**Application of argentometric Chloride determination by ICP-OES to a wide range of sample matrices**

**Application of indirect ICP-OES Chloride determination by argentometric method to a wide range of sample matrices**

**Nadav Lerner, Hanan Avraham, Nitai Leffler, Ira A. Weinstock, Offer Zeiri**

**Introduction**

Chloride is a widespread halide, which constitutes approximately 0.0145% of the earth's crust[1], and is present in various minerals and every natural body of water. Chloride plays an important part in human biology and health[2–5], environmental processes[6,7], pitting corrosion[8–10], and agriculture[11,12]. The determination of chloride, in a variety of matrices, is therefore of great importance. Consequently, many methods for chloride determination have been developed[13–18]. Of these, some of the most common and well established methods for chloride analysis are argentometric methods, based on various analytical techniques, such as colorimetric[19,20], electrochemical[21,22], and fluorescence[23] titrations, atomic absorption[24], x-ray fluorescence[25] or distance measurement[26].

Inductively coupled plasma optical emission spectrometry (ICP-OES) is a powerful and popular elemental analysis technique[27]. ICP-OES instrumentation is simple to operate, offers a wide dynamic range, and can determine multiple elements in a single measurement. Most importantly, ICP-OES can measure nearly every naturally occurring element. However, halide measurement by ICP-OES, such as chloride determination, is very limited. These limitations stem from several factors. The most sensitive emission lines of chloride are located in the vacuum UV region, circa 134 nm[28,29]. Measurements at such low wavelengths require the removal of air components (nitrogen, oxygen, water vapor, etc.) from the optical path of the instrument by using vacuum or purged optical systems, and a detector capable of operation in this region[30]. As a result, this region is below the measurement range of most common ICP-OES instruments. Furthermore, elements with high ionization potential[1], such as chloride, generally have lower sensitivity in argon-based ICP-OES instruments[31], which are the most common. Halides are also easily adsorbed to the plastic tubing of the ICP-OES instruments, leading to issues of memory effects[30,32], and often require complex sample preparation prior to measurement[33]. Despite these limitations, ICP-OES determination of chloride is still sought after. Methods for chloride determination in cement[34], oils and fuels[35–37], plants[38], water[39,40], and milk[41] using ICP-OES have been published. However, all of these methods require either specific ICP-OES instrument models, capable of measurement in the UV region, or the use of additional instrumentation. While various advancements have been recently made in ICP-OES measurements, including new calibration strategies, decreased argon consumption, and improved analytical performance[32], halide determination by ICP-OES still presents a challenge. We herein present an indirect, argentometric method for chloride determination by ICP-OES, which can be performed on any ICP-OES instrument, with no additional equipment required. The method is shown to accurately measure chloride in a variety of matrices, including biological, environmental, industrial, and food samples.

**Experimental**

**Chemicals**

Single element 1 g L-1 CRM solutions (Cl, Ag, Y, Mn, Fe, Mg, Ca, Cu, Pb, Zn, Al) were purchased from CPI international. Seawater from the Mediterranean Sea was collected at Bat-Yam beach, Israel. Wine samples (white wine, 12% alcohol content) were purchased at a local supermarket. Urine samples were collected from a healthy volunteer. Seawater, wine, and urine were all filtered (syringe filter, NY 0.22 µm) and diluted prior to measurement. All aqueous solutions were prepared using ultrapure water (18.2 MΩ∙cm, Millipore Co, USA).

**Instruments\apparatus**

Inductively coupled plasma-optical emission spectrometry (ICP-OES) measurements were performed on an Arcos 2 MultiView instrument (Spectro, Germany) using an axial plasma configuration. Instrument conditions were 1400 W plasma, and flow rates of 13, 0.8, 0.8 Lmin-1 for coolant, nebulizer, and auxiliary flow. Ion chromatography measurements were performed on a 930 compact IC FLEX with a conductivity detector (Metrohm, Switzerland), and an 858 professional sample processor autosampler and controlled by the magicnet 3.2 software. Anion separation was carried out in suppressor mode on metrosep A column (250X4mm) connected in series with a Metrosep A guard column (4/5). A low background level was kept by the use of metrohm suppressor module (MSM) for chemical suppression combined with metrohm CO2 suppression module (MCM).

**Procedures**

**Precipitation solution**

nitrate (Ag+NO3-) nitrate (Y+NO3-)++Ag+standard Y+ standard

**ICP-OES method calibration**

Calibration solutions (chloride concentrations of 0, 0.75, 1.5, 4.5, 7.5, 10, and 12 mg L-1) were prepared by dilution, using ultrapure water, of a 1 g L-1 chloride (Cl-) standard solution to 12.5 ml then adding 2.5 ml of the precipitation solution. The calibration curve was produced by plotting the Ag+/Y+ intensity ratio (at 328.068 nm and 324.228 nm, correspondingly) against chloride concentration.

**ICP-OES Measurement procedure**

t Samples were prepared for measurement by mixing 10 mL of the measured solution with 2.5 mL of the precipitation solution and adding ultrapure water to obtain a final volume of 15 mL. The sample was shaken thoroughly by hand and kept in the dark for about half an hour before being filtered (syringe filter, NY 0.22 µm) into a new vessel, and taken for measurement. The chloride concentration in the samples was then derived from the calibration curve using the Ag+/Y+ intensity ratio measured for each sample. Samples containing chloride concentrations exceeding the method's working range were diluted as necessary using ultrapure water.

**Ion Chromatography calibration (SI)**

Calibration solutions (see SI for details) were prepared from a 1 g L-1 standard chloride solution. A solution of 3.6 mM NaHCO3 was used as eluent at 0.8 ml min-1 flow rate and a solution of 0.1 M H2SO4 was used as the regenerant. Elution mode was isocratic and the temperature of the column was kept at 45 oC for the analysis period. The volume of the sample injection loop was 20 µL.

**Results and discussion**

**Method principle**

Argentometric determination of chloride, based on the low solubility of silver chloride (Ksp = 1.77∙10-10)[1] in aqueous matrices, is well-established. Previously published argentometric methods include amperometric[21] and colorimetric[19,20] titrations, as well as XRF spectroscopy[25] and distance-based μPADs[26]. Adapting the argentometric method for ICP-OES, a predetermined amount of silver is added to each sample, and measured following its reaction with chloride. The changes in the silver concentration are then used to quantify the chloride in the sample. Calibration solutions of known chloride concentrations are used to plot the calibration curve (figure 1). Since the silver concentration decreases as the amount of chloride in the sample increases, a negatively sloped calibration curve is obtained.

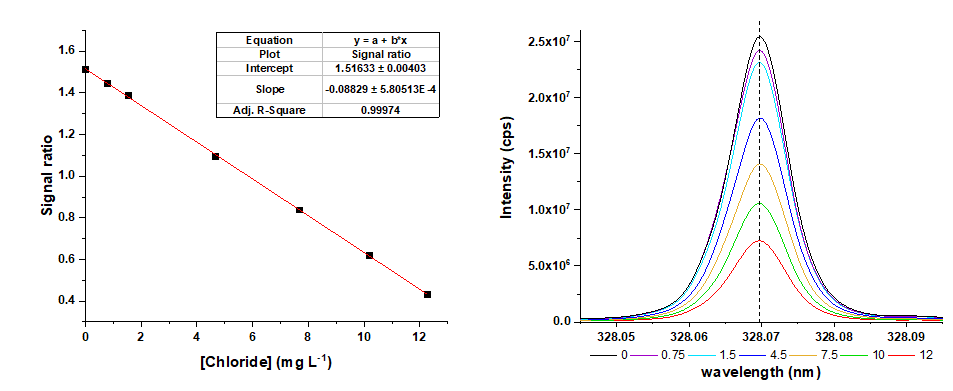


Figure 1: calibration curve

The application of argentometric chloride detection to ICP-OES requires several method parameters to be examined. These include the optimal working range and initial Ag concentration, the instrument sensitivity and precision, and the method's selectivity and robustness.

**Working range**

Since argentometric methods are based on indirect chloride measurement, their limit of detection (LOD) and limit of quantification (LOQ) values are determined by the sum of two factors. The first is the instrument variation in the measurement of a blank solution (instrumental LOD), which determines the lowest change in signal that can be attributed to the presence of an analyte. The second is the amount of unreacted chloride in the sample solution left after AgCl precipitation (Chemical LOD). Both these factors are related to the initial Ag+ concentration. The instrumental LOD of the method was derived from the reproducibility of the blank measurement, which contains no chloride; therefore, its Ag+ concentration is equal to the initial concentration added to each sample. Examining the precision of Ag measurements at different Ag concentrations (0.5, 5, 15, 30, and 50 mg L-1, with a yttrium internal standard to minimize random instrument fluctuations), the relative standard deviation (RSD) of the measurements was found to be constantly within the range of 0.54 ± 0.11%. Therefore, at this concentration range, the smallest variation in Ag+ intensity which can be reliably and reproducibly determined (the instrumental LOQ) increases with the initial Ag+ concentration. However, the initial Ag+ concentration also determines the amount of dissolved chloride in the solution. Since Ksp(AgCl) is a constant value (for a given temperature), equal to [Ag+][Cl-], the amount of dissolved chloride which remains in the solution after the Ag+ addition is equal to Ksp(AgCl)/[Ag+]. Therefore, as the initial Ag+1 concentration increases, the number of unreacted chloride ions decreases (improving the chemical LOQ). Hence, the optimized initial Ag+ concentration value should equilibrate the instrumental and chemical LOQs. In order to ascertain the optimized initial Ag+ concentration, the theoretical chemical & instrumental LOQ values, as well as their sum (Method LOQ), were plotted for different Ag+ concentrations (figure 3a, details in SI).

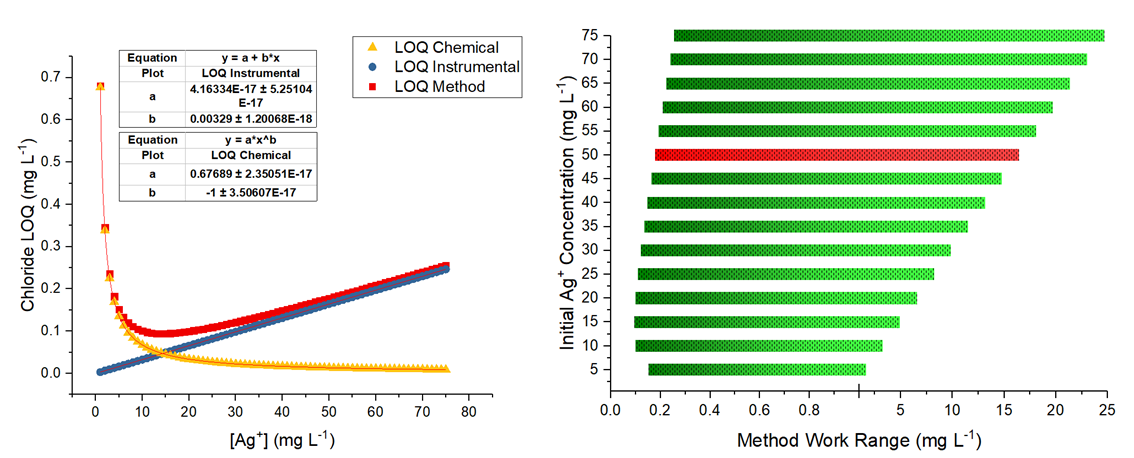


Figure 3: a. LOQs vs initial Ag+1 concentration b. Method working range vs initial Ag+1 concentration

The plot reveals the lowest LOQ for the method is obtained using an initial Ag+1 concentration of 14.32 mg L-1 and is equal to ca. 0.1 mg L-1. This theoretical value has been confirmed experimentally (see SI). However, in addition to the LOD & LOQ, the initial Ag+ concentration also determines the upper limit of the method's working range. Since the reaction stoichiometry of Ag+ and Cl- is 1:1[1], the highest concentration of chloride which can be determined using this method is 3.04 (Ag+/Cl- atomic mass ratio) times smaller than the initial Ag+ concentration (defined in mg L-1). Examining the working range of the method for different initial Ag+ concentrations (figure 3b), an Ag+ concentration of 50 mg L-1 was chosen for this work, providing a working range of 0.2-16 mg L-1 (see SI for further details). The calibration curve of the method, based on the calculated working range, is presented in figure 1.

**Selectivity and robustness**

One of the main advantages ICP-OES offers over most chloride detection methods, is the ability to simultaneously quantify additional elements in the sample. This requires the method to be selective, and neither interfere nor be interfered with by the presence of other elements. To test the selectivity of the method, a solution containing 4 mg L-1 of chloride was measured twice; once as-is and once in the presence of eight common elements (Mn, Fe, Mg, Ca, Cu, Pb, Zn, Al). The two measurements were found to be statistically identical (see SI for details), demonstrating the selectivity of the method. Furthermore, the measured concentrations of all eight elements agreed with their calculated values, demonstrating the capability of the method to quantify chloride and other elements simultaneously. It should be noted that in any argentometric method, Ag+ precipitating anions (such as I-, Br-, or CN-) can cause some interference.

The robustness of the method was tested by examining the effects of sample filtration time, pH, and temperature on the measurement. Samples (5 and 0.5 mg L-1 Cl-) were prepared and filtered at different times (relative to Ag+ addition, see SI for details). No significant changes were observed in the Ag+ signal intensity between the samples, indicating complete AgCl precipitation within five minutes. Rapid AgCl formation was supported by DLS measurements, as the hydrodynamic radius of AgCl particles in samples measured five and thirty minutes after Ag+ addition showed almost no change (see SI for details). Samples were also remeasured two weeks after their preparation and showed no significant change in Ag intensity, indicating AgCl precipitation was complete before sample filtration. To examine the effect of pH and temperature and the method, samples containing 4 and 1.5 mg L-1 of chloride, respectively, were prepared at different pH values, and different temperatures (pre-filtration). The results (Table 1) show the method to be robust, with no statistical differences detected between any of the samples

Table : Selectivity and Robustness results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Experiment | Sample | Averaged Chloride result [mg L-1] | Standard deviation [mg L-1] | T test (Critical Value 2.776) |
| Selectivity | With impurities | 4.00 | 0.05 | 1.95 |
| Without impurities | 4.06 | 0.01 |
| pH | 0.5 ml HNO3 | 4.06 | 0.04 | 2.57 |
| 2 ml HNO3 | 3.97 | 0.04 |
| temperature | 25oC | 1.57 | 0.04 | 2.21 |
| 4oC | 1.51 | 0.03 |

**Accuracy and application**

To assess accuracy, as well as the practicality of the argentometric method, samples covering a wide range of matrices were analyzed (Table 2). The samples included wine (food), seawater (environment), urine (biological), and spiked-purified water (industry). To validate the measured values, all samples were also measured by ion chromatography, a well-established method for chloride quantification[42]. Each sample was measured three times and the results of the two methods (presented in Table 2) were analyzed using a t-test (confidence level set at 95% critical t value 2.776). The results showed no statistical difference between the ICP-OES and IC results for all of the examined samples. The method accuracy was calculated by using the reference sample measurement result and the value obtained was 0.26%. These results confirm both the accuracy and the applicability of the new ICP-OES argentometric method to a variety of fields.

Table : samples measurements results using the argentometric method and Ion Chromatography

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Experiment | Sample | Averaged Chloride result [mg L-1] | Standard deviation [mg L-1] | t-test |
| Reference (7.69 mg L-1) | argentometric method | 7.71 | 0.08 | 0.89 |
| Ion Chromatography | 7.59 | 0.22 |
| Sea Water | argentometric method | 23311.99 | 233.12 | 1.36 |
| Ion Chromatography | 22763.63 | 657.87 |
| Wine | argentometric method | 51.75 | 0.52 | 1.08 |
| Ion Chromatography | 52.75 | 1.52 |
| Urine | argentometric method | 6636.74 | 66.37 | 1.32 |
| Ion Chromatography | 6795.04 | 196.38 |

**Conclusions**

In this paper, An indirect ICP-OES method for Chloride determination, using argentometric principles, was presented and the method's analytical principles were evaluated thoroughly. The dependency of the method working range on the initial Ag+ concentration was determined and the optimal LOQ was both calculated and experimentally proved. The method was shown to be robust to changes in nitric acid concentration in the sample and to the temperature during the sample preparation process. Selectivity was determined by the analysis of both chloride and 8 additional elements in the same reference sample. The results show that one of the main advantages of using ICP-OES, simultaneous quantification of multiple elements, was successfully preserved. A reference sample was used to determine the accuracy error of the method and the value found was 0.26%. Finally, the method was used to determine chloride content in samples covering a wide range of matrices from different industries. The measured results were analyzed and compared, using a t-test, to results obtained using Ion chromatography showing a good statistical fit between the two analytical methods. The sum of the results demonstrates the method's use for the determination of chloride and shows the potential of using indirect methods for ICP-OES.

[1] W.M. Haynes, D.R. Lide, T.J. Bruno, eds., CRC Handbook of Chemistry and Physics, CRC Press, 2016. doi:10.1201/9781315380476.

[2] A. Marvelli, B. Campi, G. Mergni, M.E. Di Cicco, P. Turini, P. Scardina, R. Zucchi, M. Pifferi, G. Taccetti, A. Paolicchi, G. la Marca, A. Saba, Sweat chloride assay by inductively coupled plasma mass spectrometry: a confirmation test for cystic fibrosis diagnosis, Anal. Bioanal. Chem. 412 (2020) 6909–6916. doi:10.1007/s00216-020-02821-3.

[3] N. Deane, M. Ziff, H.W. Smith, THE DISTRIBUTION OF TOTAL BODY CHLORIDE IN MAN 1, J. Clin. Invest. 31 (1952) 200–203. doi:10.1172/JCI102592.

[4] A.F. Hurst, THE CLINICAL IMPORTANCE OF ACHLORHYDRIA, BMJ. 2 (1934) 665–669. doi:10.1136/bmj.2.3849.665.

[5] A.S. Verkman, Development and biological applications of chloride-sensitive fluorescent indicators, Am. J. Physiol. - Cell Physiol. 259 (1990). doi:10.1152/ajpcell.1990.259.3.c375.

[6] J.R.F. Elphick, K.D. Bergh, H.C. Bailey, Chronic toxicity of chloride to freshwater species: Effects of hardness and implications for water quality guidelines, Environ. Toxicol. Chem. 30 (2011) 239–246. doi:10.1002/etc.365.

[7] S. Szklarek, A. Górecka, A. Wojtal-Frankiewicz, The effects of road salt on freshwater ecosystems and solutions for mitigating chloride pollution - A review, Sci. Total Environ. 805 (2022) 150289. doi:10.1016/j.scitotenv.2021.150289.

[8] C.L. Page, Initiation of chloride-induced corrosion of steel in concrete: role of the interfacial zone, Mater. Corros. 60 (2009) 586–592. doi:10.1002/maco.200905278.

[9] Y. Tsutsumi, A. Nishikata, T. Tsuru, Pitting corrosion mechanism of Type 304 stainless steel under a droplet of chloride solutions, Corros. Sci. 49 (2007) 1394–1407. doi:10.1016/j.corsci.2006.08.016.

[10] M. De Oliveira Souza, M.A. Ribeiro, M.T.W.D. Carneiro, G.P.B. Athayde, E.V.R. De Castro, F.L.F. Da Silva, W.O. Matos, R. De Queiroz Ferreira, Evaluation and determination of chloride in crude oil based on the counterions Na, Ca, Mg, Sr and Fe, quantified via ICP-OES in the crude oil aqueous extract, Fuel. 154 (2015) 181–187. doi:10.1016/j.fuel.2015.03.079.

[11] C.M. Geilfus, Review on the significance of chlorine for crop yield and quality, Plant Sci. 270 (2018) 114–122. doi:10.1016/j.plantsci.2018.02.014.

[12] R.E. Engel, P.L. Bruckner, J. Eckhoff, Critical Tissue Concentration and Chloride Requirements for Wheat, Soil Sci. Soc. Am. J. 62 (1998) 401. doi:10.2136/sssaj1998.03615995006200020016x.

[13] F. Pargar, D.A. Koleva, K. Van Breugel, Determination of chloride content in cementitious materials: From fundamental aspects to application of Ag/AgCl chloride sensors, Sensors (Switzerland). 17 (2017) 1–22. doi:10.3390/s17112482.

[14] I.K. Edwards, Y.P. Kalra, F.G. Radford, Chloride determination and levels in the soil-plant environment, Environ. Pollut. Ser. B, Chem. Phys. 2 (1981) 109–117. doi:10.1016/0143-148X(81)90046-X.

[15] F.E. Clarke, Determination of Chloride in Water Improved Colorimetric and Titrimetric Methods, Anal. Chem. 22 (1950) 553–555. doi:10.1021/ac60040a011.

[16] J. Gonzalo-Ruiz, R. Mas, C. de Haro, E. Cabruja, R. Camero, M.A. Alonso-Lomillo, F.J. Muñoz, Early determination of cystic fibrosis by electrochemical chloride quantification in sweat, Biosens. Bioelectron. 24 (2009) 1788–1791. doi:10.1016/j.bios.2008.07.051.

[17] C.A. Teixeira dos Santos, R.N.M.J. Páscoa, P.A.L.S. Porto, A.L. Cerdeira, J.A. Lopes, Application of Fourier-transform infrared spectroscopy for the determination of chloride and sulfate in wines, LWT - Food Sci. Technol. 67 (2016) 181–186. doi:10.1016/j.lwt.2015.11.050.

[18] G. Dimeski, T. Badrick, A.S. John, Ion Selective Electrodes (ISEs) and interferences-A review, Clin. Chim. Acta. 411 (2010) 309–317. doi:10.1016/j.cca.2009.12.005.

[19] H.T. Sheen, H.L. Kahler, Effect of ions on Mohr method for chloride determination, Ind. Eng. Chem. Anal. Ed. 10 (1938) 628–629. doi:10.1021/ac50127a004.

[20] J.R. Caldwell, H. V. Moyer, Determination of Chloride: A Modification of the Volhard Method, Ind. Eng. Chem. - Anal. Ed. 7 (1935) 38–39. doi:10.1021/ac50093a018.

[21] V.A. Burakhta, S.S. Sataeva, Electrochemically modified semiconductor gallium arsenide electrodes for the argentometric titration of chlorides with silver nitrate in natural samples, J. Anal. Chem. 69 (2014) 1079–1082. doi:10.1134/S1061934814110033.

[22] H.A. Laitinen, W.P. Jennings, T.D. Parks, Amperometric Titration of Chloride, Bromide, and Iodide Using Rotating Platinum Electrode, Ind. Eng. Chem. Anal. Ed. 18 (1946) 355–358. doi:10.1021/i560154a005.

[23] O.S. Wolfbeis, P. Hochmuth, A new method for the endpoint determination in argentometry using halide-sensitive fluorescent indicators and fiber optical light guides, Mikrochim. Acta. 84 (1984) 129–138. doi:10.1007/BF01204164.

[24] P. Martínez-Jimenez, M. Gallego, M. Valcárcel, Indirect atomic absorption spectrometric determination of mixtures of chloride and iodide by precipitation in an unsegmented flow system, Anal. Chim. Acta. 193 (1987) 127–135. doi:10.1016/S0003-2670(00)86145-0.

[25] L.S.G. Teixeira, T.J. Chaves, P.R.B. Guimarães, L.A.M. Pontes, J.S.R. Teixeira, Indirect determination of chloride and sulfate ions in ethanol fuel by X-ray fluorescence after a precipitation procedure, Anal. Chim. Acta. 640 (2009) 29–32. doi:10.1016/j.aca.2009.03.032.

[26] M. Rahbar, B. Paull, M. Macka, Instrument-free argentometric determination of chloride via trapezoidal distance-based microfluidic paper devices, Anal. Chim. Acta. 1063 (2019) 1–8. doi:10.1016/j.aca.2019.02.048.

[27] X. Hou, R.S. Amais, B.T. Jones, G.L. Donati, Inductively Coupled Plasma Optical Emission Spectrometry, in: Encycl. Anal. Chem., Wiley, 2021: pp. 1–29. doi:10.1002/9780470027318.a5110.pub4.

[28] L.J. Radziemski, V. Kaufman, Wavelengths, Energy Levels, and Analysis of Neutral Atomic Chlorine (Cl i), J. Opt. Soc. Am. 59 (1969) 424. doi:10.1364/josa.59.000424.

[29] J. Houseaux, J.M. Mermet, Use of a charge-coupled device detector in the 120-190 nm range in axially-viewed inductively coupled plasma atomic emission spectrometry, J. Anal. At. Spectrom. 15 (2000) 979–982. doi:10.1039/b003626i.

[30] P.A. Mello, J.S. Barin, F.A. Duarte, C.A. Bizzi, L.O. Diehl, E.I. Muller, E.M.M. Flores, Analytical methods for the determination of halogens in bioanalytical sciences: A review, Anal. Bioanal. Chem. 405 (2013) 7615–7642. doi:10.1007/s00216-013-7077-9.

[31] S.-K. Chan, A. Montaser, A helium inductively coupled plasma for atomic emission spectrometry, Spectrochim. Acta Part B At. Spectrosc. 40 (1985) 1467–1472. doi:10.1016/0584-8547(85)80170-1.

[32] G.L. Donati, R.S. Amais, C.B. Williams, Recent advances in inductively coupled plasma optical emission spectrometry, J. Anal. At. Spectrom. 32 (2017) 1283–1296. doi:10.1039/C7JA00103G.

[33] M.F. Mesko, V.C. Costa, R.S. Picoloto, C.A. Bizzi, P.A. Mello, Halogen determination in food and biological materials using plasma-based techniques: Challenges and trends of sample preparation, J. Anal. At. Spectrom. 31 (2016) 1243–1261. doi:10.1039/c5ja00488h.

[34] S.S. Potgieter, L. Marjanovic, A further method for chloride analysis of cement and cementitious materials - ICP-OES, Cem. Concr. Res. 37 (2007) 1172–1175. doi:10.1016/j.cemconres.2007.05.006.

[35] K. Krengcl-Rothensee, U. Richter, P. Heitland, Low-level determination of non-metals (Cl, Br, I, S, P) in waste oils by inductively coupled plasma optical emission spectrometry using prominent spectral lines in the 130-190 nm range, J. Anal. At. Spectrom. 14 (1999) 699–702. doi:10.1039/a807024e.

[36] M. Edlund, H. Visser, P. Heitland, Analysis of biodiesel by argon-oxygen mixed-gas inductively coupled plasma optical emission spectrometry, J. Anal. At. Spectrom. 17 (2002) 232–235. doi:10.1039/b111476j.

[37] J.S.F. Pereira, P.A. Mello, D.P. Moraes, F.A. Duarte, V.L. Dressler, G. Knapp, É.M.M. Flores, Chlorine and sulfur determination in extra-heavy crude oil by inductively coupled plasma optical emission spectrometry after microwave-induced combustion, Spectrochim. Acta - Part B At. Spectrosc. 64 (2009) 554–558. doi:10.1016/j.sab.2009.01.011.

[38] M.S. Wheal, L.T. Palmer, Chloride analysis of botanical samples by ICP-OES, J. Anal. At. Spectrom. 25 (2010) 1946–1952. doi:10.1039/c0ja00059k.

[39] C. Sánchez, S.E. Maestre, M.S. Prats, J.L. Todolí, Ion balance in waters through inductively coupled plasma optical emission spectrometry, Int. J. Environ. Anal. Chem. 94 (2014) 427–440. doi:10.1080/03067319.2013.853762.

[40] E.A. Vtorushina, A.I. Saprykin, G. Knapp, Optimization of the conditions of oxidation vapor generation for determining chlorine, bromine, and iodine in aqueous solutions by inductively coupled plasma atomic-emission spectrometry, J. Anal. Chem. 63 (2008) 643–648. doi:10.1134/S1061934808070071.

[41] J. Naozuka, M.A.M.S. Da Veiga, P.V. Oliveira, E. De Oliveira, Determination of chlorine, bromine and iodine in milk samples by ICP-OES, J. Anal. At. Spectrom. 18 (2003) 917–921. doi:10.1039/b303897c.

[42] EPA, METHOD 9056A, Revision 1, Final Updat. II to Third Ed. Test Methods Eval. Solid Waste, Phys. Methods, EPA Publ. SW‐846. (2007).

Options to submit to:

Journal of Analytical Atomic Spectrometry (IF 4)

Talanta (IF 6)

Analyst (4.6)

Analytical and Bioanalytical Chemistry (IF 4.1)

Spectrochimica Acta Part B: Atomic Spectroscopy (IF 3.7)

Analytical methods (IF 2.9)

Analytica Chimica Acta (IF 6.5)

Microchemical Journal (IF 4.6)

Applied Spectroscopy (IF 2.4)