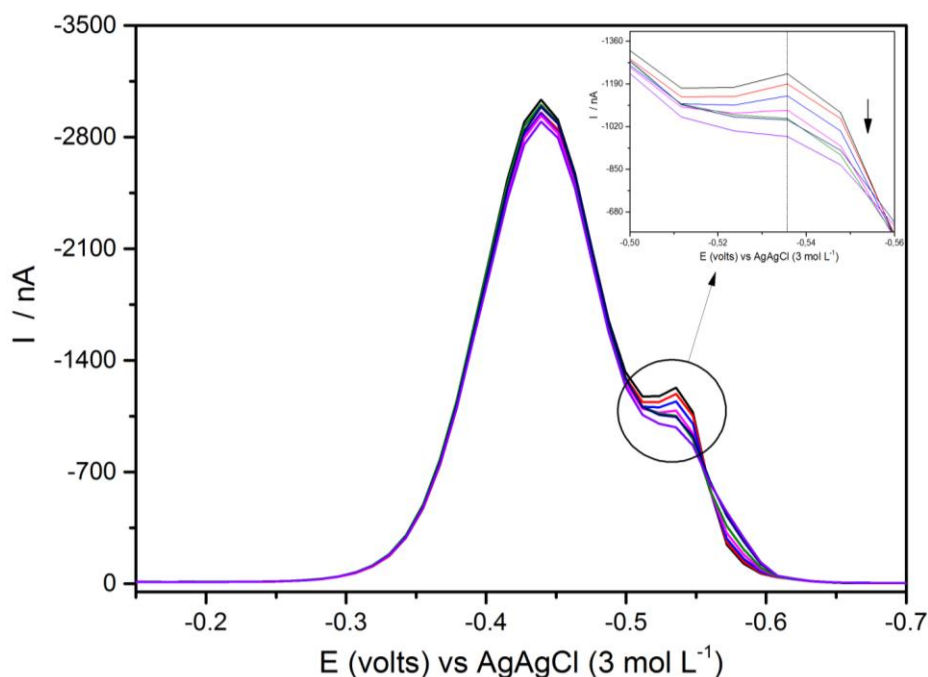

Figure 8: Cathodic scan of the ASR-La complex from -0.15 to -0.7 V. Complete voltammogram and in detail the peak formed by the ASR-La complex, after fluoride additions.

Analyzing the currents obtained at the potential of -0.536 V in the detail of Figure 8, linear regression was obtained, with a determination coefficient of 0.954 for the fluoride concentration in the voltammetric cell as a function of the current obtained for the peak (Figure 9).
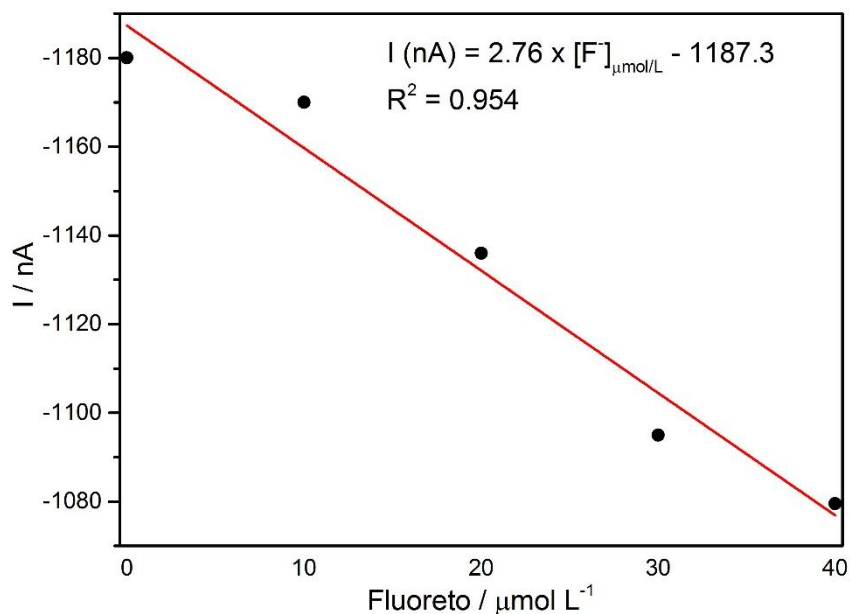
$$I\ (nA) = 2.76 \times [F^-]_{\mu mol/L} - 1187.3$$
$$R^2 = 0.954$$

Figure 9: Analytical curve for fluoride quantification.

Interferent Study

According to ALVES (1986), the main interfering factors for a study using the ASR are iron, aluminum, zinc and tellurium because the cations of these metals present a considerable formation constant with the complexing agent. Considering that in a water treatment plant, contaminants such as metallic cations are removed, the presence of iron and aluminum in the solutions was considered in this study.

Iron can come from some mechanical part of the fluid transport process, and aluminum can become a contaminant when the flocculation treatment process leaves some residue remaining.

The compounds used in the tests were iron(III) nitrate, aluminum(III) nitrate, iron(III) sulfate and aluminum(III) sulfate. All solutions were prepared at the same concentration (0.012 mol L^{-1}), thus, for stoichiometry purposes, additions of 100 μL of Fe(III) or Al(III) nitrate solutions or 50 μL of sulfate solutions were used of Fe(III) or Al(III).

Figure 10 shows the voltammograms referring to the analysis of each interferent. In part (A) it is observed that after the addition of iron (III) nitrate decreases occur in the peaks of the ASR and the ASR-La complex, showing that there is interference both in the alizarin signal and in the signal of the complex. After the addition of fluoride to this system, the alizarin peak grows while that of the complex remains practically constant, leading to the conclusion that there was no release of alizarin from the complex with La(III) under study, but from that formed with the interferent.

In figure 10 (B), after the addition of iron (III) sulphate, a slight displacement occurs only at the peak of the complex, which also decreases. This can be a consequence of the formation of a new component in the system. When aluminum was added to the system, there was a large variation in the voltammogram, as can be seen in parts (C) and (D). In these two tests the addition of the interferent drastically reduces the alizarin peak and in the presence of fluoride the complex peak decreases in intensity.
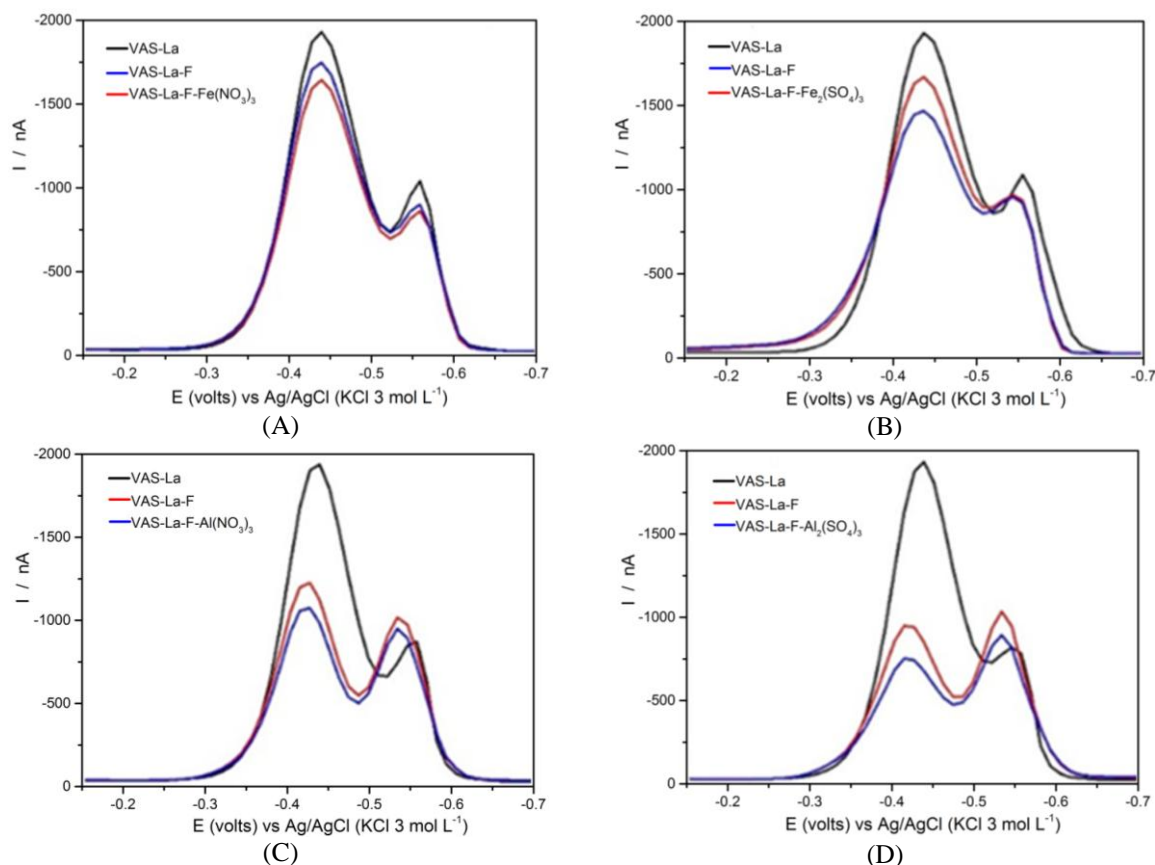
Figure 10: Voltamograms obtained for the analysis of each interferent in relation to the ASR-La complex and fluoride: A) iron (III) nitrate; B) iron (III) sulfate; C) aluminum (III) nitrate; D) aluminum (III) sulphate.

Application in Real Samples

      The optimized methodology was applied to real water samples. Five samples were obtained from different locations and with different fluoride contents. Table 9 lists the samples and fluoride concentrations determined by potentiometric measurements with ion selective electrodes and by the optimized voltammetric methodology.

- ✓ Sample 1: collected at the Water Treatment Station in Federal University of Viçosa - Brazil – before fluoridation.
- ✓ Sample 2: collected at the Autonomous Water and Sewage Service in the city of Viçosa - Brazil – before fluoridation.
- ✓ Sample 3: collected at the Water and Sewage Service in the city of Viçosa - Brazil – after fluoridation.
- ✓ Sample 4: obtained in an experiment of spraying an aqueous solution of fluoride on plants at the Federal University of Viçosa - Brazil.
- ✓ Sample 5: obtained in an experiment of spraying an aqueous solution of fluoride on plants at the Federal University of Viçosa - Brazil.

      According to the results obtained, presented in Table 9, the optimized voltammetric method is equivalent to the potentiometric methodology using selective electrode for the fluoride ion.

Table 9: Fluoride concentrations in water samples, with potentiometric (ESI) and optimized voltammetric techniques.

Sample	Determined fluoride (mmol L^{-1})		Relative error (%)
	ISE	Voltametry	
1	ND	ND	-
2	ND	ND	-
3	0.541 ± 0.00	0.540 ± 0.00	-0.22
4	3.860 ± 0.00	3.867 ± 0.00	+0.18
5	1.621 ± 0.00	1.606 ± 0.00	-0.95

The relative error for each sample was low, showing that the proposal to obtain a routine procedure for fluoride analysis was achieved.

IV.   CONCLUSION

The proposed method, using differential pulse voltammetry with hanging drop mercury electrode (HMDE) to analyze the complex formed by alizarin red S and lanthanum(III), proved to be valid for the quantification of fluoride in aqueous samples, presenting high sensitivity with a relatively simple and fast operating procedure.

The methodology optimization step demonstrated great importance in the effectiveness of the study of fluoride determination, using acetic acid/sodium acetate buffer as a support electrolyte and the complex formed by the lanthanum cation and the alizarin red S, being explicit that the alteration of the instrument's instrumental factors affects the obtained response.

Factorial design is an important and indispensable tool for verifying how each studied parameter influences the current response.

Statistical analysis, using the Pareto chart, was efficient to define which variables were significant in the process, as well as their respective interactions, defining which could be better addressed to carry out the optimization.

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