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THE-STATE-OF-THE ART FOR AUTOMATIC MEASURING SYSTEMS USED IN THE MONITORING OF AIR POLLUTANTS

In the world, there is a growing concern about determination of toxic and potentially toxic chemicals in the atmosphere. Currently, air pollution is being monitored by means of various measuring methods and techniques. This paper deals with some aspects of air pollutant measurements. Emphasis is being placed on principles of operation, performance characteristics and development of automatic measuring systems. On-site, in-situ and remote systems are chosen to illustrate recent trends in the development of the techniques used in the monitoring of air pollutants. Their advantages and disadvantages are discussed.

1. INTRODUCTION

Environmental pollution is one of the most serious and urgent problems of our time. Obviously, it is not a new problem but its importance was rather limited in the past. Now, environmental pollution is the focus of interest which has broadened from the purely local scene to a world-wide interactive pattern, thus being the subject of global concern. The need to reconcile the economy with ecology in our rapidly advancing industrial world is fully recognized today.

The hazards to environment can be classified into four main groups: air and water pollution, solid waste disposal and noise. Among environmental pollutants air contaminants are of particular interest which follows from the fact that it is rather difficult to gather them. We have divided the land into neatly-labelled administrative, political, ethnic areas, regions, etc., but Nature does not need these, air pollutants need no passport to move over the Earth and seas.

Because of the above, it is important to have information about:

substances entering the air, their quantities, sources and distribution,

the effects of these substances on environment,

trends in their concentrations and effects,

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the causes of their changes,

how far these input concentrations, effects and trends can be modified, by what means and at what cost.

Measurement of air pollutant concentrations is a very important source of data. The concentrations of pollutants can be measured and controlled for various purposes. In addition to many specific types of applications, there have emerged four major fields where gas analysis has proven to be indispensable. They are as follows:

surveillance of ambient air quality,

global monitoring,

process control and optimization,

monitoring of flue and exhaust gas emissions,

occupational safety in working environment and plant security.

The surveillance of ambient air quality is not an easy task because many of the air contaminants undergo time-dependent changes due to chemical or physical processes. For example, these may include transport and distribution of pollutants, formation of ozone in photochemical reactions of reactive organic species and nitrogen oxides, conversion of sulfur dioxide to sulfates, formation or transformation of aerosols by chemical and condensation mechanisms. In order to understand better these processes, monitoring of air pollutants is required.

Space and time are essential dimensions in these measurements. Utmost attention must be paid to temporal and spatial resolution because of the dynamics of the processes being examined. Increasing attention is being paid to both vertical and horizontal distributions of contaminants. Another problem is low concentration of air pollutants and their interaction with other gases. Since the atmosphere contains a wide variety of trace gases, their interaction with other substances is a major factor to be considered in the analysis of a given pollutant.

Due to the complexity of environmental problems, the variety of both pollutants of our concern and of the media that must be investigated, the range of the measuring methods and techniques used in the measurements of ambient air quality is very wide. The methods can be classified as chemical and physical (more exactly physicochemical). Chemical methods are in most cases the so-called wet chemical methods because they involve interaction between a liquid reagent and contaminant of interest.

Recently wet chemical methods are not so popular, because their application is often connected with the problems of interferences, reagent stability, need to control reagent flow rate, complex plumbing, air-reagent contactor efficiency and relatively short response time. On the other hand, many of these methods are well known, sensitive enough because they require no sophisticated electronic amplification and exhibit little signal drift. Also initial costs of the instruments are in many cases lower. Thus, some wet chemical methods will likely be used in environmental analysis, especially in manual measurements.

Nowadays, in the ambient air quality monitoring we use the measuring methods which are based on physical rather than chemical principles. Physical methods involve direct determination of a physical property either of the pollutant itself or following its interaction with another compound. This results in stability, reliability, sensitivity, selectivity and reduced maintenance of the methods. Therefore they are considered as the best for measuring pollutants even at a great distance from the emission point.

These methods offer another advantage – they allow us to state the presence of pollutants in a continuous and automatic way. Complex real-time automatic measurements are used to acquire high resolution data. The application of these methods is now of deep interest because automation not only gives the minimum cost of measurements but it also provides a continuously updated picture of environmental situation. The automatic methods yield all the information required to assess hourly, daily, monthly and annual phenomena.

Because of the great number of the methods used for measuring pollutants, the international organizations involved in the air quality monitoring have chosen a series of reference methods [1]. These are not necessarily absolutely accurate, but they are judged the best available and their results are comparable with the results of other methods. The reference methods are especially important when the agreement between the results obtained and air quality standards is in question.

Automatic, continuous ambient air quality monitoring requires extremely sensitive instrumentation. The most advanced techniques of chemistry, physics and microelectronics should be used. For practical considerations, not only the measuring principle of equipment is of importance. Depending on its application and measuring task, such an equipment can be exposed to environmental impact that requires special attention. Typical environmental impacts are as follows: low and high temperatures, dustiness and humidity of air, aggressive components of air, vibrations and transportation stress.

The automatic methods enable us to combine sample collection with chemical analysis, acquisition and data processing and thus to limit the procedure to one automated process. Such methods require many different devices, which are very often connected, producing one measuring system. Systems of air quality monitoring may be classified as on-site, in-situ and remote. They can be used in a mobile or stationary version.

2. STATIONARY, ON-SITE MEASURING SYSTEM

In on-site systems, a representative sample of ambient air is taken by means of a suitable probe and carried to the analyzer through the sample line.

It is essential in these systems that all components of air have to be transferred unchanged to the analyzers. Therefore, a manifold sampling system is used. It is constructed from glass and PTFE.

The gas analyzers are designed for continuous and quantitative detection of certain pollutants in a gas sample. This measuring equipment is based on the following reference methods [2]–[4]:

ultraviolet absorption of O_3,

chemiluminescence of NO_x,

fluorescence of SO_2,
infrared (IR) absorption of CO,
flame ionization detection of H_nC_m,
beta-beam absorption or tapered element oscillating microbalance (TEOM) of particulate matter [5].

The instruments are modularly interchangeable and programmable by the user himself, allowing considerable flexibility of their operation and service. They are regulated by microprocessors and define a homogeneous and coherent range. This range of automatic and continuous (24 hours/day) analyzers and a range of calibration, control, acquisition and data processing devices can complement each other.

The analyzers continually output analogue voltages proportional to pollutant concentration. The analogue outputs are connected to a programmable logger for data collection and storage. The data logger records and averages pollutant concentrations and monitors instrument alarm and diagnostic functions. This device is also programmed to trigger the daily autocalibrations of analyzer. All logger functions and outputs can be set up and monitored using computer linked with logger or via the network central computer station.

The calibrations of analyzer are performed every twenty-four hours, using cylinders containing standard gas or permeation tube ovens permanently installed on-site [6]. The automatic calibration facility provides a zero and span check initiated by the data logger.

Measurements of air pollutant concentrations have to be correlated with a meteorological conditions to provide a continuous profile of air. Therefore, sensors for meteorological measurements such as wind direction, wind speed, relative humidity, temperature, rain fall, atmospheric pressure and solar radiation are also available.

All monitoring equipment is housed in stand-alone, self-contained cabinets. They are used to protect instruments from corrosion, dust or humidity. The housings are fully air conditioned in order to maintain within enclosure a constant operating temperature of approximately 20–25 °C. Typically, analyzers can operate within a temperature range from 15 to 35 °C; however, in order to ensure firm instrument response it is important to reduce variation in operating temperature to a minimum. Instrument calibrations should also be performed within a known consistent and constant temperature range.

The sampling system, analyzers, calibration units, meteorological instruments, logger equipment for displaying, processing, and transmitting data and cabinet with infrastructure form a stationary air quality monitoring station. Usually, such a station is an element of the monitoring network used for environmental management. All monitoring stations are linked to a data telemetry system which allows continuous transmission of data from field stations by standard telephone lines or on radio to a computerised centre of network control. Data are acquired automatically.

The monitoring networks are used for:
on-site urban air profiles,

on-site monitoring of street-level urban air,
on-site monitoring of diffuse emissions,
on-site monitoring of rural air.

3. STATIONARY, IN-SITU MEASURING SYSTEM

The environmental monitoring stations equipped with the on-site measuring systems are very expensive, therefore it would be useful to replace traditional gas analyzers with instruments containing cheap gas sensors [7], [8]. These elements are in direct contact with an ambient air. Hence, it is possible to measure the pollutant concentrations without sampling procedure. It is in-situ monitoring.

The complete in-situ measuring system consists of three basic components: gas sensor, transmitter and data logger or controller. Such a system can work with many sensors of various operating principles, e.g. optical, thermal, electrochemical, semiconductor. The gas sensors and transmitters are installed in detection heads or monitoring stations. Detection heads may be placed directly in monitoring zones at several locations. The monitoring stations comprise self-supporting frame, gas sensors with transmitters, data logger, accessories (tools, battery, charger, cable, etc.). Sometimes, this station is equipped with sensors for recording meteorological parameters.

The in-situ system is well suited to difficult-to-access areas. It allows us to overcome the problem of manual recording arising in the case of some methods and to replace them with a simple-to-use data logging system which can be left unattended in remote areas and harsh environments. The data can be collected at convenient intervals using a portable computer.

The measuring system basing on gas sensors may be used for monitoring the specific pollutants (toxic or flammable). Unfortunately, the sensitivity and selectivity of gas sensors are very often insufficient to measure the pollutant concentrations in ambient air.

4. STATIONARY REMOTE MEASURING SYSTEM

Measurement of air pollutant has traditionally been conducted in the form of ‘point monitoring’, i.e., as a measurement at a single location space. This is very suitable for intrinsically defined gas problems. However, point monitoring is inadequate to measure poorly mixed gases such as fugitive emissions from industrial plant over large areas. Clearly, in some circumstances if the point monitor is wrongly placed, the results of measurements will not be representative.

A number of remote monitoring techniques are being developed which do not have the disadvantages of these ‘point’ monitors and are capable of making measurements difficult or impossible to carry out using conventional method [9], [10]. Remote sensing involves monitoring in which analyzer is physically removed from the volume of air being analyzed. These remote monitoring techniques employ a beam of optical, usually infrared or ultraviolet radiation, to detect the gas directly in the atmosphere. The optical remote systems operate on the measuring principle that the radiation interacts with gases via Raman scattering, fluorescence or absorption processes.

The remote systems can be divided into active or passive, depending on whether the system contains its own source of radiation or relies on external emissions (such as from the sun). Active systems are currently used. They are generally set up to transmit a beam across a parcel of air to be measured.

The remote systems can be configured as monostatic or bistatic. In the monostatic configuration, the transmitter and receiver are collocated and either a topographic target (building wall, ground, vegetation), atmospheric aerosols and molecules or a retroreflector are used to reflect the transmitted radiation back to the receiver. In the bistatic configuration, a radiation source (transmitter) is placed at one location with a sensor (receiver) at another location. The two locations define the optical path. In this case, the monitor is an open-path optical instrument.

The active, remote systems can be grouped into two different classes: with monochromatic or specially broad-band source of radiation.

The radiation source in the monochromatic instruments is laser generating a very coherent, monochromatic light used as analytical beam. Raman backscatter, resonance fluorescence, thermal radiation and resonance absorption principles have been evaluated by several researches for use in air monitoring. Although resonance absorption requires retroreflectors or scatterers, it can be operated at safe energy levels to provide high sensitivity over a large range and has the further advantage of being the only method capable of detecting pollutants in their natural airborne state. Recent developments in microwave, correlation laser spectroscopy indicate their high potential for measuring certain air pollutants without separating or sampling of the air. The unique spectral lines occurring at high microwave, ultraviolet and infrared frequencies allow identification and measurement of air pollutants.

Broad-band instruments are subdivided into: non-dispersive and dispersive. Non-dispersive instruments do not contain diffraction elements splitting the radiation beam into discrete wavelengths, therefore they are non-specific and have only moderate sensitivity. Non-dispersive analyzers have been designed to detect specific constituents of gas only. Concentrations of gas constituents in gas mixtures are derived from the intensities of incident R/VIS/UV radiation transmitted through paths in the gas mixtures.

Dispersive monitors are used to obtain more information about the absorption spectrum of the air. More detailed shape of the spectrum can be achieved by means of a diffraction grating. Dispersive instruments (i.e. spectrometers) are specific but even at long path lengths their sensitivities are barely adequate to monitor the ambient air quality. Furthermore, they are complicated, fine and expensive and are not readily utilized for continuous operation.

Very interesting examples of monostatic systems with monochromatic source of radiation are Differential Absorption Laser, Lidar and Differential Absorption Lidar

[11]. Differential Absorption Laser is a system in which two laser beams of different wavelengths are passed through a cloud of gas along the same path to a beam return target. If one wavelength is selected to be at the absorption maximum of the gas of interest and the second is a nonabsorbing wavelength, then the difference in absorptions of two returned beams is proportional to the amount of absorbing gas in the beam. Species quantification is possible if there are no interfering gases.

Lidar (Light Detection and Ranging) is a pulsed laser system used like a radar system where the time of return of reflected light is measured and used to determine the distance to the cloud of reflecting material or solid reflecting target.

Different Absorption Lidar (DIAL) is a system with a high-energy source of tuneable wavelength radiation. Two pulsed laser beams of different wavelengths are passed through a cloud of gas along the same path. If one wavelength is selected to be at the absorption maximum of the gas of interest and the second is a nonabsorbing wavelength, then the difference in absorptions of two returned beams is proportional to the amount of absorbing gas in the beam. Therefore, it is possible to measure pollutant concentration as a function of the distance from the source along the line of sight of transmitted beam. Because the air acts as a very inefficient reflective medium, a pulse source emitting radiation of high intensity and a sensitive detector are required to take accurate measurements. Appropriate sources and detectors are now available and the DIAL technique can be used to make measurements of the concentration profiles over a wide range of gaseous industrial pollutants, i.e. from a few meters to one kilometre.

The example of remote active system with the spectral broad-band source is OPSIS [12]. The system allows the measurement of more than 20 specific gaseous constituents in the beam of light between a transmitter and a receiver. This method is based on optical absorption measurements in the ultraviolet and near infrared range. The principle is known as differential absorption spectroscopy (DOAS).

The broad-band absorption has little spectral structure and therefore it is difficult to differentiate it from scattering in water vapour and by other particles. Furthermore, it is impossible to obtain a 'clean gas reference spectrum'. Therefore, the DOAS technique takes into account only the narrow-band structure, the differential absorption, and ignores all broad-band absorption.

In the OPSIS, a beam of light is projected from a transmitter to a receiver through a pre-determined path. The transmitter can be as far as 2 km from the receiver. The light changed by gases in air is then sent over a fiber-optic cable to a central unit containing a computerized spectrometer. The computer collects more than 100 spectra of the wavelength in question per second. These spectra are converted to digital signals, stored and compared to library of spectra for various known gases to determine the type and quantity of gaseous substances present in the measurement path.

OPSIS is used to monitor such gaseous substances as oxides of sulphur (SO_x), oxides of nitrogen (NO_x), hydrochloric acid, mercury vapours, ozone and a long list of hydrocarbons from methane to styrene, toluene and xylene.

5. MOBILE MEASURING SYSTEM

Environmental surveys often require extensive field work in remote areas. The use of well equipped mobile monitoring stations can help substantially and has clear benefits:

results available without delay,

sample deterioration minimised,

extensive range of equipment available on-site,

site work can respond immediately to new results.

In mobile stations there are required:

operating conditions,

appropriate installations,

floor and wall covering, thermal installations,

ability to withstand vibrations during transport,

power supply,

communication.

The mobile stations are equipped with the same measuring instruments as stationary stations.

6. CONCLUSIONS

The primary drawbacks of the measuring systems applied in air quality monitoring are their cost, size of equipment, sensitivity of the equipment to vibration or movement and sometimes inadequate sensitivity to the concentration range of many pollutants.

Nowadays, there first of all on-site systems are used. However, further development of optical instruments and gas sensors may lead to the measuring systems which are less expensive and more sensitive to air pollutants.

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PRZEGLĄD AUTOMATYCZNYCH SYSTEMÓW POMIAROWYCH DO MONITORINGU POWIETRZA ATMOSFERYCZNEGO

Zanieczyszczenia powietrza atmosferycznego mogą być mierzone za pomocą różnych technik pomiarowych. W artykule przedstawiono przegląd automatycznych systemów pomiarowych przeznaczonych do monitoringu stanu zanieczyszczenia atmosfery. Uwagę skoncentrowano przede wszystkim na stacjonarnych systemach typu *on-site*, *in-situ* i zdalnych. Omówiono również wymagania stawiane mobilnym stacjom pomiarowym.