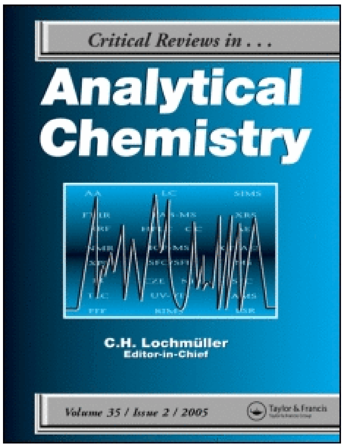

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The State of the Art in the Field of Non-Stationary Instruments for the Determination and Monitoring of Atmospheric Pollutants

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The growing interest in obtaining rapid and more reliable data on air quality indicates a need for non-stationary (transportable and portable) instrumentation. This trend results in the designing and manufacturing of new instruments that are more sensitive, selective, precise and accurate. This paper presents some examples of new instrumentation based on different principles. In the first part, a general classification of devices used for air monitoring and analysis is presented. Finally, the mobile monitoring system (MMS) proposed by the authors for air monitoring along communication lanes is briefly described.

Keywords Air quality, environmental monitoring, non-stationary (portable, transportable) instrument, automatic measurements, real time monitoring, continuous analysis

INTRODUCTION

Air quality is a basic factor of good life. Scientific research conducted starting 200 years ago has shown that polluted air negatively influences health and in some cases may even lead to death. Pollutant levels which negatively affect life on earth are nowadays well defined.

The most important tool in environmental protection is monitoring. In the broadest context, environmental monitoring is defined as a system of measurements, evaluations and forecasts of environmental states, and the collecting, processing and spreading of information on the environment.

Monitoring of air pollution, in comparison to monitoring of other elements of the environment, poses the biggest problems. The difficulties arise from the large dynamics of the atmosphere; the air is main route of spreading and transporting pollution between remaining environmental compartments. Polluted air can affect large populations without the chance for isolation, which is possible in cases, of polluted waters and soil.

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Proper monitoring is fundamental in indicating areas in which the quality of air does not fulfill proper standards. The main objectives of air monitoring are:

- assessment of emission sources,
- measuring of pollutant mixing ratios and their fate in the environment,
- ecotoxicological studies.

The detailed goals of all activities in environmental studies are presented in Figure. 1.

In Poland, monitoring of air quality has been performed systematically since 1992. At present, monitoring and evaluation of air quality is performed according to an act of Parliament—Environment Protection Law, in accordance with EU law—Directive no. 96/62/EC for the evaluation and management of air quality, and executive directives 1999/30/EC, 2000/69/EC , 2002/3/EC and 2004/107/EC. The allowable and concern levels and tolerance margins of some substances are given in the decrees of the Environmental Minister, published in the Official Gazette (no. 87/2002 pos. 796, no. 87/2002 pos. 798 and no. 1/2003 pos. 12).

This review presents some examples of new non-stationary instrumentation developed for air monitoring in environmental

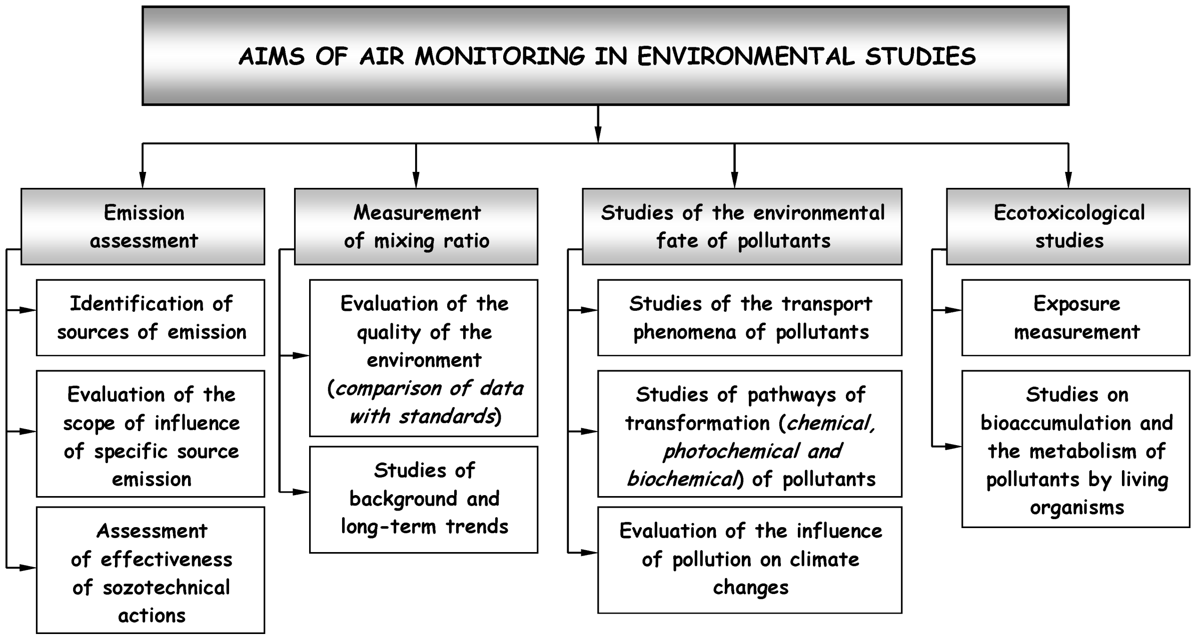

FIG. 1. The detailed goals of air monitoring in environmental studies.

studies. In our earlier papers, analytical techniques and selected examples of equipment used for collecting air samples, and analyses performed in the laboratory, were described (1, 2).

GENERAL REQUIREMENTS OF THE INSTRUMENTS USED IN ENVIRONMENTAL ANALYTICS AND MONITORING

Taking into account the analytical characteristics of instruments used in environmental analytics and monitoring (both methodological requirements and technical challenges), two types of measurement devices are usually distinguished:

- analyzers and
- monitors.

A monitor is an instrument used for the continuous measurement of a condition which must be kept within prescribed limits. Monitors are not the same as analyzers. An analyzer is capable of determining the quality, quantity and/or type of specific substance or substances in a mixture. Monitors are frequently equipped with alarms which warn the users of any immediately hazardous conditions. Analyzers can be automated to varying extents. Depending on the degree of automation, analyzers can be automatic or semi-automatic.

The basic requirement of both types of instruments is high measurement sensitivity, i.e., the low limit of detection (LOD) and the low limit of quantitation (LOQ). It gives a chance to detect the pollutants at required levels. Monitors however, due to the fact that they should acquire analytical data in real time

TABLE 1
Allowable values of typical air pollutants in Poland

No.	Name of substance	Number of substance according to CAS[1]	Reference values D_{1h} [μg/m^3]	Reference values D_a [μg/m^3]	Alarm values (1 h) [μg/m^3]
1	Sulphur dioxide	7446-09-5	350	20	500
2	Nitrogen dioxide	10102-44-0	200	40*	400
3	Ozone	10028-15-6	120**		240
4	Benzene	71-43- 2	30	5***	
5	Particulate matter (PM_{10})	—	280	40	

[1]Chemical Abstract Service Registry Number.
*in 2007 $D_a = 46$ μg/m^3.
**8-h sampling period value.
***in 2007 $D_a = 8$ μg/m^3.

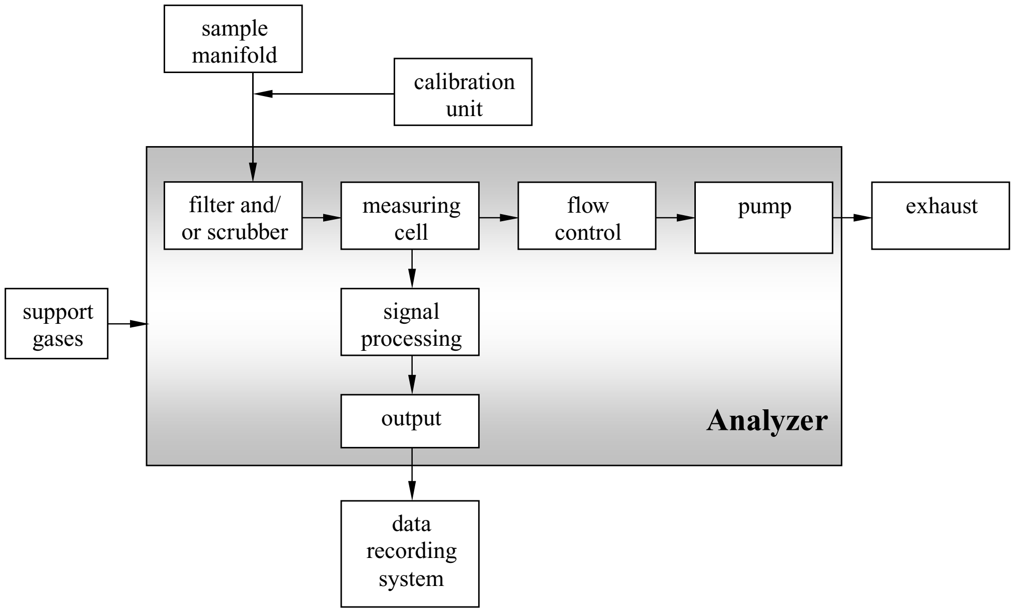

FIG. 2. Typical elements of a monitoring system.

or only with a small time delay, have to possess the additional capabilities of:

- providing of high data resolution (characterized by low response time),
- providing of automatic calibration and zeroing,
- long functioning without service.

The last demand means that they should be equipped with an independent power supply and be able to automatically regenerate or exchange worn out filters and, depending on the type of detector used (sensor), fulfill special demands, e.g., for electrochemical sensors, exchange or supplement the working solution and reagents, and in devices with FID (Flame Ionization Detector) or FPD (Flame Photometric Detector) detection protect against flame extinguishing .

For mobile systems the registered values of pollutants have to be correlated with information about the geographical site and actual meteorological conditions (temperature and humidity).

Depending on the number of analytes that an instrument can determine in a single sample, they can be single-parameter (single-gas) or multi-parameter (multi-gas) instruments.

Based on sampling frequency, analyzers can be discrete (for single measurement), periodic (for measurements at preset intervals) or continuous (for permanent monitoring).

The basic elements of a pollutant measuring system are shown in Figure. 2. The sample manifold (made of an inert material) transfers a moving stream of air into the immediate vicinity of the instrument in order to minimize the time that the air sample resides in the measurement cell. Monitors may include filters to remove particulates that might clog orifices and dampen the light streams in optical sensors. Some monitors may use a scrubber to remove interfering components.

Measurement cells, containing sensor(s), can be made based on different principles depending on the pollutant(s) of interest. Basically, the pollutant is introduced into a cell where it undergoes a chemical or physical reaction, after which output is converted to an electrical signal. The most typical devices are based on electrochemical, optical and semi-conductor principles.

CLASSIFICATION OF THE DEVICES USED FOR THE DETECTION AND MONITORING OF AIR POLLUTANTS

The analytical instruments currently used for the detection and determination of atmospheric pollutants can be classified according to various criteria (Figure. 3), some of which are discussed below.

Basically, all instruments can be classified as chemical or physicochemical. Chemical methods are usually called wet chemical methods because they involve interaction between a liquid reagent and a pollutant of interest. Several instrumental systems with sufficient sensitivity have been designed and applied in practice because they did not require sophisticated electronics and exhibited small drift. On the other hand, they are not popular mainly due to fact that their application is connected with troublesome maintenance (reagent stability) and relatively long response times.

Recently, measuring techniques based on a physical (or physicochemical) principle are more frequently used in the assessment of air quality. Such methods involve direct determination of a physical property of a pollutant, sometimes after its interaction with another compound. In this approach, better stability, sensitivity and reliability may be easily achieved. Furthermore, the practical application requires less maintenance. Instruments based on this principle can be easily automated, which enables their use in providing continuous measurements needed for up-to-date assessments of air quality. It is especially relevant to environmental monitoring because many existing standards refer to a specified period of time, i.e., 1 hour, 24 hours or a year.

According to the location where measurements are taken, instruments can be stationary or “on-site”. In the first case, analysis is performed in the laboratory and sophisticated instruments are applied, such as mass, electron mobility or X-ray fluorescence spectrometers. On-site systems enable measuring of pollution levels in the field. Since access to a sophisticated laboratory is not required, the devices (usually uncomplicated, relatively cheap and portable) hold great promise for use in remote locations. The main advantage of on-site analysis is the potential for rapid assessment and response to a particular problem.

Considering the site where a gas matrix is sampled, the analytical information can be obtained in four different modes: off-line, at-line, on-line and in-line.

“Off-line” measurements require transport of the sample from a measuring site to a laboratory for measurement. They have the advantage of sophisticated measurement systems and trained laboratory personnel, but do not provide sufficiently rapid measurements. “At-line” measurements, in which the instrument is brought into the measuring location, are more efficient, but still require trained personnel. They still may not provide rapid measurements. “In-line” instruments inserted directly into a measuring stream are convenient for obtaining continuous measurements, delivering results almost immediately. In such cases, the results are obtained in real-time. The relationship between the rapidity of obtaining results and correla-

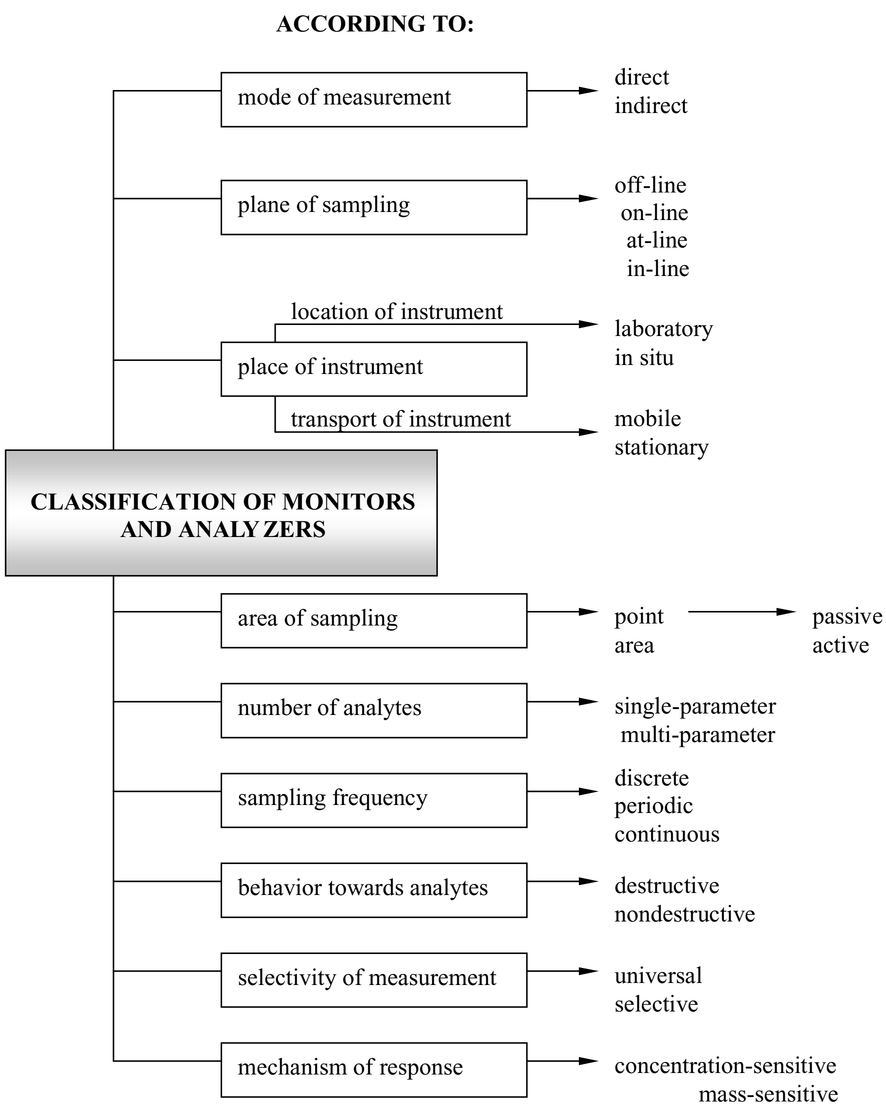

FIG. 3. Classification of analyzers according to different criteria.

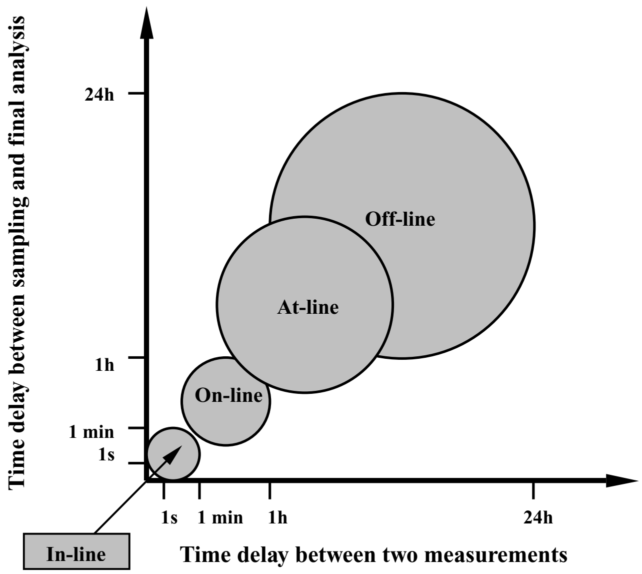

FIG. 4. Time saving in different measurement models.

tion of sampling with final analysis is schematically shown in Figure.4.

Taking into account space parameters, measurements are divided to a point, averaged along a defined part of an area and averaged on the selected area. Final measurements enable determination of weighted averaged concentrations over a sampling period. Point monitoring is inadequate to measure poorly mixed gases such as fugitive emissions over large areas. If the point instrument is wrongly placed, measurement results are not representative.

Depending on their flexibility for adaptation to different situations, analyzers can be specific, for the determination of a single of several analytes, and thus difficult to modify for alternative, or generic applications, without specific operational mode and thus readily adaptable for use with different types of samples and/or analytes simply by replacing one or more modular elements.

All measuring systems can also be classified as mobile or stationary. Mobile refers to a continuous-monitoring instrument that is portable or transportable. They are usually designed to perform analytical measurements without preliminary operations. Portable refers to self-contained, battery-operated instruments that are worn or carried by the person using it, or it may require the use of special vehicles for placement in a specific area to be monitored. Transportable gas monitors can be mounted on a vehicle such as a car, plane, balloon, ship or space shuttle, but not to a mining machine or industrial truck.

Portable systems for field measurements should meet the following requirements:

- compactness and robustness,
- ease of handling,
- adaptability to on-site measurements,
- automated operation with a long-lasting power supply,
- stability under aggressive environmental conditions.

Under normal use, an analyzer operates in diffusion mode through remote air sampling, which is important for determining ambient air quality in remote or confined areas prior to entry, and using either a built-in or external pump is possible. Finally, analyzers can be either commercial or laboratory-made.

The general trend in the field of creating instruments for air quality assessment is combining several instruments into one system and forming so-called hybrid multi-sensor systems, controlled by a micro-processor capable of transferring the obtained data to a central station, frequently using a wireless system. In the central station the data are collected both from single objects (houses, plants) or from large areas. Many systems are equipped with devices for testing the sensors and for providing diagnosis of the whole instrument. Frequently they have alarms which warn the user of any dangerous situation due to the breeching of some value limit. Such systems are battery-powered and able to work continuously for several days or months.

The environments in which analyzers are used differ from the relative calm of the laboratory. Analyzers have to withstand wide ambient temperatures, fluctuations and vibrations. Due to this, many systems are completely sealed so as to operate independenty of outside conditions and be able to withstand the onslaught of monkey-wrench mechanics.

EXAMPLES OF NON-STATIONARY INSTRUMENTS USED FOR THE MONITORING AND ANALYSIS OF AIR COMPONENTS

Scientific literature describes a great number of newly developed non-stationary analytical instruments that can be applied for the determination of different pollutants in atmospheric air. Many systems are applying well established methods: i.e., gas chromatography (GC) and mass spectroscopy (MS) (3, 4). Field-portable GC-MS systems are widely used in situations that require rapid identification of analytes and a high degree of data certainty. Both methods yield high sensitivity and selectivity but require some kind of sample preparation and hence lack time resolution. In addition, they are generally not as universally applicable to all kinds of components as optical spectroscopic schemes.

Among several new techniques developed for environmental applications, laser-based techniques are beginning to emerge as important tools for chemical analysis because of the prospects they offer for the selective, minimally destructive and highly sensitive detection and analysis of solid, liquid, aerosol and gaseous materials in real time. Laser-induced breakdown spectroscopy (LIBS) is one such technique (5, 6). LIBS is a chemical sensor technology undergoing rapid advancement in a variety of geochemical, mineralogical and environmental applications. Due to its simple and direct nature, which makes it an optimal technology for use as a real-time, field-portable sensor, LIBS has recently received renewed attention.

A LIBS is an atomic emission spectroscopy technique utilizing a pulsed laser beam directed at a sample to create a high temperature microplasma. The resulting light emission is collected optically and then resolved temporally and spectrally to produce an intensity versus wavelength spectrum containing emission lines from the atomic, ionic and molecular fragment created by the plasma. A recent breakthrough in component development, the commercial launching of a small, high-resolution spectrometer, has greatly expanded the application of LIBS in field-portable uses. The most important features of a LIBS sensor system in environmental analysis include:

- small size and weight,
- real-time response,
- *in-situ* analysis with no sample preparation required.

In Table 2, some examples of non-stationary systems designed in the last decade for air analysis and air monitoring are presented.

MOBILE MONITORING SYSTEM (MMS) FOR AIR POLLUTANT MONITORING ALONG COMMUNICATION LANES (30, 31)

General Characteristics of the System

The measurements of air pollutants from line sources are still very rare. Current traditional systems used to determine pollutant concentrations along communication lines are based on stationary measurements; this means that they are related only by a precisely defined point or space. The novelty of the proposed fully automated system is connected with fact that it can be used to monitor emissions from urban traffic along roads, in streams of vehicles, and in those areas where traditional monitoring stations cannot be placed. Thanks to the small dimension of the system, it is possible to mount it on moving vehicles.

Weather conditions such as temperature and humidity are also measured. The proposed mobile system is cheap, reliable, and does not require frequent routine maintenance procedures like calibration, filter changes, etc. The mobile monitoring system can determine representative concentrations of air pollution in highly populated areas, the impact of communication sources on pollution, general background pollution levels in areas directly affected by cars and the highest pollution levels in the cities. The proposed mobile monitoring system is a unique solution in the European Union.

Characteristics of Selected Pollutants Produced by Traffic

Urban traffic has become the most significant cause of air pollution in cities. Air pollution is still a major problem as current thresholds are frequently exceeded. Therefore, further reductions of emissions are necessary. The first and essential step in controlling and mitigating air pollution is to quantify air pollutant emissions. For this it is important to be able to monitor air quality in towns, especially along roads. Road traffic is responsible for emission of several air pollutants; the most important being nitrogen oxides (NO and NO_2 together called NOx), sulphur dioxide (SO_2), particulate matter (PM), carbon monoxide (CO) and volatile organic compounds (VOCs), all of which can pose a health hazard.

Traffic on roads is the greatest source of noise and local air pollution, and a considerable contributor to global emissions of greenhouse gases. These emissions to the atmosphere badly influence vegetation, human and animal life, agriculture and climate. Air pollution from road traffic consists of a number of harmful substances. Emissions of CO, NOx and hydrocarbons (HC) are controlled by catalytic converters on new gasoline driven cars. Emissions of sulphur oxides are being reduced through a lower sulphur content in gasoline. However, emissions of particulate matter are not decreasing. Any successful strategies for controlling or countering these problems must be based on reliable air quality monitoring data for management to make informed decisions on air pollution control.

VOCs is a collective name for a very large number of different chemical species which have different physico-chemical properties and can contribute to the formation of secondary pollutants with different efficiencies. For vehicular emissions, the list of compounds is long and variable depending on fuel, engine type and operating conditions. Hydrocarbons such as ethane, ethyne, higher aliphatic hydrocarbons, benzene, toluene and xylenes (BTX) are typical emissions in most cases. Each of these compounds can be released unreacted or can undergo oxidation reactions. One of them, benzene, is found in the highest concentrations. In the unreacted state it has undesirable ecotoxicological properties. Besides causing annoying physiological reactions such as dizzness and membrane irritation, it is known to be a human carcinogen.

NO_x is present as a consequence of various combustion processes, including those in vehicle engines. These molecules have very short atmospheric lifetimes, around five days, before being ultimately converted to nitric acid and removed in rainfalls. However, NO is important because it is a precursor to tropospheric ozone. Whereas NO does not affect climate, ozone does. A typical sea-level mixing ratio of NO is 5 pptv (parts per trillion, 10^{12}, by volume) but in urban regions, NO mixing ratios reach 0.1 ppmv (parts per million, 10^6, by volume) in the early morning, but decrease to zero by mid-morning due to reaction with ozone. A major source of NO_2 is oxidation of NO, being an intermediary between NO emission and O_3 formation. NO, is one of the six criteria air pollutants for which ambient standards are set by the United States Environmental Protection Agency U.S. EPA under the Clean Air Act Amendments of 1970 (CAAA70). In urban regions the mixing ratio of NO_2 ranges from 0.1 to 0.25 ppmv. It is more prevalent during mid-morning than during mid-day or afternoon because sunlight

TABLE 2
Selected examples of non-stationary systems for air monitoring and analysis

Analytical system	Measured parameter	Detection level	Remarks	Ref.
Transportable, field-portable GC-MS and FTIR system	VOCs		Continuous, unattended operation for 12- or 24-hours	3
Field-portable laser-induced breakdown spectrometer (LIBS)	All metal element (e.g., Pb, Cu, Mo, Fe)	mg/kg	For real-time, in-field environmental analysis	5,6
Portable multi-sensor system	SO_2, $CO_{2,}$ meteorological parameters	ppm		7
Proton-transfer-reaction mass-spectrometer (PTR-MS)	Monoterpenes, CO_2, NO_x, meteorological parameters	ngms	On-line field measurement	8
Fast response chemical ionization MS	HNO_3	ppb	In-situ measurements in the upper troposphere and lower stratosphere	9
Automated mercury analyzer	Atmospheric mercury	single μgm^{-3}	Aircraft measurements	10
Photoacoustic spectrometer	NO, CO_2	low ppm	Based on fundamental and frequency doubled high-pressure CO_2 laser	11
Portable tandem MS	Dimethyl methyl phosphonate arsine, benzene, toluene, pyridine and vinyl acetate	low ppbv	Direct monitoring of toxic compounds in real-time	12
Mobile platform with triple quadrupole MS (TAGA)	Styrene and other ambient airborne chemicals	1 μgm^{-3}	Real-time monitoring airborne ambient chemicals to differentiate emissions from different neighboring companies	13
Atmospheric pressure ionization MS (APIMS)	SO_2	LOD $\sim$ 1 pptv	Used on aircraft at altitudes to 12 km	14
Supersonic jet/resonance-enhanced multiphoton ionization(SSJ/REMPI) TOF-MS	PCDD/Fs in flue gas	sub ppq	On-line real-time monitoring of PCDD/Fs	15
Photoacoustic instrumentation (PA)	Aerosols		For measuring light absorption aloft for aircraft sampling of aerosol light absorption	16
Scanning imaging absorption spectrometer for atmospheric calculations (SCIAMACHI)	Glyoxal (CHOCHO), formaldehyde (HCHO)		To determine ratio of glyoxal to formaldehyde	17
Michelson interferometr (MI)	SF_6	pptv	For passive atmospheric sampling	18
Aircraft-based GC-ECD	Peroxyacetic nitric anhydride (PAN), peroxypropionic nitric anhydride (PPN), peroxymethacrylic nitric anhydride (MPAN)	$\sim$ 5pptv	Aircraft-based instrument	19
Portable fully automatic GC	CO	ppb	Continuous monitoring (every 10 min) in remote site (island in ocean)	22

(Continued on next page)

TABLE 2
Selected examples of non-stationary systems for air monitoring and analysis *(Continued)*

Analytical system	Measured parameter	Detection level	Remarks	Ref.
Time of flight aerosol MS (TOF-AMS)	Mixture of non-refractory particle component: nitrate, sulfate, ammonium, organics	μgm^{-3}	Information on single particle composition, average particle composition, size distribution	20
HR-TOF-MS	Inorganic and organic species	0.04 $\mu g/m^3$	Field-deployable quantification of several types of organic fragment (C_xH_y, $C_xH_yO_2$, $C_xH_yN_p$, $C_xH_yO_zN_p$), identification of nitrogen and organosulfur content, size distribution of all ions, in aircraft studies	21
Portable pack sampler	SO_x(particulate SO_4^{2-} + gas SO_2) NO_x ($NO + NO_2$)	LOD: SO_x 0.2 ppbv, NO_x 1 ppbv	In mountainous or remote site	23
GC analyzer	VOCs (n-hexane, acetone, ethyl acetate, alcohols, BTX)	sub ppb	For continuous risk assessment, every 30 min	24
Prototype of vacuum-outlet GC	VOCs	tens ng	Polymer-coated surface acoustic wave (SAW) detector	25
Portable FTIR analyser	VOCs	tens of ppmv	In-field campaign in New York City	26
Multi-sensor instrument	O_3, NO_y ($NO+NO_2+HNO_3+PAN+...$)	tens pptv	Chemiluminescence detector for O_3, dual beam UV absorption photometer and chemical ionization for HNO_3	27
Multi-parameter analytical system (NOAA Tween Otter)	Aerosols, primary and secondary trace gases (O_3, CO, SO_2, NO, NO_2,NO_y, HNO_3, HCHO, H_2O_2, PAN, NMHC)	from 10 ppt to ∼4 ppm	Mounted on the aircraft to compare with the surface measurements	28, 29

breaks down most NO_2 past mid-morning. Exposure to high concentrations of NO_2 harms the lungs and increases respiratory infections. It may trigger asthma by damaging or irritating and sensitizing the lungs, making people more susceptible to allergens. At higher concentrations it can result in acute bronchitis or death.

O_3 is not directly emitted from anthropogenic or natural sources. Its only source into air is through chemical reaction. In urban air, O_3 mixing ratios range from less than 0.01 ppmv at night to 0.5 ppmv (during afternoons in the most polluted cities world-wide), with typical values of 0.15 ppmv during moderately polluted afternoons. O_3 causes headaches at concentrations greater than 0.15 ppmv, chest pains at mixing ratios greater than 0.25 ppmv, and sore throat and cough at mixing ratios greater than 0.30 ppmv. Over a level of 0.30 ppmv it decreases lung function. Symptoms of respiratory illness include coughing and trouble breathing. O_3 can also accelerate the aging of lung tissue. It also interferes with the growth of plants and deteriorates organic materials such as rubber, textiles and some paints and coatings. Furthermore, O_3 increases stress in plants and trees and their susceptibility to disease, infestation and death.

Particulate matter (particles), especially those smaller than 2.5 um in diameter, cause more severe health problems than do gases. Additionally, they cause visibility degradation. They enter into the atmosphere by emissions and nucleation. In the air, their concentrations and sizes change by coagulation, condensation, rainout, sedimentation, dry deposition and transport.

Characteristics of a Mobile Monitoring System

The proposed MMS for air pollution in traffic, as depicted in Figure 5, consists of five major components, namely the air monitoring unit (AMU), the data server (DS), the data warehouse

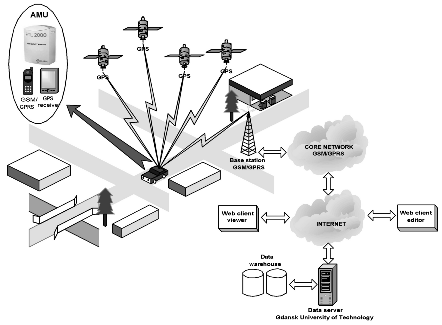

FIG. 5. The concept of the mobile monitoring system for chemical agent control in the air.

(DW), the Web client editor (WCE) and the Web client viewer (WCV).

AMU is suitable for air quality monitoring, being very easy to install and simple to use. Using thick film sensors, it allows measurements of up to 12 components. Thick film sensor technology exploits electrical conduction phenomena which happen above the surface of nanostructured metal oxides (composed of 30–50 nm diameter micrograins) at temperatures between 200 and 400°C. An electrical response from a semi-conductor is obtained that is proportional to a particular atmospheric gas concentration; using a suitable fitting calibration curve the response signal is converted into a gas concentration. In such conditions, atmospheric oxide adsorption takes place above the semi-conductor surface. The instrument is used for measurements of NO_2, O_3 and benzene, as representative of BTX. In the future, its application can be easily extended for measuring of other pollutants, e.g., CO and H_2S. In addition to temperature, relative humidity is also measured. The AMU also includes a GPS receiver and a mobile terminal connected to a GSM/GPRS (Global System for Mobile Communications/General Packet Radio Service) network.

Upon receiving on/off line monitoring information from the AMU, the DS will upload the data to the *(DW)*, and also perform long-term trend analysis. Through deriving the pattern and trend from the data collection, the DS is able to perform a prediction on air condition. The data server is located at Gdańsk University of Technology.

Manages databases via personal computers, utilizes data to analyze air condition.

User may connect to the mobile monitoring system operating on a remote system through an Internet protocol.

Based on the data obtained from measurements of pollutant concentrations, the emission characteristics for selected communication arrangements (crossing, traffic circle, canion type street, etc.) can be found. Knowing the particular concentrations, it is possible to calculate model calibration coefficients which can be useful for creating simulation models of different scenarios for better mitigation of air pollution caused by traffic. Furthermore, having collected high quality emissions data, the system should able to identify the most risky areas (hot spots), i.e., the places with the highest concentrations of pollutants. The results can eventually be used in the placing of traditional monitoring systems and for proposing possible abatement measures.

An additional advantage of the proposed mobile station is the fact that it does not need frequent routine maintenance procedures like calibration, filter changes, etc.

CONCLUSION

Direct detection and quantification in real-time of toxic substances in the air is desirable for early identification of a pollutant's release, especially for security applications. Early warning of such releases is best accomplished *in-situ* using reliable, transportable and portable instrumentation. These instruments meet stringent performance requirements with respect to sensitivity, specificity, broad applicability and quantitative accuracy. In this paper some exemplary solutions from the last decade have been presented.

The MMS proposed by the authors allows determination of representative air pollution in highly populated areas, to assess the impact of communication sources of pollution, general background pollution levels in areas directly affected by cars and the highest pollution levels in the cities. The proposed mobile monitoring system is a unique solution in Poland.

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