CHEMICAL SENSORS FOR OUTDOOR AIR QUALITY MONITORING

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Abstract: *Air pollution is a global threat leading to large impacts on human health and ecosystems. Emissions and concentrations have increased in many areas and worldwide. In some areas of Europe, air quality remains very poor, despite reduced emissions and concentrations in the environment. Currently the most important environmental risk to human health is air pollution, and Europeans are considered the second biggest concern for the environment, right after climate change. Major problems related to air quality have an impact on human health, and in particular on respiratory diseases. In response to the problems of poor air quality, there is political, media and public interest in air quality issues. The growing public influence over air pollution challenges, including ongoing civic scientific initiatives involved in supporting air quality monitoring and targeted initiatives to raise public awareness and change behavior, has led to increasing support and demand for measures to improve air quality. Due to increasing air pollution, great efforts are being made to develop various chemical methods and chemical sensors used to measure air quality. Cheaper gas-based sensors based on the Arduino system are available today. Given their simplicity and given that they are more cost-effective, these sensors have proven to be very useful in some situations where it is necessary to detect certain gases in the air in a very short time. Several chemical methods have been developed that can also detect certain gases in the air. In this paper, only some methods by which gases and particles can be detected will be mentioned.*

Keywords: *chemical sensors, emissions, air pollutants, stationary sources, Arduino*

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1. INTRODUCTION

Responsibility to protect the environment and human health must be ensured through an effective air quality monitoring system which is a necessary instrument. It is recommended that the system be simple, reliable, sensitive, and economically viable. This system must be highly sensitive to the low concentrations of gaseous air pollutants such as hydrogen and carbon monoxide that exist in cigarette smoke. Today's trend of developing air pollution monitoring system and alarm systems increases sensitivity and reduces response time, especially at low concentrations of air pollution. Very common environmental sampling methods for these pollutants use manual capture samples that are collected on site and then transported and tested in analytical laboratories. Some sampling methods can be very expensive, and time consuming, and ongoing research can be focused on developing sensors that can replace traditional sampling methods for monitoring environmental pollution. Chemical sensors are among the modern technologies such as mobile phones and personal computers. The term "sensor" is easy to understand. Humans can visualize sensors such as sensitive organs or ant tentacles. Chemical sensors belong to a special type of sensor, and as an example, sensors in refrigerators in the form of freshness sensors that detect spoiled food can be mentioned. Sensors are very commonly used devices in everyday activities today. Given that the world is changing rapidly day by day, these devices play an important role in this process. Sensor devices have been developed in such a way that they have the ability to detect substances that are present in our environment, ie they detect compounds and substances that are present and in what quantity. These are the domains of analytical chemistry whose main goal is to solve such problems with the help of precise and fast instruments in well-equipped laboratories. For many years, there has been a trend of increased centralization of analytical laboratories, but only in certain aspects do we now see a reversal of this tendency away from instrumental gigantism. The main goal and desire to create smaller devices instead of larger ones appeared at a time when a personal computer appeared and began to replace large, highly centralized databases. The same kind of reversal happened with the use of chemical sensors. Of course, in addition to chemical sensors, it is very important to mention sensors based on the Arduino system, which can also be used to measure gases if the calibration process is carried out correctly and thus represent a cheaper and more affordable alternative. In addition to these sensors themselves, which are used to determine air quality, it is very important to mention analytical methods that can also determine particles in the air. More about the methods used for gas detection will be discussed at the end of this paper.

2. AIR QUALITY MONITORING

A mass threat that poses a great danger to human health and the environment is air pollution. Emissions and concentrations have increased significantly in many parts of the world. Air pollution is a global threat leading to large impacts on human health and ecosystems. Emissions and concentrations have increased in many areas and worldwide. In some areas of Europe, air quality remains very poor, despite reduced emissions and concentrations in the environment. Currently the most important environmental risk to human health is air pollution, and Europeans are considered the second biggest concern for the environment, right after climate change. Major problems related to air quality have an impact on human health, and in particular on respiratory diseases. Cardiovascular diseases, asthma, and allergies, and are considered a very serious problem. In response to the problems of poor air quality, there is political, media and public interest in air quality issues. The growing public influence over air pollution challenges, including ongoing civic scientific initiatives involved in supporting air quality monitoring and targeted initiatives to raise public awareness and change behaviour, has led to increasing support and demand for measures to improve air quality. The European Commission is supporting Member States to take appropriate action and to take various initiatives to increase their cooperation with them. The European Commission has also initated misdemeanour proceedings against several Member States that violate air quality standards, while national and local authorities are facing and increasing number of lawsuits filed by non-governmental organizations and groups of citizens. In order to effectively reduce air pollution and its impacts, it is necessary to understand and know the sources from which this pollution originates, and it is necessary to know the ways in which these pollutants are transported and transformed in the atmosphere and how the chemical composition of the atmosphere changes over time and how substances affect human health, ecosystems, climate, and the economy as a whole. In order to reduce air pollution, cooperation and coordinated action at the international, national, and local levels are needed and must be maintained, in coordination with other environmental, climate and sectoral policies. It would also be good to use holistic solutions that include technological development, structural change, and behavioural change, along with an integrated multidisciplinary approach. Great efforts are needed to achieve the larger goals of sustainable development, which are directly or indirectly related to the mitigation of air emissions and changes in the composition of the atmosphere (Ortiz & Guerreiro 2020).

2.1. Air quality monitoring and objectives

The design, operation and strategies of the network that serve to monitor air quality (AQ) are determined by the objectives of monitoring activities:

- **Compilance air quality monitoring** – monitoring is done in support of legislation on air quality objectives (guidelines): monitoring compliance with directives.
- **Damage assessment and exposure monitoring**: -monitoring is performed to create a basis for assessing the damage caused by air pollution, human health, vegetation, materials: it is necessary to describe the effects of air pollution and support the development of cost-effective pollution reduction strategies.
- **Monitoring programs to support scientific research**.
- **Online monitoring:** - monitoring to predict high air pollution episodes: inform and warn population, and implement short-term reduction actions episodic high concentrations.
- **Operational supervision**: monitoring of air pollution in the vicinity of certain sources: in order to avoid unacceptable pullution of neighboring areas.
- **Repersentative air quality monitoring system** – a monitoring process to facilitate a representative description of AQ in a city / region, country or in Europe as a whole: to describe the state and trend of air quality.

Monitoring of air pollution is one of the very important activities required for a complete assessment of air pollution and its effects, as well as in the work on effective reduction of pollution (Larssen et al. 1999).

2.2. Ordinance on the monitoring of air pollutant emissions from stationary sources

The Ordinance contains provisions prescribing actions necessary for monitoring air pollutant emissions from stationary sources, preforming measurements, checking the correctness and calibration of measuring instruments, sampling and evaluating measurements results and submitting data to the competent institutions for air protection. The Ordinance is in line with Directive 2010/75/EC of the European Parliament and of the Council of 24 November 2010 on industrial emissions, and concerns the first, periodic and continuous measurements of emissions from stationary sources. The fixed source operator is obliged to provide a permanent measuring point at each outlet from the installation, ie additional measuring points (to check the correct operation of the continuous emission measurement system) that meets the requirements of Directive 2010/75/EC, and where, depending on the need, preform first, periodic or continuous measurements. Measurement of the parameters of the state of waste gases and concentrations of substances in them is preformed according to the methods prescribed in the standards, which are given in Annex 1 of the Ordinance, where the following order of priority must be observed: 1. Reference method, 2. CEN norms, 3. ISO standards, 4. National norms (Krizmanić, 2016).

2.3. Regulation on limit values for emissions of air pollutants from stationary sources

The Regulation prescribes limit values for emissions of air pollutants from stationary sources, monitoring and evaluation of emissions, entry of data on stationary sources using organic solvents or products containing volatile organic compounds in the register, the method of reducing emissions of air pollutants, the method and deadline for submission of emission reports to the Environmental Protection Agency, method of informing the public, method of submitting data to the competent bodies of the European Union and permitted exceeding of emission limit values for a certain period. The emission limit value (ELV) is the maximum permissible release of pollutants into the air from a stationary source unless a decision issued under a special regulation on the basis of which and environmental permit is issued stipulates stricter ELVs. The decree defines the first, periodic and continuous measurements. The first measurement of pollutants is performed during the trial operation of a stationary source, and before obtaining a certificate of use according to a special regulation governing construction for that stationary source, but no later than twelve months from the date of commissioning. Occasional measurements at a stationary source with predominantly constant operating conditions shall be performed with at least three individual measurements with uninterrupted continuous operation and at least one other measurement with regularly repeated operating conditions with variable emission. In the case of a stationary source with predominantly variable operating conditions, at least six individual measurements shall be made under operating conditions which, in experience, may cause the highest emissions. The duration of an individual emissions measurement is determined by a measurement method in accordance with a special regulation governing the monitoring of air pollutant emissions from stationary sources, and the result of a individual measurement is always expressed as a half-hour average, unless otherwise prescribed by Regulation. When continuously measuring the emission from measured data, a half-hour average is made every half hour. From the value of half-hour averages, a daily average is made with regard to daily working hours, unless otherwise prescribed by the Regulation. The frequency of emission measurements (**Table 1***)* for the discharge of a stationary source, unless otherwise prescribed by a Regulation or a decision issued according to a special regulation on the basis of which the environmental permit is issued, is between emitted mass flow ($Q_{emitted}$) and limit mass flow (Q_{border}) (Krizmanić, 2016).

Table 1. Determining the frequency of emission measurements (Krizmanić, 2016)

$Q_{emitted}/Q_{border}$	EMISSION MEASUREMENT FREQUENCY
0.5 to ≤ 1	Periodic measurements, at least once every 5 years
>1 to 2	Periodic measurements, at least once every 3 years
>2 to 5	Periodic measurements, at least once a year
>5	Continuous measurements

A stationary source is considered to meet the set conditions if the mean value based on the appropriate number of measurements under normal conditions does not exceed the ELV in the first periodic measurements (Krizmanić, 2016). In the case of continuous measurement, ELVs are considered to be met if:

- All mean 24-hour verified values less than ELV,
- 97% of half-hour verified mean values less than 1.2 ELV,
- All half-hour verified mean values less than double ELV.

2.4. Permissible concentrations for gases in the European Union

Residents and their environment in the European Union are exposed to a complex mixture of many air pollutants emitted from different sources and subject to atmospheric processes that can create new pollutants. Many of these pollutants can cause serious health problems and adverse effects on the ecosystem. Accepting status and improving air quality in Europe is crucial to support the development and implementation of European, national, and regional policies, as well as to inform research and innovation communities about the most important challenges in air quality assessment and management that need to be addressed in the near and medium term. Given the success of legislation seen over decades and the successful resolution of certain air emissions, much of the European Union's population still breathes air with air pollution levels that exceed EU and World Health Organization standards on air quality for health. Levels of air pollution continue to cause important impacts on human health as well as on the ecosystem in Europe. Emissions that cause air pollution arise from almost all economic and social activities. In the European Union, emissions of many air pollutants have been reduced by legislation and regulations. Great progress has been made in combating air pollutants such as sulphur dioxide

(SO_2), carbon monoxide (CO), lead (Pb) and benzene (C_6H_6). Road transport, industry, power plants, households and agriculture continue to emit significant amounts of air pollutants. Combustion of biomass and solid fuels in households is an important source of directly emitted particulate matter (PM) and poly aromatic hydrocarbons (PAHs) (Guerreiro et al. 2014).

2.5. Determination of quality

Assessments of air quality and quality based on measurements that European countries are eligible for the European Environment Agency (AAE) from 2011 for the period 2002 to 2011 are available in Airbase v. 7. The analysis covers all regulated pollutants in the Directive on air quality (EU, 2004 and EU, 2008) in the EU-27 and the EEA-32 Member States, ie the EU-27 Member States and the remaining five EEA Member States (Iceland, Liechtenstein, Norway, Switzerland, and Turkey). In some cases, the analysis includes, in addition to the EEA-32 member states, the new EU member state Croatia and five countries cooperating with the EEA (Albania, Bosnia and Herzegovina, the former Yugoslavia, the Republic of Macedonia, Montenegro, Serbia) were data available. In the analysis of PM particles with a diameter of 10 µm or less (PM_{10}), small particle diameters of 2.5 µm or less, only monitoring stations with at least 75% coverage data were taken into account (the part of the year for which valid concentration data are available). Less ($PM_{2.5}$), ozone (O_3), nitrogen dioxide (NO_2), SO_2 and CO. For the analysis of benzene concentration, the data coverage criterion is set at 50%, in accordance with the requirements of the European Commission Working Group on Benzene. For toxic metals (arsenic, cadmium, lead, mercury, and nickel) and benzo (a) pyrene (BaP), today's coverage requirement of at least 14% has been applied, which is in line with the targets set in EU directives (EU, 2004 and EU, 2008) for measurement accuracy (Guerreiro et al. 2014).

2.6. Indicator analysis

A nonparametric Mann-Kendall test was used to detect and estimate trends in altered environmental concentrations to examine the presence of a monotonic trend of increase or decrease. A nonparametric Sen method (as a change per year) was applied to estimate the slope of the linear trend. The calculated trends were considered as statistically significant for levels of significance 0.1 (corresponding to 10% chance there is no trend) or lower. PM_{10}, O_3 and NO_2 values are calculated based on officially reported data in Airbase v.7 from a consistent set of stations with a minimum data coverage of 75% of valid days per year for at least 8 years for a period of 10 years. PM concentrations not measured by reference methods (gravimetric) must be corrected with correction factors found in demonstrating the equivalence of non-reference methods (e.g., BAM and TEOM) used in some countries. The number of measuring stations with available long time series $PM_{2.5}$ is limited, by calculating the trends of $PM_{2.5}$ made for the period 2006-2011. Stations must contain a minimum data coverage of 75% of the valid days of the year at least 5 of the 6 distances per year. National trends are calculated on the basis of the average of trends estimated at individual measuring stations. Measuring stations located outside continental Europe (French overseas possessions, Canary Islands, Azores, Madeira) are excluded. Due to some air quality standards in the EU, it is allowed to exceed the limit concentration of standards during a certain number of hours or days. (**Table 2**). In Table 2., only some values can be seen, while the values for other elements can be seen in the references listed at the top of the table. This is the case, for example, for the daily limit value of PM_{10} (LV) (allowed 35 days with concentrations above 50 $\mu g / m^3$ per year), the target value of O_3 for human health protection (25 days in a calendar year may exceed values greater than 120 $\mu g/m^3$ maximum daily 8-hour mean concentrations) and NO_2 LV hourly rates (allowing 18 hours per year with concentrations above 200 $\mu g/m^3$). In order to obtain a statistically better calculation of trends for these standards and taking into account that up to 25% of daily coverage may be missing per year, trends corresponding to percentages were calculated, instead of Kth maximum values. For the PM_{10} daily LV, the 90.4 percentile of daily concentrations was used; for the O_3 TV for the protection of human health, the 93.15 percentile of maximum daily 8-h mean concentrations was used; and for the NO_2 hourly LV, the 99.79 percentile of hourly concentrations was used to calculate the trends (Guerreiro et al. 2014).

3. SENSOR GAS DETECTION METHODS

Gas measuring devices are all those used to measure gas concentrations by detecting a single layer of stress (potential ionization) and this is the main property for almost all gases and different for different types of gases. The sensors register the gas molecules based on the voltage breakdown. The gas concentration can be estimated by estimating the instantaneous discharge in the devices. These types of gas sensors are very often used in industrial production for process control, environmental monitoring, combustion in incinerators, testing drivers for alcohol, detection, and removal of unsafe gases in mines, households, inspection of products such as espresso and flavouring. Temperature and humidity are basic operating parameters of gas sensors. Some sensors have certain disadvantages: they can be bulky and at some point require high voltage operation. Standard gas resistance sensors depend on the different estimated resistance values of the thin film used, in light of the adsorption of gas particles on the nanostructure surface of semiconductor metal oxides. The gas-solid interaction affects the resistance of the thin film due to the thickness of the type of electronics present in the film (Abdullah et al. 2020).

Table 2. Limit and target values of air quality and long-term objectives defined in the directives (EU, 2004; EU, 2008)**, and the WHO Air Quality Guidelines** (WHO, 2000; 2006)

POLLUTANT	AVERAGE PERIOD	LIMIT/ TARGET VALUE	LTO	WHO AQGS
		Value/Max/Va-lue occurances	Value	
Arsenic	Annual	6 ng/m^3		
Cadmium	Annual	5 ng/m^3	5 ng/m^3	
Nickel	Annual	20 ng/m^3		
Lead	Annual	0.5	0.5	
Benzene	Annual	5	1.7	
SO_2	10 min	350 / 24	3	20

*Units in μg/m^3, if not specified.

Chemical sensors are among the modern technologies such as mobile phones and personal computers. The term "sensor" is easy to understand. Humans can visualize sensors such as sensitive organs or ant tentacles. Chemical sensors belong to a special type of sensor, and as an example, sensors in refrigerators in the form of freshness sensors that detect spoiled food can be mentioned. At the time sensors began to be used, the word sensor was not used very much. Sensors are very commonly used devices in everyday activities today. Given that the world is changing rapidly day by day, these devices play an important role in this process. Sensor devices have been developed in such a way that they have the ability to detect substances that are present in our environment, ie they detect compounds and substances that are present and in what quantity. These are the domains of analytical chemistry whose main goal is to solve such problems with the help of precise and fast instruments in well-equipped laboratories. For many years, there has been a trend of increased centralization of analytical laboratories, but only in certain aspects do we now see a reversal of this tendency away from instrumental gigantism. The main goal and desire to create smaller devices instead of larger ones appeared at a time when a personal computer appeared and began to replace large, highly centralized databases. The same kind of reversal happened with the use of chemical sensors (Gründler, 2007).

3.1. Electrochemical (Amperometric) Sensors

Amperometric sensors function in such a way that analyte particles diffuse through the membrane (separating the gaseous environment from the internal electrolyte) and the internal electrolyte (usually aqueous solutions of strong bases or acids or proton solvent mixtures) going to the polarized working electrode surface suitability relative to the reference electrode. The electrode, called the working electrode, undergoes an electrochemical reaction, while the opposite electrode experiences a reaction that ensures the balance of the electron. The result of the redox reaction is the creation of an electric current that creates a signal on the sensor. Said signal is equal to the concentration of analyte present in the immediate vicinity of the sensor (gas environment). **Figure 1** shows an embodiment of an electrochemical sensor having three electrodes with a working (measuring) electrode, a counter electrode and a reference electrode having a constant potential relative to the working electrode (Szulczyński & Gębicki, 2017).

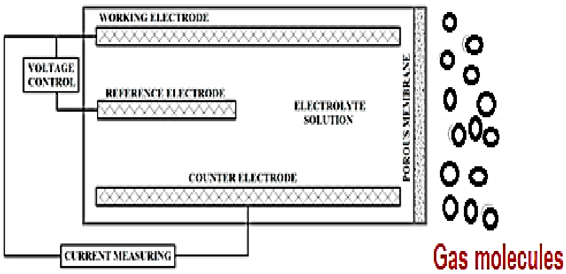

Figure 1. Electrochemical sensor in a three-electrode version (Szulczyński & Gębicki, 2017)

Table 3. present commercially available electrochemical (Amperometric) sensors by Environmental Sensors Co. Intended for measurement toxic compounds in air.

Table 3. Electrochemical sensors by Environmental Sensors Co. For measurement toxic compounds in air (Szulczyński & Gębicki, 2017).

POLLUTANTS	RANGE (ppm)	RESOLUTION (ppm)	RESPONSE TIME (s)
Ammonia	0-50	0.5	150
Carbon oxide	0-100	0.5	35
Chlorine	0-20	0.1	60
Nitric oxide	0-1000	0.5	10
Nitrogen dioxide	0-20	0.1	35
Sulfur dioxide	0-20	0.1	15

3.2. Optical particle sensor

Optical particle sensor (OPS), which serves to scatter light from the particle, and a very large application and are often used in clean rooms and in the monitoring of the atmospheric environment. The process of optical counting is one of the main technologies used in monitoring the state of the environment and controlling many materials present in the environment in the form of the particles. (**Figure 2.).** Because these sensors have on-site measurement capabilities, the optical particle sensor (OPS) is widley used to analyse contamination of, for example, water, clean rooms, and hydraulic fluids, and for atmospheric analyzes of fluid, and for atmospheric analyzes of fluid or airborne particles. There are several types of optical methods for detecting particles, such as measuring the relaxation time of a particle using optical aerodynamics, measuring the scattering intensity of particles, imaging particle size (including holography), and measuring the Doppler phase. In the above methods, the measurement of light scattering intensity has the lowest cost, is very easy to handle and has the advantage of in-situ measurement without physical contact with particles. The study of composite characteristic of particles, flame-formed particles, particle liquids and microbes were performed. The performance of OPS depends on various factors despite its simplicity. The minimum particle size that can be detected and the ability to count particles are strongly influenced by the laser source, photo detector, nozzle shape and particle size. In addition, to the proper selection of the laser source and photo detector, the nozzle is one of the critical factors affecting particle beam size and flow rate in the detection area, and to reciprocate the shape can affect particle counting efficiency (Kim et al. 2009).

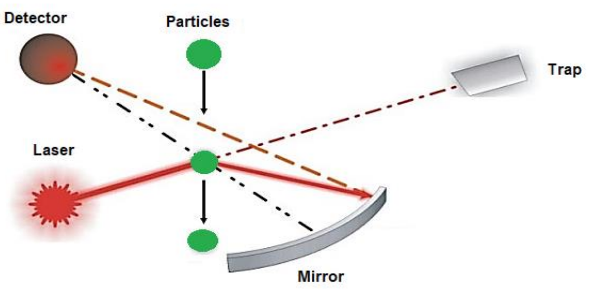

Figure 2. Optical particle counter mode (Szulczyński & Gębicki, 2017)

The vast majority of cheap PM sensors work by measuring particles by scattering light. The particle we want to detect intercept a beam of light (usually from a laser or LED whose wavelengths are between 405 and 780 nm), and the light that is scattered is measured and correlated with the mass concentration of the PM. Such instruments are commonly referred to as optical particle sensors (OPS). OPS can be divided into two main types: nephelometers and optical particle counters (OPCs). Nephelometers measure particle as a set, collecting light scattered by all particles at a wide range of angles, usually 7-173^{o} to avoid clear scattering back and forth. The scattering amplitude is then correlated with the mass measurement performed by the reference instrument. Nephelometers that measure scattered light at one angle are sometimes called photometers. OPCs, unlike photometers, detect particles separately and provide information on their number and size. The light scattered by each individual particle is measured and each pulse is assigned to a container size based on its total light intensity, resulting in a histogram that is converted to a mass load after the entire distribution is measured. These technologies have been around for many years but have only recently become available during to a much lower fact due to the availability of small, inexpensive light sources and electronic components. In situations where light scattering is used, it introduces a number of fundamental limitations for measuring PM mass. Most of these limitations arise from the environmental conditions and/or properties of the aerosol being meaured, and these limitations can be problematic when calibration is performed using only one type or state of aerosol. The vast majority of studies for OPC that have been conducted recently have explored some of these limitations. Some of these problems include (1) inability to adapt to changes in particle size distribution, (2) hygroscopic particle growth due to changes in relative humidity, (3) changes in spray efficiency due to differences in aerosol optical properties, and (4) the need for correction factors specific to for aerosol to take into account differences in density. Although it has been investigated how these individual effects in isolation may affect the accuracy of PM, to some knowledge there has been no systematic, comprehensive investigation of all of these factors together. The matter is complicated by the fact that all these individual properties are intertwined–for example, when relative humidity increases, it can cause particles to take on water, which can change not only their size and mass, but also their shape, refractive index, and density (Hagan & Kroll, 2020). **Table 4** shows the specifications of some optical particle counters.

Table 4. Specification of optical particle counters (Hagan & Kroll, 2020)

PRODUCER	TYPE	MODEL	λ (nm)	VIEWING ANGLE (Ø1, Ø2)	NO. OF SIZE BINS
Alphasense, Ltd.	OPC	OPC-N2	658	(32.0∘, 88.0∘)	16 (0.38–17.5 μm)
Alphasense, Ltd.	OPC	OPC-N3	658	(32.0∘, 88.0∘)	24 (0.35–40.0 μm)
Particle Plus	OPC		785	(58.0∘, 118.0∘)	6 (0.3–10.0 μm)
NOAA/Handix	OPC	POPS	405	(38.0∘, 142.0∘)	16 (0.132–3.65 μm)
Plantower	Nephelometer	PMS5003	~ 650	?1	6 (0.3–10+ μm)2
Sharp	Nephelometer (photometer)	GP2Y1010AUOF	870-980	?1	1 (?)3
Shinyei	Nephelometer (photometer)	PPD42NS	870-980	?1	1 (> 1 μm)
Samyoung	Nephelometer (photometer)	DSM501A	870-980	?1	1 (> 1 μm)

3.3. Gas measuring sensors based on the Arduino system

This section shows the development of a measurement system for gas detection using development boards called Arduino, which is based on a microcontroller. This board is usually called an Arduino microcontroller (Gonzalez et al. 2018). The Arduino is an open-source microcontroller that can be easily programmed. Deleted and reprogrammed at any time. The Arduino platform is designed to provide hobbyists, students, and professionals with a cheap and easy way to create devices that interact with the environment using sensors and activators. Arduino is an electronic prototype platform designed to create electronic projects. It consists of a hardware part that is actually a physical electronic programmable circuit (known as a microcontroller) and a software part called an IDE (Integrated Development Environment) that you run on your computer and program and control the board from it. The tile itself was created in Italy in 2005 and was created by a group of students. It gained its popularity primarily because of its simplicity. The board programming itself does not require an additional piece of hardware (called a programmer) as for other microcontroller systems, but a USB cable that can be connected to any computer, regardless of the operating system, is sufficient. You can program the Arduino from Windows, Mac, Linux, Android. The Arduino platform is a set of electronic and software components that can be easily connected into more complex units with the aim of creating fun and educational electronic circuits. The heart of the Arduino is microcontrollers. A microcontroller is a small computer contained on a single integrated circuit. The Arduino environment most commonly uses 8-bit microcontrollers manufactured by ATMEL. The most common model is the ATMEGA328P used on the basic Arduino prototype board. As Arduino is an open-source platform - it is allowed to share and rearrange it in order to create new platforms that are compatible with each other, so with the development of many more versions of development environments based on the Arduino platform. Basically, all Arduino compatible boards consist of a microcontroller, an integrated circuit for communication with a computer, and peripheral electronic parts to ensure the operation of the microcontroller - voltage stabilizers, a quartz oscillator to generate the clock frequency and the like. To begin with, a microcontroller can be thought of as a black box that has a number of outputs that can be controlled by a program written by a user on a computer and then run on the microcontroller itself. The Arduino programming environment is used to write programs for Arduino microcontrollers. In order to be able to transfer written programs to the microcontroller on the development board, we use a USB connection to a computer. If we use an Arduino standard board that is not a new compatible platform, no additional driver installation is required. Also, tile programming is done in a customized version of the C++ programming language. The programming language itself has been simplified to the point that you can learn the basics of handling and programming a tile in just a few hours. Given that there are a large number of different Arduino tiles available on the market, a number of surveys need to be conducted to select specific development boards with regard to their specifications and capabilities, which can be used to carry out a project in accordance with these applications (Louis, 2018). Furthermore, in the continuation of this paper, some of the sensors for measuring gas concentration, which are based on the Arduino system, will be briefly described and their specifications will be presented.

3.3.1. CJMCU-811 (CCS 811) gas sensor

This type of Arduino sensor is intended for measuring gas concentrations, and in particular for measuring CO_2 and Volatile Organic Compounds (VOC), and which can detect VOC based on seven types of chemical character according to documents from the manufacturer's website; alcohols, aldehydes, ketones, organic acids, amines, and alpha and aromatic hydrocarbons. The manufacturer further does not specify the types of VOCs detected. It is assumed that the sensor ideally measures Total Volatile Organic Compounds (TVOC), which will be the source of the unknown error. In addition to TVOC, the sensor can also detect hydrogen and measure humidity and temperature levels. One of the sensor outputs is eCO_2 or CO_2 equivalent, which is calculated using an algorithm, making the sensor a virtual CO_2 sensor. The concentration range for CO_2 measurement is from 400 ppm to 29206 ppm. The algorithm for converting TVOC to e-CO_2 and accuracy sensors are not listed in the manufacturer's website, nor can they be obtained directly from the manufacturer or service provider for reason of confidentiality (Högdahl, 2018). **Table 5**. shows the specifications of the CJMCU-811 gas sensor.

Table 5. Specification of CJMCU-811 gas sensor (AMS, 2017)

SPECIFICATION	DESCRIPTION
TVOC sensing from	0-32768 ppm
eCO2 sensing from	400-29206 ppm
Module size	15mm * 21 mm
Working voltage	1.8-3.3V DC

CCS811 (**Figure 3**) is an ultra-low power digital gas sensor that integrated a metal oxide gas (MOX) sensor to detect and read a wide range of volatile organic compounds (VOCs) for indoor air quality monitoring with a single microcontroller (MCU) that includes an analog-to-digital converter (ADC) and Inter-Integrated Circuit (I^2C) interface. This sensor is based on the unique ams microplate heating technology that provides a very reliable solution for gas sensors, a very fast cycle time and a significant reduction in energy consumption. The MCU integrated in the sensor controls the operating modes and measurements of the sensor driver. The I^2C digital interface greatly simplifies hardware and software design, allowing for faster runtime. The I^2C signal output represents communication with the main system. I^2C is a serial communication protocol that requires only two signal lines. The communication between the chips on the printed circuit board (PCB) has changed. The I^2C protocol uses only two bidirectional signal lines to communicate with devices. The two signals used are: serial data line (SDL) and serial date clock (SDC). It also supports an intelligent algorithm for raw sensor processing measurements to output equivalent values of total VOC (eTVOC) and CO_2 equivalent (eCO_2) where the main cause is VOC from humans. It also supports multiple metering modes that are optimized for low power consumption during active sensor metering, and sleep mode produces battery life in portable applications. This sensor is available in an LGA package with 10 lead 2.7 mm x 4.00 mm x 1.1 mm conductors, 0.6 mm pitch. The CJMCU-811 has a very wide application that includes measuring indoor air quality: smartphones, air purifiers and purifiers, smart thermostats, home controllers, smart accessories, and Internet of Things (IoT) devices (AMS, 2017).

3.3.2. MQ-135 gas sensor

The MQ-135 sensor from the MQ sensor group is a stable, inexpensive electrochemical gas sensor that has the ability to detect multiple types of gases. It is sensitive to ammonia, sulphide and benzene, it is also sensitive to smoke and other harmful gases (Kalra et al. 2016). The MQ-135 sensor is actually sensitive to various air pollutants and changes in the ratio of carbon dioxide (CO_2) to other gases in the air (Daugela et al. 2021). The MQ series of gas sensors uses a small heater inside with an electro-chemical sensor and is typically used indoors at room temperature. Their calibration preferably requires a known concentration of the measured gas. The absence of electronic components allows the use of both AC and DC voltage. A major drawback of this sensor is that it detects a number of gases such as ammonia, CO_2, SO_2, etc., but is unable to identify the individual gas concentration in the environment. The sensor also uses a built.in heater to heat the air near the sensitive part for oxidation or reduction. It is advisable source as it will drain your battery quickly. It takes the sensor for 24-48 hours to warm up to start emitting stable gas concentration readings (Kalra et al. 2016). **Figure 4** displays the MQ-135 gas sensor.

Figure 3. CJMCU-811 gas sensor (AMS, 2017)

Figure 4. MQ-135 sensor specification (left) and MQ-135 sensor (right) (Arduino, 2021)

3.3.3. MG-811 gas sensor

The MG-811 (**Figure 5**) is a very powerful sensor for measuring accurate concentrations of CO_2 (carbon dioxide) in the air. One of the first CO_2 sensors to be compatibile with the Arduino system. The output voltage of the module decreases as the CO_2 concentration gradually increases. The sensor has a built-in potentiometer that is designed to set a voltage threshold. As long as the CO_2 concentration is high enough (voltage is below the thres-hold), the digital signal (ON/OFF) will be readable. This MG-811 sensor module is very sensitive to CO_2 and less sensitive to alcohol and CO, depending on whether low or high humidity and temperature are present during the measurement. The built-in heating circuit delivers the best temperature for sensor operation. Internal power incre-ase to 6V for best heating sensor performance. Also, this sensor has a built-in conditioning circuit that serves to amplify the output signal. To make it easier to use this CO_2 sensor, the Gravity Interface has been customized to enable plug & play. The Arduino IO expansion shield best fits this CO_2 sensor that connects to your Arduino microcontroller. This is an electrochemical CO_2 sensor based on Arduino, suitable for qualitative analysis: air quality, in the regulation of fermentation processes and in the detection of CO_2 indoors. (Arduino, 2021).

Figure 5. MG-811 gas sensor (Arduino, 2021)

Table 6 shows basic data on the type of commercially available sensors for measuring toxic gases and flammable gases from the VOC groups and their meteorological parameters. The listed parameters include (unless information is not available); measurement range, measurement accuracy, resolution, response time. Other sensors that are not listed in this table as well as other sensor parameters are listed in the reference found in the title of this table.

Table 6. Commercial chemical sensors available for measuring volatile organic compounds (Szulczyński & Gębicki, 2017)

MANUFACTURER	SENSOR TYPE	RANGE	ACCURACY	RESOLUTION	RESPONSE TIME
Aeroqual	MOS	0-500 ppm	<±5 ppm+10%	1 ppm	30 s
AMS	MOS	10-5000 ppm	nd	nd	< 10s
Alphanese	PID	1 ppb – 50 ppm	nd	<50 ppb	< 3s
Winsen	EC	0-1 mg/dm^3	nd	nd	< 20s
Wuhan Cubic	NDIR	0-100%	±1% full scale	0.1%	< 25s
MICROcel	Pellistor	0-100% LEL	nd	nd	< 5s
SixthSense	Pellistor	0-100% LEL	±10% LEL	nd	< 10s

4. REFERENCE METHODS FOR THE DETERMINATION OF GASES

Recently, there has been great concern about the presence and level of concentration of harmful gases in the Earth's atmosphere due to the combustion of industrial energy. Combustion occurs when fossil fuels, such as natural gas, fuel oil, coal, or gasoline, react with oxygen in the air and generate heat. The heat of combustion of fossil fuels is used for industrial equipment such as boilers, furnaces, and engines. Fossil fuels are hydrocarbons, which means that they consist primarily of carbon and hydrogen. When fossil fuels are burned, carbon dioxide (CO_2) and water (H_2O) are the main chemical products formed from the reactants of carbon and hydrogen in the fuel and oxygen in the air and carbon in the fuel to generate carbon dioxide and generate heat is a complex process, requiring true mixing turbulence, sufficient activation temperature, and sufficient time for the reactants to come into contact and combine. If combustion is not properly controlled, high concentrations of undesirable products can occur (Rahman et al. 2018). Many gases are extremely difficult to detect because most of them are odorless. Some specific gases are extremely dangerous and harmful to humans if inhaled in too high concentrations. Thanks to the effort, researchers have developed many powerful techniques for analysing the different types of gases present in the environment and those that are formed and released from industrial processes. In earlier times when mining was carried out, the presence of harmful gases such as carbon monoxide, methane and carbon dioxide had to be determined before excavation began. Scientists followed the earliest methods of detecting harmful gases that involved the use of birds such as canaries. The birds were brought into the mines because of their sensitivity to poisonous gases. Birds would stop singing in the event of the appearance of such gases. In that way, it was a signal to the miners for evacuation. Today, there are various effective optical, laser, and spectroscopic methods used to analyse gases. Mass spectrometry (MS), Fourier infrared technology (FTIR) and gas chromatography (GC) are the three most common methods for evolving gas (EGA) analysis. Recently, the thermal analysis technique for EGA has been combined with thermogravimetry (TG). For example, TG-MS or TG-FTIR are used for the analysis of allowable gases. The distribution of the emitted gas depends on its flow profile, volume ratio and diffusion coefficients of its molecules (Bose, 2021). Various techniques are used to detect gases, but only some will be briefly described below. Two more methods that are very often used when measuring air quality are the X-ray method and PIXE (Particle Induced X-Ray Emission).

4.1. Gas Chromatography

Gas Chromatography was mentioned back in 1906 and was first used by the Russian botanist Michael Twsett. This method (GC) is widley used in propulsion research. This type of chromatography is used in analytical chemistry, especially to separate and characterize compounds that can evaporate without decomposition. This method determines the purity of the substance and separates the components from the mixture. This method is a fast, accurate and efficient method of analysis of gaseous combustion products. The most common detectors found in simple gas chromatography are the following: a) thermal conductivity detectors, b) gas-density detectors, c) ionization detectors and d) infrared detectors. The mixtures of gases used in this technique are helium (very high thermal conductivity) and argon (very low thermal conductivity). Flame ionization detectors are especially used for the determination of organic compounds, but they do not determine the presence of water vapour (Bose, 2021).

4.2. Mass Spectrometry (MS)

Pyrolysis mass spectrometry (PYMS) is a method used in EGA. This method is very similar to thermal gravimetric analysis, however, PYMS does not use a column compared to other standard techniques. The samples are gradually heated at a lower temperature to a higher temperature (50-800 ^{o}C) followed by the release of gases or vapours by desorption or decomposition. These gases have unique thermal effects and are subjected to mass losses. This method is very widley used to identify different polymers. When analysing trace gases, this involves the detection of gaseous compounds present in the environment, mostly organic, in very low concentrations (parts per million (ppm) or billion (ppb). The MS method is very often used to detect trace gases because it has high sensitivity and selectivity. The efficiency of the MS method is improved by the incorporation of special input techniques or the ionization process. For example, high-pressure ionization of a sample followed by negative ion detection could lead to an increase in the detection range for parts per trillion (mol) of sulphur hexafluoride (a highly electronegative compound) (Bose, 2021).

4.3. Laser Absorption Spectroscopy

Laser absorption spectroscopy uses an adjustable infrared laser. An adaptive laser is a type of laser (semiconductor) that can be adapted to optically select a specific wavelength of light (Lenior, 2009). The principle of operation of this method is based on the developed various methods for gas analysis. In this method, different gas molecules absorb a certain light spectrum, and the amount of energy that the gas absorbs indicates a characteristic absorption spectrum. On the absorption spectra it is possible to determine unknown gases with very high accuracy. Laser absorption spectroscopy is applied in an adjustable laser spectrometer (TDLS), which is used to measure very low concentrations of gases, such as methane, ammonia, carbon dioxide and water vapor. Said instrument uses a photodiode to measure the signal intensity of the emission wavelength. The known wavelength is compared to the wavelength of the target gas molecule and thus the concentration of the gas to be determined is quantified. In order to obtain a correct and accurate result, it is important to select the appropriate absorption line for the compound under study. Such a measure makes this technique extremely sensitive, accurate and specific. The technique is used in burn diagnostics (Bose, 2021).

4.4. Infrared (IR) Spectroscopy

The Fourier-transform infrared spectroscopy method, a method based on IR spectroscopy, is used to determine the composition of gases. The detection method involves introducing combinations of different light frequencies (IR wavelengths) into the gas molecules, and a detector inside the instrument measures the amount of light that the gas can absorb. The obtained data are processed using a computer, and the obtained result is subsequently converted using Fourier transform algorithms. With the help of IR radiation, it is possible to detect more than 20 different gases at the same time. This method is effective in measuring and detecting gases such as carbon dioxide and unknown organic compounds. This method is also used in the development of an ammonia detection sensor, which is a very sensitive device used to analyse atmospheric ammonia levels. Furthermore, accurate measurements of cyclic nucleotide-mediated photosynthetic responses to plant hormone can be performed (Bose, 2021).

4.5. Off-Gas Analysis

Gases generated during biological processes can be estimated, and this can be done using tandem gas analysis. This technique is used in the analysis of culture that is in a stable state. This method allows the analysis of the amount of oxygen used and the carbon dioxide released by the action of the microbial culture (Bose, 2021).

4.6. X-ray methods

X-ray methods include a group of spectroscopic methods that have different applications. These methods are similar to optical methods based on emission, diffraction, absorption, and X-ray diffraction. Similar to optical spectroscopy, X-ray methods are better when applied to pure compounds and can also be used on mixtures when there are unique characteristics for the components of the mixture such as the wavelength of X-ray fluorescence for elements with atomic numbers greater than 8 (oxygen). In addition to X-ray diffraction and X-ray fluorescence (XRF), other methods are often used. These methods also include electronic spectroscopy (X-ray photoelectron spectroscopy, electron impact spectroscopy, Auger spectroscopy). Chromatographic separation methods are very rarely associated with X-ray based methods (Moldoveanu & David, 2017). One of the most common X-ray based methods used in the Republic of Croatia to determine air quality is the X-ray fluorescence method (XRF) (Čargonja et al. 2019).

4.7. PIXE method

The PIXE method is included in the category of ion beam analysis (IBA) methods and this method is the most widespread among other methods. This method is used for elemental analysis of a sample used as a target for bombardment with a beam of accelerated particles; the interaction of the beam particles with the target atoms leads to the emission of X-rays that have a characteristic energy whose detection can be used to determine the target composition. In this method, protons are universally chosen to induce X-ray emission. This method enables the simultaneous detection with high sensitivity of the entire range of elements present in the sample being analyzed. This method also has some limitations that partially limit the number of detectable elements, but the multi-element capability is actually retained to a large extent. In a single measurement that usually takes a few minutes, all elements with Z>10 are detected with minimum detection limits (MDL) down to trace levels. The X-rays emitted by the lower Z elements are of such low energy that they are absorbed in the entrance window of the detector (Lucarelli, 2020).

5. CONCLUSION

Nowadays, air pollution is a great danger that leads to serious problems for human health, but also for ecosystems. In many parts of Europe, emissions and concentrations have risen dramatically. In some European countries, air quality remains very poor, despite reduced emissions and concentrations in the environment. Currently, the most important environmental risk to human health is air pollution, and Europeans consider it the second biggest environmental problem, right after climate change. Major problems related to air quality affect human health, and especially respiratory diseases. For these reasons, great efforts are needed to reduce pollution concentrations in all parts of Europe. Today, various chemical methods have been developed, but also different types of sensors that can detect air quality. This paper presents some types of commercial sensors that are used to detect air quality, but also those that are more economically viable, and which are based on the Arduino system. Sensors based on the Arduino system in some aspects have proven to be very good at measuring air quality. In order to make the measurements of these sensors as high quality as possible, it is necessary to perform calibration procedures for individual sensors. Also in this paper, chemical methods are presented by which it is possible to detect individual components in the air.

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