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Review

Moving your laboratories to the field – Advantages and limitations of the use of field portable instruments in environmental sample analysis

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ABSTRACT

The recent rapid progress in technology of field portable instruments has increased their applications in environmental sample analysis. These instruments offer a possibility of cost-effective, non-destructive, real-time, direct, on-site measurements of a wide range of both inorganic and organic analytes in gaseous, liquid and solid samples. Some of them do not require the use of reagents and do not produce any analytical waste. All these features contribute to the greenness of field portable techniques. Several stationary analytical instruments have their portable versions. The most popular ones include: gas chromatographs with different detectors (mass spectrometer (MS), flame ionization detector, photoionization detector), ultraviolet–visible and near-infrared spectrophotometers, X-ray fluorescence spectrometers, ion mobility spectrometers, electronic noses and electronic tongues. The use of portable instruments in environmental sample analysis gives a possibility of on-site screening and a subsequent selection of samples for routine laboratory analyses. They are also very useful in situations that require an emergency response and for process monitoring applications. However, quantification of results is still problematic in many cases. The other disadvantages include: higher detection limits and lower sensitivity than these obtained in laboratory conditions, a strong influence of environmental factors on the instrument performance and a high possibility of sample contamination in the field. This paper reviews recent applications of field portable instruments in environmental sample analysis and discusses their analytical capabilities.

1. Introduction

Environmental quality assessment and pollution control would not be possible without analytical chemistry that provides methods and techniques for determinations of inorganic and organic pollutants. Since the 1960s, with the first enactment of the complex environmental legislations, there has been an increased demand for quantitative analyses of environmental samples (Anastas, 1999). The data obtained from these analyses can be used, for example, in environmental quality monitoring, in evaluation of spatial and temporal distribution of contaminants, for studying the extent of contamination and in assessment of the remediation progress. Of special importance is acquiring fast and reliable data about pollutant levels in emergency situations (e.g. accidents, disasters) when an immediate action is required (Crume, 2000). In each of these actions, reliable, accurate and precise results are needed, but in some cases, a short time devoted to achieve the data is even more critical. Analysis performed on site allows us to dramatically shorten the period between sampling and acquisition of final results. Moreover, thanks to advances in manufacturing of portable instruments and development of procedures that provide effective data, it is possible to perform a real-time analysis without compromising the quality parameters. Thus, a trend toward the use of portable instruments in environmental site assessment has emerged (Kinney et al., 2002).

Environmental sample analysis is one of the major areas of application of portable instruments. They are especially useful for measuring parameters which are not stable during time, such as

Abbreviations: ANN, artificial neural networks; BTEX, benzene, toluene, ethylbenzene, and xylenes; EC, electric conductivity; EPA, Environmental Protection Agency; GC, gas chromatography; GC–MS, gas chromatography–mass spectrometry; GC–PID, gas chromatography with photoionization detector; GOLDD, Geometrically Optimized Large Area Drift Detector; GPS, Global Positioning System; IMS, ion mobility spectrometer; LED, light emitting diodes; MOS, metal oxides semiconducting sensors; MS, mass spectrometer; NIOSH, National Institute for Occupational Safety and Health; NIR, near infrared; PCA, principal component analysis; PIN, Positive Intrinsic Negative; PLS, partial least squares; RSD, relative standard deviation; UV–vis, ultraviolet–visible; XRF, X-ray fluorescence spectroscopy

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pH, redox potential, concentrations of ammonium, nitrite, nitrate, ferrous and ferric irons and others. In such cases, the accuracy is improved by a process of elimination of sample preservation and transport (Garrigues and de la Guardia, 2013). The direct methods are perceived as the best alternative in green analytical chemistry (Gałuszka et al., 2013; Garrigues and de la Guardia, 2013). Many goals in greening of analytical methods can be achieved with their application, for example: reduction of energy consumption, increased safety for an operator, elimination or reduction of the reagent use and waste generation. Miniaturization of the portable instruments also contributes to sustainable development through a lower use of materials from non-renewable resources during their production. This can be well illustrated by comparison of weight of field portable instruments and their full-size equivalents. For example, a typical weight of stationary UV–vis spectrometer is usually 10–20 kg, whereas portable UV–vis instruments are typically from two to ten times lighter. All these features combined with economic reasons (less expensive instrumentation and lower operation costs) cause an increased recent interest in developing new and improving the existing field methods (Garrigues and de la Guardia, 2013). Lower costs of on-site analyses may also result from revision of sampling strategies for obtaining the more efficient data of interest (Norgaard, 2005).

The use of portable instruments has gained recognition in environmental monitoring and in studies of polluted areas, such as hazardous waste sites or industrial brownfields. The US Environmental Protection Agency (EPA) Triad Approach can be given as an example (Kinney et al., 2002). One of the three components of this approach is a real-time measurement system, in which portable instruments play a key role. There are also official methods based on portable instruments such as: EPA Method 8540 (determination of pentachlorophenol in soil by UV-induced colorimetry) (EPA Method 8540, 2007), EPA Method 6200 (determination of 26 elements in soil and sediments by field portable X-ray fluorescence (XRF) spectrometers) (EPA Method 6200, 2007), National Institute for Occupational Safety and Health (NIOSH) Method 7702 (determination of Pb in air filters by field portable XRF spectrometer) (NIOSH Method 7702, 1998).

In this review we focus on benefits and drawbacks of the use of field instruments that are routinely used in environmental sample analysis. Selected commercially available field portable instruments are described in more detail. The aim of this paper is to show the potential of field analysis in the context of green analytical chemistry.

2. General characterization and application of field portable instruments

Portable instruments should possess the following features: (i) should be low weight and have small dimensions; (ii) be capable of rapid analysis; (iii) should operate on a simple infrastructure; (iv) should be equipped with a portable energy source; (v) should be designed to be used in harsh environment (e.g. high humidity, extremely low and high temperatures, high airborne dust levels), and (vi) should generate data similar to those acquired in the laboratory. Although the term "transportable instrument" is sometimes used as a synonym of "portable instrument", a device which is adapted for performing analysis in the field ought to weigh no more than 20 kg and be easily handled on site, but, in fact, be much lighter. Some authors name these light instruments "truly portable" (Berkley, 2000; Lewis et al., 2013). Depending on their weight, three categories of field analytical instruments can be distinguished (Trojanowicz and Alexander, 1997). The other features, such as application, installation site and instrument type can also be useful for portable instrument characteristics (Fig. 1).

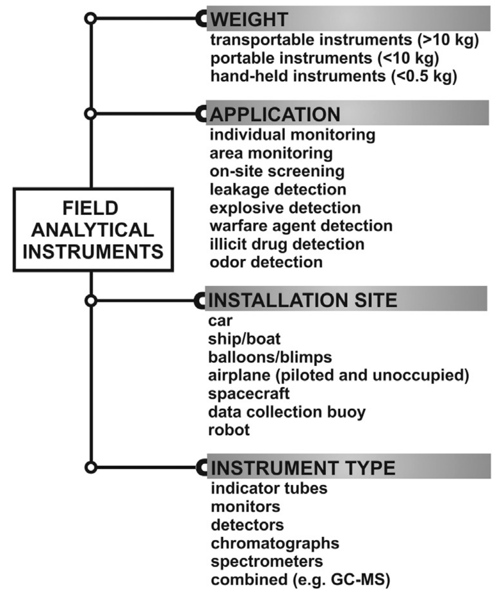

Fig. 1. Important features of field portable instruments.

According to the different classification, the field instruments can be divided into portable and field-deployable. The first category includes devices that are battery powered and do not require an additional gas supply whereas the field deployable instruments do not have an internal carrier of gas supply and use a line power (Berkley, 2000).

The most important feature of field portable instruments is their capability of on-site analysis. The term "on-site analysis" and its synonym of Latin origin "in situ analysis" is most often defined as an analysis performed in the study area, without the necessity of sample transport and without or with a very simple sample treatment. However, this term is sometimes understood as autonomous analysis, which means that the instrument can perform analyses without the presence of a user (Lewis et al., 2013). In this case, the instrument does not have to be portable, but has to show other features, such as: efficient power source, no requirements for frequent maintenance and other similar characteristics.

Miniaturization is another feature of field portable instruments. Smaller dimensions allow easy transport and use of portable devices in the study area. However, not all miniaturized instruments can be used in the field. These instruments are designed to analyze a very low sample volume. In case of heterogeneous environmental samples, this may be a source of a high analytical error. Another important issue that should be considered is a proper protection from instability of environmental conditions that may influence the instrument performance in the field. A field portable equipment should be made of a robust material, and be able to work in the sunshine, rain, high humidity, temperature fluctuations. Some of the instruments, which are used for environmental sample analyses, must have a fit for the purpose design, for example they must be fully waterproof if they are to be used underwater (Short et al., 2001).

An important feature of the commercially available portable instruments is their capability of data storage and real-time processing with the use of different software applications. These instruments have either a built-in memory or enable users to transfer the results of field measurements to a PC via a serial interface, USB or Bluetooth™. For some instruments, such as Thermo Scientific NITON XRF analyzers, there is dedicated software which can be used for viewing, analyzing and reporting data, spectral graphing, adding customized empirical calibrations, creating