3rd PEROSH Research Conference in Copenhagen

Innovative Solutions in Occupational Safety and Health, 10-11 September 2019

The National Research Centre for the Working Environment (NFA), **Copenhagen, Denmark**

Ionizing detector to study the emission of nanoparticles at workplaces

Przemysław Oberbek, Szymon Jakubiak

CIOP PIB

Central Institute for Labour Protection – National Research Institute

LEGAL STATUS OF THE INSTITUTE

- The Central Institute for Labour Protection was established by the act of law of 4 April, 1950
- Since 1973 the Institute has operated under the Minister of Labour and Social Policy
- In 2002 the Institute was granted the status of a National Research Institute (Resolution of the Council of Ministers of 5 November, 2002)

OUR MISSION:

- to conduct scientific research aimed at new technological and organizational solutions which are useful in the design of working conditions that conform to OSH and ergonomics requirements
- to determine scientific foundations for the development of socio-economic policies of Poland in the field of OSH.

Headquarters in Warsaw

Tech-Safe-Bio laboratories

PPE Department in Łódź

CIOP-PIB has been awarded a prestigious "A" category from the Polish Ministry of Science and Higher Education

http://www.ciop.pl

CIOP PIB

Central Institute for Labour Protection – National Research Institute

7 RESEARCH DIVISIONS

Vibroacoustic Hazards

Safety Engineering

Chemical, Biological and Aerosol Hazards

Ergonomics

Bioelectromagnetic Hazards

Personal Protective Equipment

OSH Management

http://www.ciop.pl

CIOP PIB

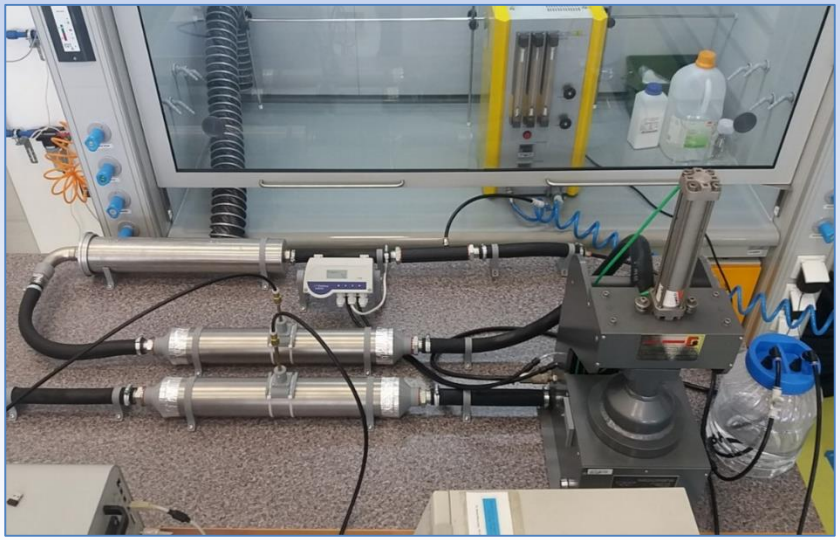
Aerosols, Filtration and Ventilation Laboratory

- Developing and testing of new devices and methods
- measurement of exposure to nanoobjects, their aggregates and agglomerates, e.g. **NECID project** (https://necid.ifa.dguv.de) perosh
- training, expertise, standardization work
- dustiness measurements, evaluation of the emission from consumer products
- determination of the inhalable and respirable fraction of the aerosol
- air conditioners and filters testing
- thermoanemometers calibration
- evaluation of the air quality and risk assessment at workstations

CIOP PIB

Nanoparticles filtration

Test stand to measure the efficiency of flat filter media against spherical DEHS nanoparticles in the size range from 20 nm to 500 nm according to **ISO 21083-1:2018** standard and silver nanoparticles in the size range from 3 nm to 30 nm according to **ISO 21083-2:2019** standard.



CIOP PIB

Nanomaterials

EU definition: nanoparticles (NPs) have at least one dimension under 100 nm. **Nanoobjects, and their aggregates and/or agglomerates** greater than 100 nm can exhibit properties that differ from those of non-nanoscale (bulk) material.

The matter in the nanometric scale obtains new properties compared to the micrometer scale:

- chemical
- biological
- mechanical
- physical
- ... and toxicological properties

Nanoparticles, by their size, behave in the air like gases, move easily, rise with warm air but also fall very slowly (in non-ventilated areas it can take days).

CIOP PIB

Exposure in the work environment

Source of NOAA:

- **Processes of nanotechnology** (nanotechnology production rooms).
- Technological processes (typical production rooms): grinding, crushing, screening, transport, mixing, blending, sharpening, grinding and polishing – mostly sources of ultrafine particles.
- Personnel operating machinery and equipment (clean rooms).
- Air supplied from the outside through the ventilation systems, doors, windows, leakage or due to infiltration (office premises, clean rooms).
- Other, like; thermal processes, soot or fumes, natural nanoobjects etc.




CIOP PIB

Ionization sensor - old technology, new applications

Problem: most real-time (or close to real-time) devices for concentration monitoring are expensive, complex and/or stationary.

Need: a small, cheap and mobile device to immediately alert against NOAA high concentrations and to monitor nanoparticles in work environment in real time.

Solution: we have reached for an old, well-known and cheap technology - ionization smoke alarms that have been widely used as fire safety devices since 1950s.

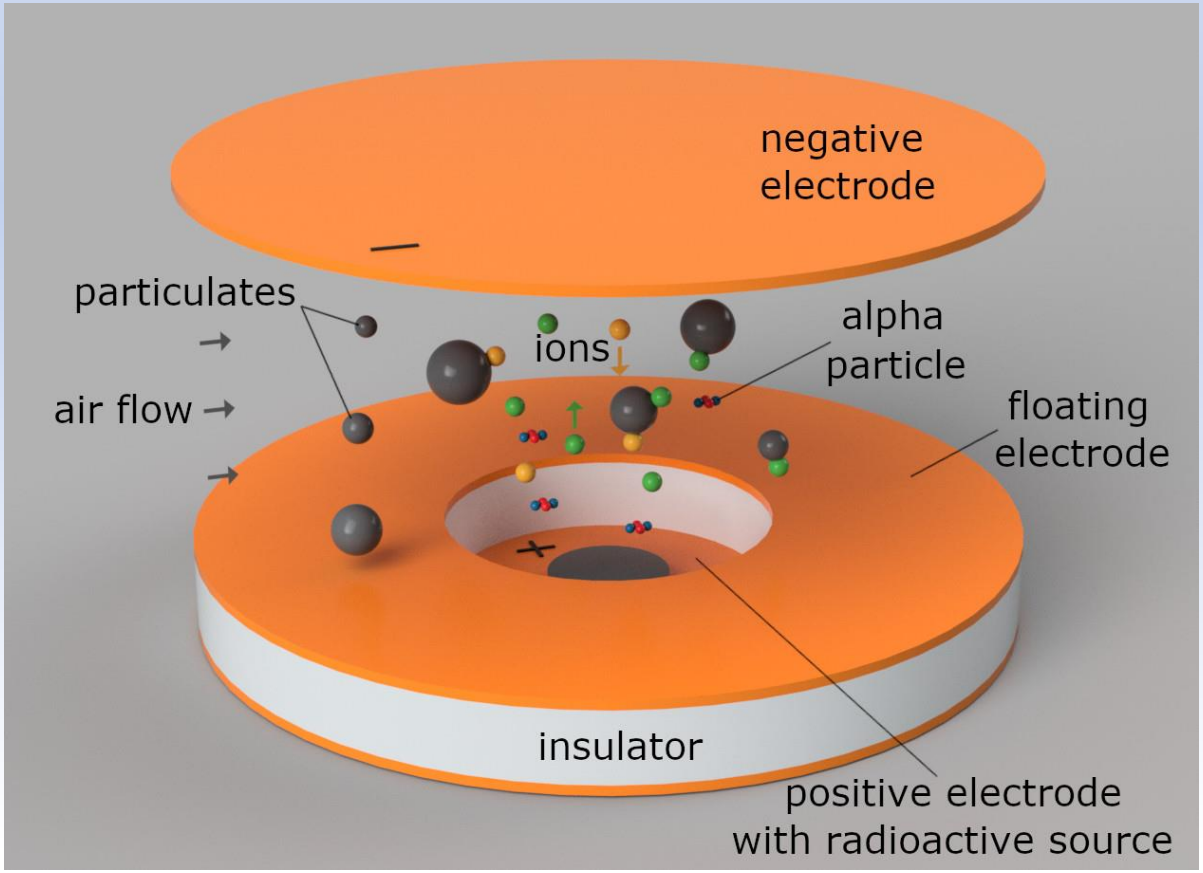
Ionization sensor

- A small amount of **radioactive material** (e.g. americium-241 isotope, ^{241}Am) is placed in the centre of a disk working as a **positive electrode**.
- The **floating electrode** at the upper part of a bottom disk is electrically insulated from other components and connected to an electronic circuit capable of measuring the electrostatic potential.
- The volume beneath the floating electrode is the **reference chamber**. The volume above it, bound with a negative electrode, is the **active chamber**.
- Alpha particles (α, He^{2+}) emitted from the radioactive material ionize the air causing the formation of positive and negative ions.
- If particulates enter the active chamber, some ions attach to their surface causing a change in electrostatic charge. In case of the smoke alarm, this change is compared to a threshold value and is used to trigger the alarm.

CIOP PIB

Ionization sensor

The detector has two ionization chambers, one open to air, and a reference chamber isolated from particles. The electric charge on the ions allows the electric current to flow. Particles brought to the open chamber weaken the voltage and a current difference can be recorded.



Schematic diagram of the ionization sensor

Methods

The modified detector based on an ionization smoke alarm (POLON-ALFA DIO-40) was tested with laboratory generated diesel soot.

The sensor was mounted in a laminar flow cabinet. The air flow was generated using HEPA filtered air from the central compressed air system.

Raw sensor output values were read by the microcontroller with the frequency of 50 Hz and sent to the PC. The measurements were carried out in still air and in an air flow of 0.5 m/s.

CIOP PIB

Methods

The output signal V_{out} was calculated by a microcontroller with a frequency of 1 Hz:

$$V_{out} = \bar{V}_{ref} - \bar{V}_{act}$$

were $\bar{V}_{ref}$ and $\bar{V}_{act}$ are the average values of voltage signals from the reference and active chamber respectively (calculated from 50 measurements).

The output signal was sent to the PC by a serial port and saved to a file by a Python script.

Output signal stability test

Conditions	Reference chamber (V)				Active chamber (V)			
	avg.	st. dev.	min.	max.	avg.	st. dev.	min.	max.
still air	3.400	0.007	3.382	3.407	2.248	0.010	2.224	2.268
laminar flow 0.5 m/s	3.397	0.008	3.382	3.407	2.243	0.006	2.219	2.258

The sensor output signal V_{out} changed only by 0.002 V. For all performed measurements, the standard deviations were below or equal to 0.010 V.

CIOP PIB

Methods

The test aerosol consisting of ultrafine particles (carbon soot) was generated from graphite electrodes using PALAS GFG 1000 spark discharge generator in argon atmosphere (4 LPM, 2 sparks/s) diluted with filtered and dehumidified air.

The spark frequency setting was used to change the aerosol concentration (1 Hz, 5 Hz, 15 Hz, 30 Hz, 60 Hz, 120 Hz).

In this experiment there was no forced air flow through the ionization sensor chamber, therefore its operation was similar to that of a typical smoke detector.

CIOP PIB

Methods

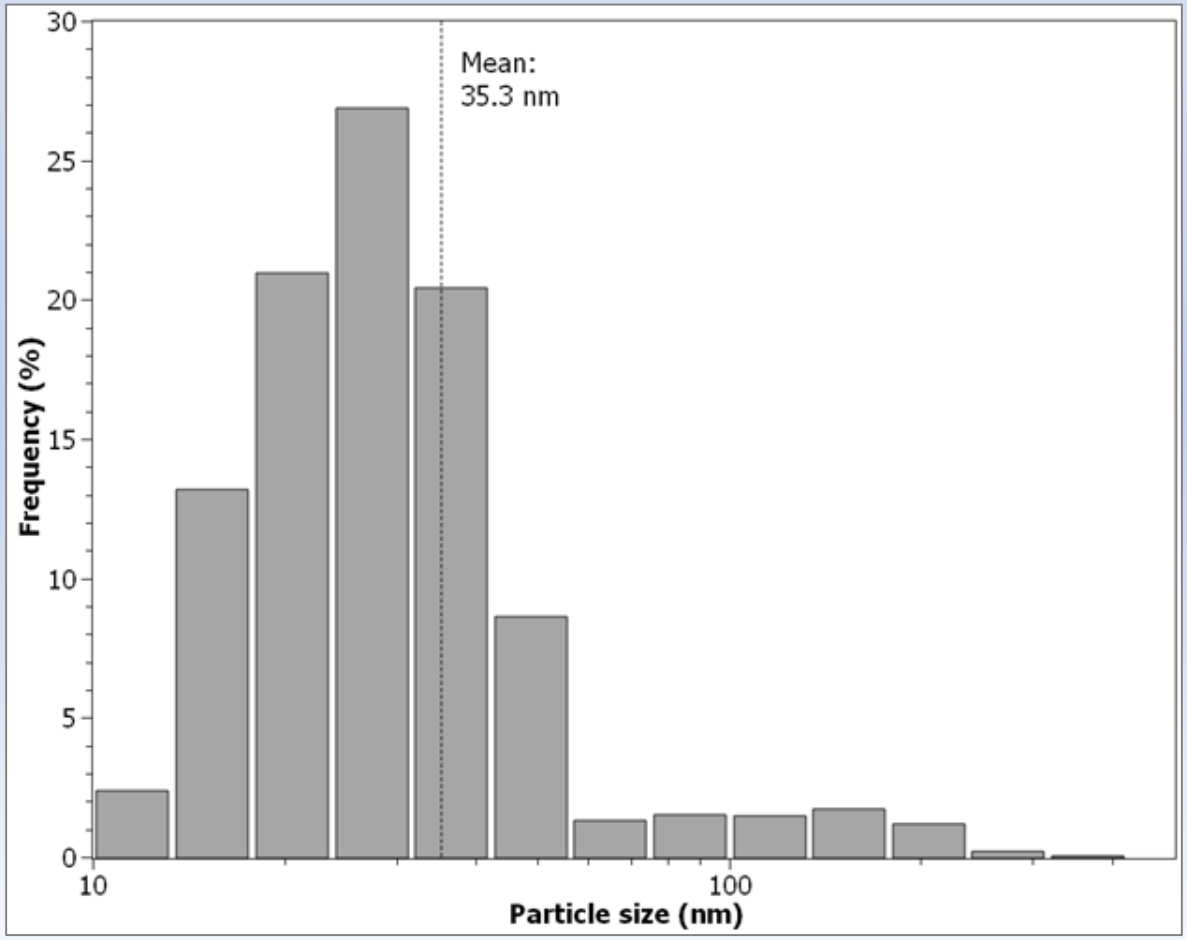
The particle size distribution was determined using the TSI NanoScan SMPS Model 3910 condensation particle counter (with 13 channels in a size range from 10 to 420 nm).

To assess the capability of detecting rapid concentration changes, comparative tests with the TSI AeroTrak 9000 were conducted. It measures the surface area concentration of nanoparticles by detecting a charged aerosol with an electrometer (results output with 1 second resolution).

The influence of air temperature, relative humidity, pressure and linear velocity on the sensor output signal value was analysed.

CIOP PIB

Results



Aerosol particle size distribution (lognormal distribution with a maximum frequency peak of 26.9% for particles of 27.4 nm and mean size of 35.3 nm; SMPS).

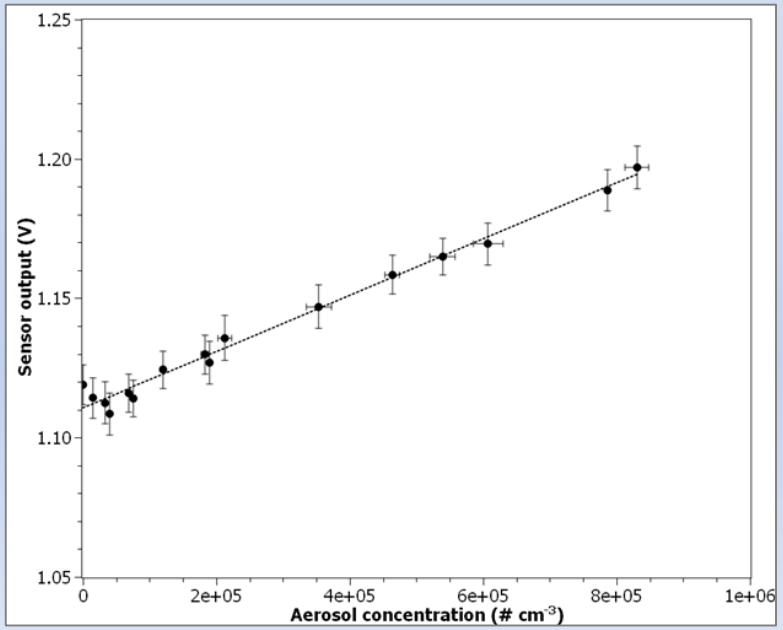
CIOP PIB

Results - response to an aerosol concentration change

The sensor output increases linearly with aerosol concentration increase, which can be explained by the decrease in V_{act} due to the bonding of ions generated in the chamber with the surface of aerosol particles. The above relationship in a measured aerosol concentration up to $8.3 \cdot 10^5$ particles/cm^3 can be approximated by the following equation (coefficient of determination $R^2 = 0.986$):

$$V_{out} = 1.010 \cdot 10^{-7} \cdot c_n + 1.111$$

Where: c_n is number concentration of aerosol particles in particles/cm^3.



The relationship between the ionization sensor output and ultrafine aerosol particles concentration (SMPS).

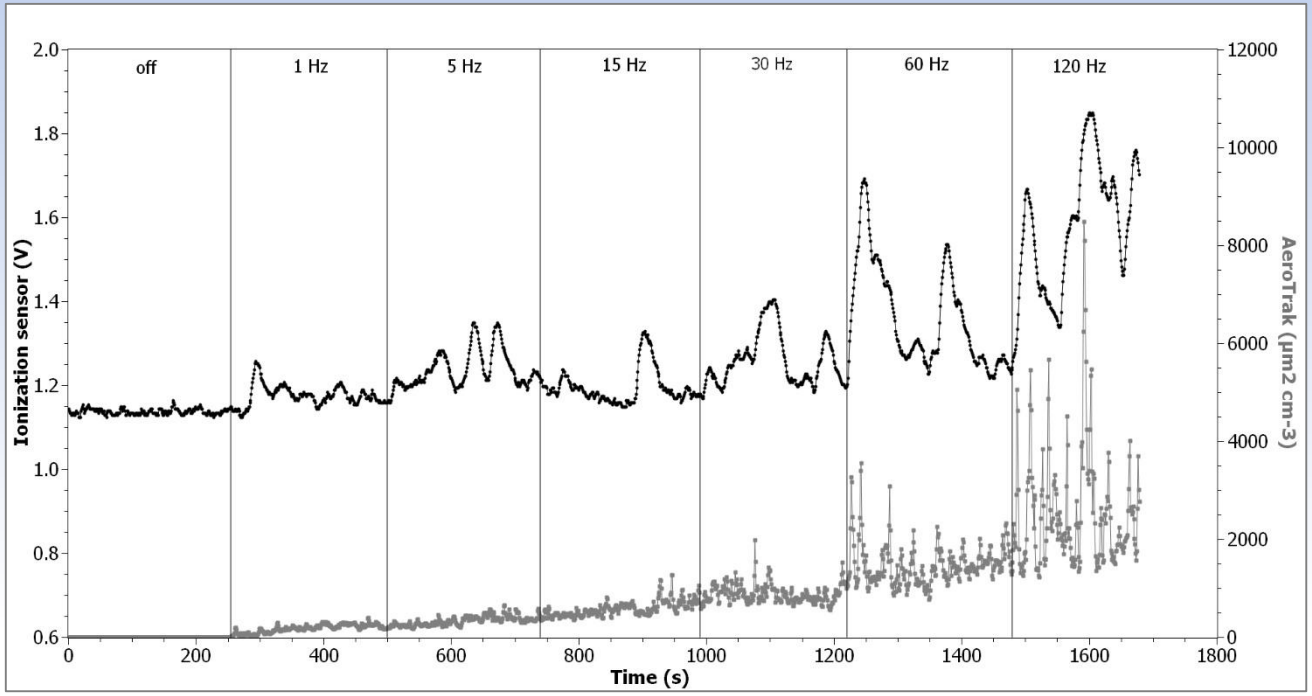
The value of the Pearson correlation coefficient (PCC) calculated for 48 data points (1-minute averages) was equal to 0.990. Air parameters during measurements: temperature: 25.5 ± 0.1°C, relative air humidity: 0%, pressure: 100.70 kPa, velocity: 0.15 ± 0.02 m/s.

CIOP PIB

Results - determination of rapid concentration changes

Peaks in output values can be observed for both sensors (AeroTrak vs. ionization sensor), although they are broader and slightly shifted to the right in case of the ionization sensor due to the lack of forced air flow through the measurement chamber.

There is a strong correlation between the output values of both sensors (PCC 0.77 from 1679 data). The amplitudes of the signal peaks increase with increasing sparking frequency setting of GFG 1000 generator.



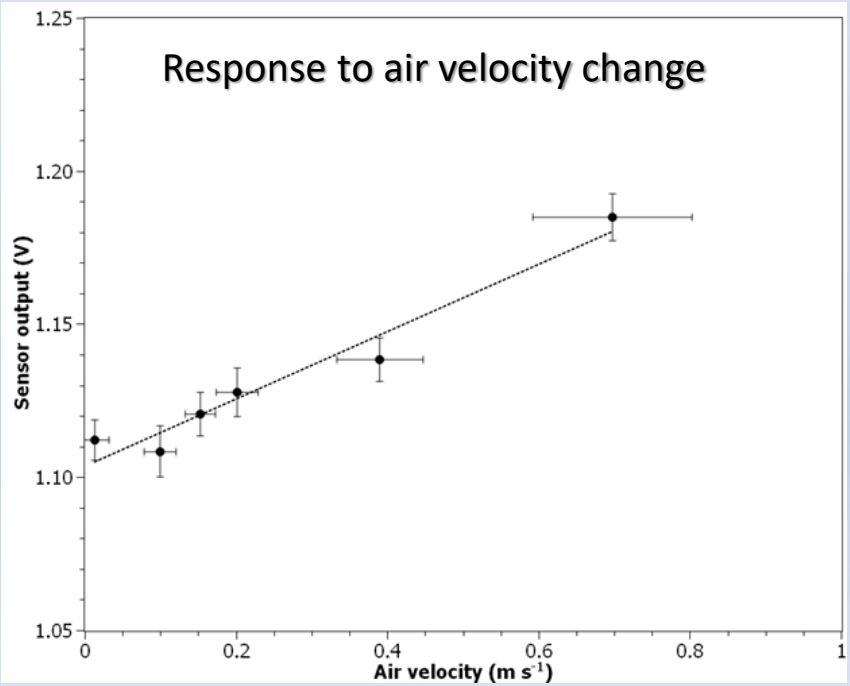
Ionization sensor output compared with the results of the surface area concentration measurements performed using TSI AeroTrak 9000.

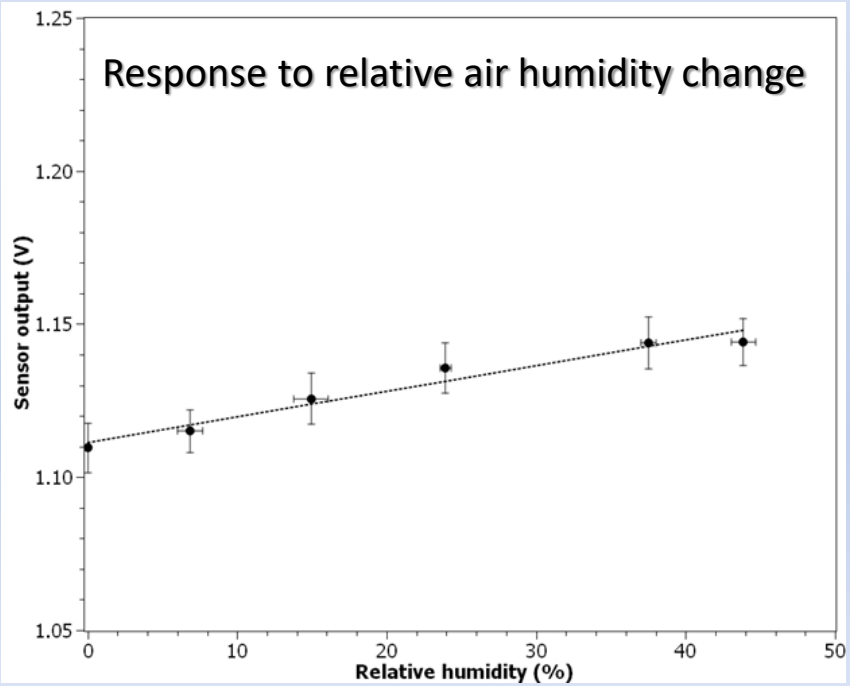
<u>During the experiment:</u>

- temperature 25.2 ± 0.3 °C,
- relative humidity: 49.3 ± 0.8%,
- pressure: 100.73 ± 0.02 kPa.

CIOP PIB

Results - influence of air parameters on sensor output signal value





The sensor output increases with increasing air velocity (U, m/s) (ions leaching causes a decrease in V_{act}) and the relationship in a measured air velocity range can be approximated by a linear regression (R^2 = 0.955, PCC = 0.973; for 18 data points, 1-minute averages):

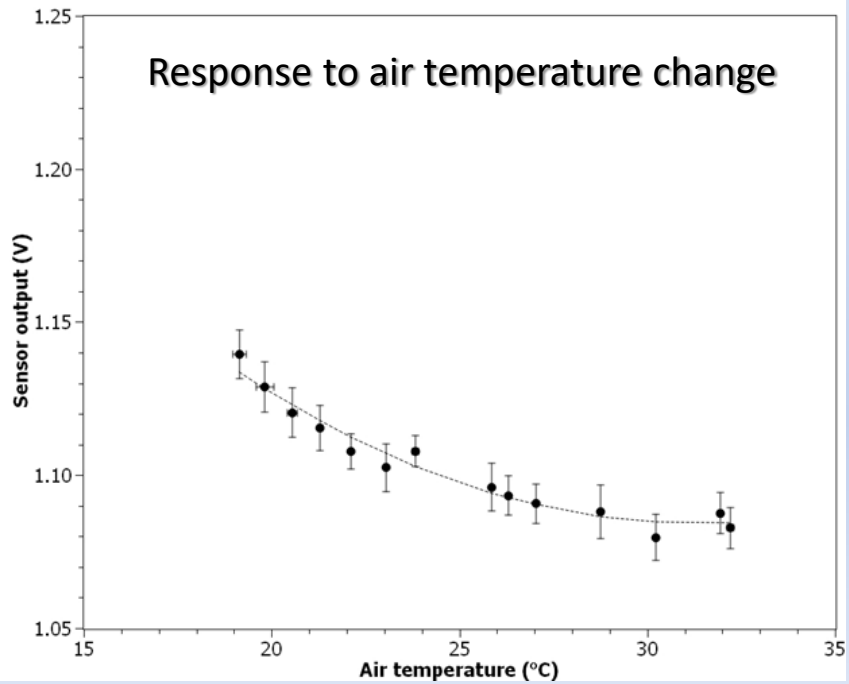
$$\mathbf{V_{out} = 0.110 \cdot U + 1.104}$$

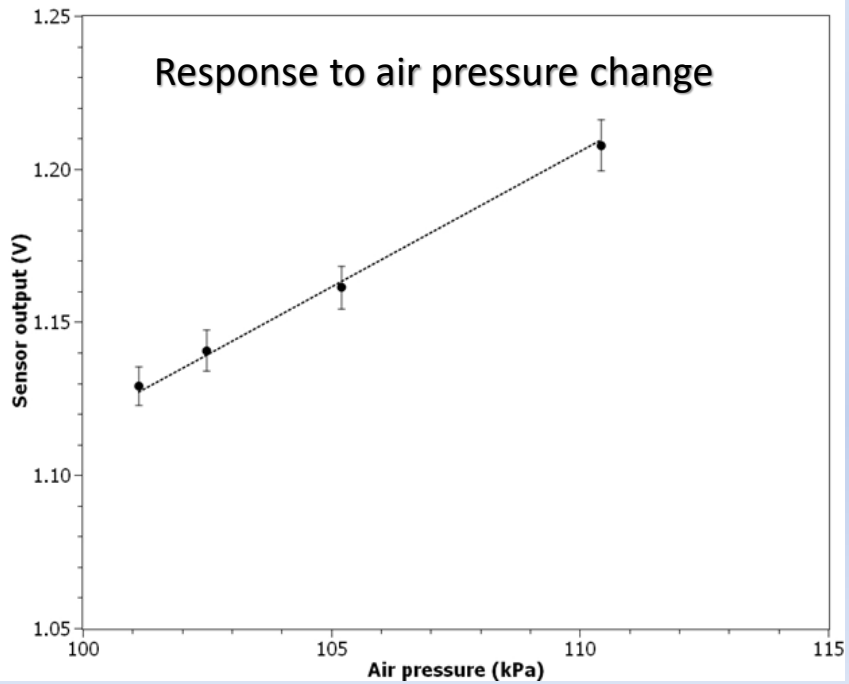
In the measured humidity (H, %) range from 0 to 43.9%, the relationship was linear (R^2 = 0.958, PCC = 0.960; for 21 data points, 1-minute averages):

$$\mathbf{V_{out} = 0.083 \cdot 10^{-2} \cdot H + 1.111}$$

CIOP PIB

Results - influence of air parameters on sensor output signal value





In a measured range from 19.2 to 32.2°C, the sensor output decreases with air temperature (T, °C) increase. The relation can be approximated by a polynomial equation ($\mathbf{R^2 = 0.951}$, **PCC = -0.928**; for 14 data points, 15-seconds averages):

$$\mathbf{V_{out} = 0.334 \cdot 10^{-3} \cdot T^2 - 2.091 \cdot 10^{-2} \cdot T + 1.412}$$

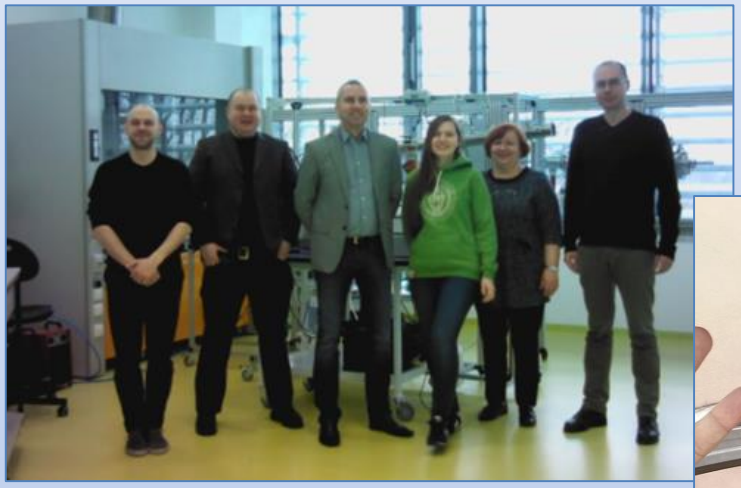
Measured voltage value on the output of the sensor increases linearly as the air pressure increases (P, kPa). The relation can be approximated by a linear regression function ($\mathbf{R^2 = 0.999}$, **PCC = -0.999**; for 7 data points, 1-minute averages):

$$\mathbf{V_{out} = 8.857 \cdot 10^{-3} \cdot P + 0.231}$$

Conclusions

- Well established technology used in smoke detectors with radioactive source was tested in laboratory conditions to verify its applicability to determine the ultrafine aerosol number concentration.
- A safe threshold level of 20 000 particles/cm^3 or 40 000 particles/cm^3 - depending on the material density - can be set. The device can also monitor real-time changes in NOAA concentration (the sensor is capable of detecting rapid changes of aerosol concentration).
- The sensor output changes in a linear manner as the diesel soot concentration changes up to $8.3 \cdot 10^5$ particles/cm^3.
- Empirical equations were determined to describe the influence of air velocity, temperature, relative humidity and pressure on the sensor output.
- The results gathered confirm that the ionization sensor can be used to assess exposure to ultrafine aerosol, although additional engineering work needs to be done to reduce signal noise and the influence of atmospheric conditions.

Thank you for your attention!



Contact:

- Przemyslaw Oberbek, PhD
  ober@ciop.pl
- Szymon Jakubiak, PhD eng.
  szjak@ciop.pl

Acknowledgements: *this presentation has been based on the results of a research task 3.G.03 carried out within the scope of the fourth stage of the National Programme "Improvement of safety and working conditions" partly supported in 2017–2019 — within the scope of state services — by the Ministry of Family, Labour and Social Policy. The Central Institute for Labour Protection – National Research Institute is the Programme's main co-ordinator.*