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Low-Cost Method for Quantifying Sodium in Coconut Water and Seawater for the Undergraduate Analytical Chemistry Laboratory: Flame Test, a Mobile Phone Camera, and Image Processing

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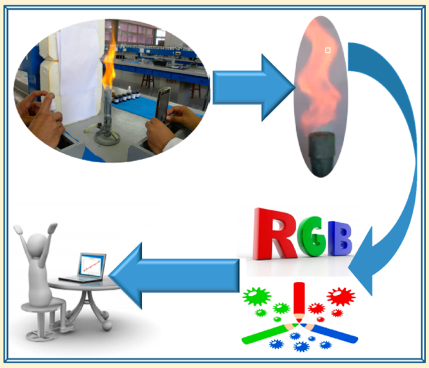
S Supporting Information

ABSTRACT: The flame test is a classical analytical method that is often used to teach students how to identify specific metals. However, some universities in developing countries have difficulties acquiring the sophisticated instrumentation needed to demonstrate how to identify and quantify metals. In this context, a method was developed based on the flame test to quantify sodium in coconut water and seawater using recorded videos of a flame during the experiment and subsequent image treatments with an R statistics platform. This experiment provided undergraduate students an opportunity to study important topics such as atomic theory, emission spectroscopy, quantitative analysis, and image processing. Finally, students measured the sodium content in seawater collected from a region of the Rio Grande do Norte coast, an important region for manufacturing salt. They obtained sodium concentrations that ranged from 11.2 to 12.2 g dm^{-3} and calibration curves that presented good linearity (R^2 > 0.91). The sodium content of coconut water determined was 48 ± 4 mg dm^{-3}. The results demonstrate an interesting and simple method that can easily be applied in experimental Analytical Chemistry courses, and this experiment would also be appropriate for pre-college students.



KEYWORDS: *Second-Year Undergraduate, Analytical Chemistry, Laboratory Instruction, Hands-On Learning/Manipulatives, Atomic Spectroscopy, Water, Quantitative Analysis, Chemometrics*

The flame test is a very interesting experiment that is often used to introduce qualitative analysis[1] and atomic emission spectroscopy[2] for educational purposes. Many different methods have been described in this Journal that utilize Bunsen burners to identify metals, in addition to the use of alcohol burners,[2−4] flask sprayers,[5] or both.[6] However, quantitative methods based on these principles have been developed using expensive commercial analysis systems, thereby limiting their use, especially in universities in developing countries where instruments are not available.

Image processing has been developed as an analytical tool in recent years because images are versatile and easy to capture, and the results can be converted to numeric values. Image processing involves[7,8] certain steps, including background removal, noise reduction, the location of dead pixels, the identification and handling of spiked points, outlier detection, spectral preprocessing, image compression, and image analysis, to extract the relevant information, and it returns numeric values and/or graphs that are related to the image characteristics.

Marbach and coauthors[9] have reported an image processing approach for the detection of fire from video images, therefore allowing its use in fire alarms. The flame color was characterized using a digital camera and subsequent image processing,[10] and specific bands associated with a methane flame could be attributed correctly to methane combustion. More recently, a group from Federal University of Paraíba/Brazil developed a digital image-based flame emission spectrometry method.[11] The digital images were based on the RGB (red-green-blue) color system and presented the color of the emergent radiation. The images were retrieved in the three individual R, G, and B components. This system was used to indirectly determine the concentrations of different drugs.[12] They explored an interesting approach for quantifying sodium diclofenac, sodium dipyrone, and calcium gluconate based on sodium and calcium flames.

In the experiment described herein, geology students used chemistry to analyze sodium in seawater while simultaneously acquiring skills involving the identification of important salt sources. The determination in the coconut water can be used in courses related with processing food. The students used a mobile phone as a detector, which brought a common element of the younger lifestyle into the classroom. The sodium flame is spectacular and brilliant, and students can easily participate in this demonstration. Moreover, sodium is present in many matrixes, and it can contribute to a contextualized chemical

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education[13] because the experiment can motivate undergraduate and precollege students to learn chemistry and to understand its societal significance, in addition to providing hands-on experience with the chemical compositions of samples from nature and life sciences.

The objective of this paper was to introduce a simple approach for measuring the sodium content of coconut water and seawater, and the reason for its use in an Analytical Chemistry laboratory is discussed. An image processing algorithm was developed to assist in the automation of the data analysis. As evidence of its reliability and validity, the proposed method was applied for geology students in an Applied Analytical Chemistry course.

■ EXPERIMENTAL DETAILS

Materials

Sodium chloride (>99.5%) was obtained from Dinâmica Química Contemporânea (Diadema, Brazil). The perfume bottle spray atomizer was purchased in a local retail store (<$1 U.S. each). All the standard solutions and samples were prepared with distilled water.

Procedure

This procedure required 4 h of lab time and the students worked in groups of three to four. For the analytical curve, a sodium chloride stock solution was first prepared in distilled water at 640 mg dm^{-3} of sodium. The students prepared standard solutions of 20, 40, 80, 120, and 160 mg dm^{-3} of sodium from stock solution. The solutions were placed in the spray bottles. Then two students performed the test; one student sprayed the solution into the flame while the other student acquired the video. A standardized experimental setup (Supporting Information, Figure 1) was used to control the distances and the image recording. This procedure was repeated in duplicate for each standard solution. Finally, students examined samples consisting of commercially available pure coconut water and seawater. These samples were analyzed in triplicate. The seawater was collected from a region of the Rio Grande do Norte coast (5° 52′ 52″ S, 35° 10′ 16″ W), and it was diluted by a factor of 100 prior to analysis.

To validate this approach and to evaluate the RGB intensity results, the instructors also analyzed the samples using a flame photometer Analyzer 910 M (Sao Paulo, Brazil).

Data treatment was implemented in the R statistics platform[14] (R Foundation for Statistical Computing), and the statistical procedure is available in the Supporting Information.

■ HAZARDS

The flame test has the potential to be a dangerous laboratory experiment; therefore, the experiment should be performed in a ventilated laboratory or under a vent hood. Maintain a safe distance from the Bunsen burner, and be careful at all times. The audience should maintain a minimum distance of 1.5 m from the flame, and the students who conduct the experiment should be no closer than 0.4 m from the flame. Care should be taken to protect the students' eyes.

■ RESULTS AND DISCUSSION

A calibration curve was produced by one of the groups from duplicate measurements of five sodium standard solutions presented in Figure 1. The calibration curve was obtained by plotting the RGB-based value (||v||)[11] versus the concentrations of the five sodium standard solutions. ||v|| is a vector norm based on RGB and a detailed description about ||v|| is in the Supporting Information. The equation for the calibration curve that was obtained by the students was ||v|| = (0.267 ± 0.005) [Na] + 66.6 ± 1.4, as shown in Figure 1. As seen in Figure 1, a linear behavior between the analytical response and the analyte concentrations was observed. The LOD and LOQ corresponded to sodium levels of 6 and 19 mg dm^{-3}, respectively. These values were calculated according Silva Lyra and coauthors.[11] The Supporting Information contains a section about data treatment and residuals analysis.

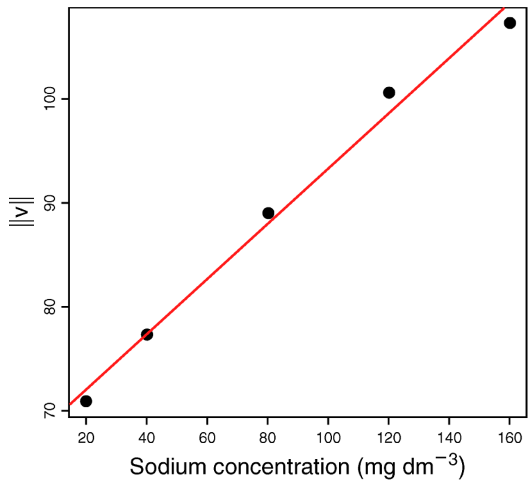

Figure 1. Calibration curve for sodium analysis showing the vector norm ||v|| vs sodium concentration. Adjusted R^2 = 0.98.

The sodium concentrations measured in the coconut water and seawater samples are shown in Table 1. Each sample was analyzed in triplicate, and the results from the flame test were compared with the flame photometer results. The F-test (at a 95% confidence interval) indicated that there were no significance differences between the two methods.

Table 1. Concentration of Sodium in the Samples

Sample	Sodium Concentration/(g dm^{-3}): Flame Test[a]	Sodium Concentration/(g dm^{-3}): Flame Photometer[b]
Seawater	11.4 ± 0.5	11.2 ± 0.4
Coconut water	48 ± 4	41 ± 4

[a]Data determined by the students. [b]Data determined by the instructors.

As evidence of its reliability and validity, this method was applied for geology students in an Applied Analytical Chemistry course to quantify sodium in seawater. The same sample presented in Table 1 was analyzed by five groups of students. The measured sodium concentration ranged from 11.2 to 12.2 g dm^{-3}. Typically, the concentration of sodium in seawater is 10.5 g dm^{-3}, but the salinity of surface seawater is high (up to 37.0 g L^{-1}) in the latitude investigated.[15] All groups found good linearity in their models (i.e., R^2 values ranging from 0.91 to 0.98). Additionally, RSD values ranging from 3.2 to 15.5% were obtained. LOD values in the range of 3−8 mg dm^{-3} and LOQ values from 10−25 mg dm^{-3} were reported. The sodium content of coconut water determined by the flame test (48 ± 4 mg dm^{-3}) was higher than that determined by flame photometry (41 ± 4 mg dm^{-3}). This flame test approach will

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be introduced to a food engineering course for the analysis of coconut water in the next semester.

In this assignment, students learn analytical chemistry and associate it with real problems using a simple and applicable method. Moreover, they develop analytical skills, critical judgment, and hands-on experience with chemical phenomena. As homework, students can discuss whether it is possible to use the method for other elements and the effects of possible interferences.

■ CONCLUSIONS

The method reported here provides an excellent illustration of the relationship between atomic emission and RGB intensities from digital images. By learning about these topics, students gain insight into the current research in analytical chemistry and image processing.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Detailed experimental procedures, the flame image processing script, and data analysis. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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