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White Paper Pegasor AQ Indoor™

What needs to be measured from indoor air?

Today there is no legislation for indoor air ultrafine particle (UFP) concentration.
Particulate matter found indoors will include particles of outdoor origin that migrate indoors and particles that originate from indoor sources. Indoor Particulate Matter (PM) can be generated through cooking, combustion activities (including burning of candles, use of fireplaces, use of unvented space heaters or kerosene heaters, cigarette smoking) and some hobbies. Indoor PM can also be of biological origin.
Indoor PM levels are dependent on several factors including outdoor levels, infiltration, types of ventilation and filtration systems used, indoor sources, and personal activities of occupants. In homes without smoking or other strong particle sources, indoor PM would be expected to be the same as, or lower than, outdoor levels [1].

Optical instruments are often used to measure particle concentrations indoors. Unfortunately, optical devices are not sensitive to ultrafine particles and therefore instruments report mass of particles, which is dominated by particles larger than 300 nm in size. This is the lower detection limit for optical measurement instruments. 300 nm is outside the ultrafine particle size range and ultrafine particles go through the measurement device undetected. Engine emissions are dominated by UFP and these particles migrate easily indoors.

It is well understood that mass of particles does not correlate with the adverse health effects of UFP. For outdoor air particle concentrations there is legislation for mass of particles in the air. Legislation of outdoor air particle concentration measurement is slow to change. Therefore, therefore it can be expected that legislation for indoor air particle concentrations will take time and plenty of research to be realized. Low sensitivity to ultrafine particles is true also for Beta Attenuation monitors (Beta Gauge) and Tapered Element Oscillating Microbalances (TEOM) used to measure outdoor air particle mass concentrations and sometimes also indoor air particle mass concentration for research purposes. Condensation Particle Counter (CPC) in combination with Differential Mobility Particle Sizer (DMPS) can be used to measure ultrafine particle number concentrations indoors. Also Electrical Low pressure Impactor (ELPI) can be used to measure ultrafine particle number concentration, ultrafine particle surface area and Ultrafine particle mass in indoor air. Unfortunately all of these instruments are big, heavy, complex to use and terribly expensive.

Some countries like Canada, Hong Kong, Mainland China, India, Mexico, United States, United Kingdom and even Europe have established Air Quality Indexes (AQI) or similar to better correlate air quality with health effects. AQI can also be applied for indoor air. Lung Deposited Surface Area of Particles (LDSA) is used today to describe adverse health effects of ultrafine particles and this should be the target to measure.

It is known that PM1 (mass of particles below one micron in size), PN (total particle number concentration), PA (total ultrafine particle surface area) or LDSA better correlate with the harmful effects of particle pollution than TSP, PM10 or PM2.5. Most of the particles that contribute to the PN, PA and LDSA come from combustion sources such as vehicle engine, wood combustion,

cooking and remote combustion sources. Ultrafine particles produced in combustion remain airborne for very long time and can travel thousands of kilometers away from the initial source and migrate indoors through ventilation and open windows.

Advanced organizations and universities have started to measure PN, PA and LDSA in indoor air. Pegasor AQ Indoor™ can be used to measure PN, PA and LDSA with one single unit. This paper describes the benefits of Pegasor AQ Indoor™ in indoor air measurement.

Pegasor AQ Indoor™

Operation principle

The operation of Pegasor AQ Indoor™ is based on Faraday Cage filter. Sample of air is pumped inside Pegasor AQ Indoor™. First there is a PM2.5 separator cyclone in the sampling line to prevent large particles from loading and distorting the measurement. After the precut cyclone particles contained in the sample flow are being charged by a corona discharge inside the measurement unit. Trap electrode placed inside the corona discharge chamber removes ions from the sample flow allowing only the charged particles to enter the measurement unit. Trap voltage is modulated to provide particle size information for data calculation. The current collected on the faraday cage filter in combination with modulating trap provides the user with the following concentration information

- ultrafine particle number
- ultrafine particle surface area
- LDSA
- ultrafine particle mass

Additionally inside Pegasor AQ Indoor there are state of art sensors for Temperature and Relative Humidity % (Vaisala HUMICAP® sensor). Sensor for CO_2 (Vaisala CARBOCAP® GM10) is also inside the Pegasor AQ™ Indoor monitor.

Pegasor AQ Indoor™ operation principle is shown in fig. 1, and Pegasor AQ Indoor™ sensor is shown in fig. 2.

In the sensor all flows are continuously monitored and adjusted. Therefore, for example filter loading or altitude of measurement has no effect on the sample flow. Also, all critical insulators are protected with sheath air flows to assure long term independent operation without user attention.

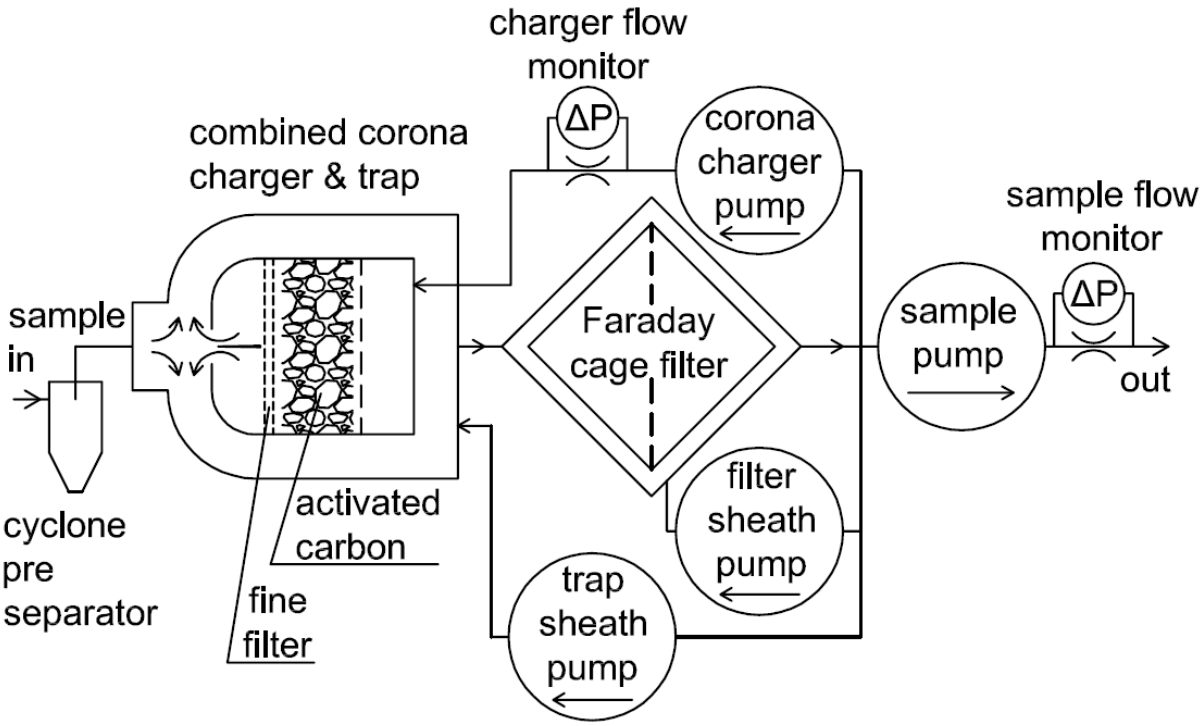

Fig. 1. *Operation principle of Pegasor AQ Indoor™ sensor.*

Fig. 2. *Pegasor AQ Indoor™ sensor.*

Fig.3. *Pegasor AQ Indoor in a suitcase*

Pegasor AQ Indoor™ is equipped with a 98 Wh internal battery. This battery enables 8 hours of measurement in places where there is no mains power available. Internal battery below 100 Wh enables easy transportation of the unit. Water condensation inside Pegasor AQ Indoor™ must be prevented. Pegasor AQ Indoor™ needs no sampling systems to temperature control the sample or to separate water from the sample. The only consumable in Pegasor AQ Indoor ™ is the faraday cage filter, which needs to be replaced in the worst case once per year. In more normal concentrations filter lasts for several years without need to change it. Internal functions are built in the unit to compensate for filter loading. In the end, alarm function tells the user to exchange the filter. Additionally, there is self-diagnostics inside the unit to inform the user e.g. for a missing filter.

Charge that the particles may initially carry has no effect on the result since all particles are charged to their positive maximum in the charger and then ions and ultrafine particles below selected particle size are collected on the trap electrode.

Benefits

Consumables in Pegasor AQ Indoor™ include the Faraday Cage filter and Active Carbon filter for corona air flow. Exchange of these filters can be done by the user easily. User is informed of service need and both filters should be changed during the service. Annual or biannual sensor calibration at manufacturer's site is provided for Q&A purposes if needed.

Pegasor AQ Indoor™ has internal compensation functions correct for variable air flow to the filter (due to filter loading or measurement at variable altitudes from the sea level). All critical parameters of the monitor (corona current, corona voltage, impedance and trap voltage) are measured and can be recorded on the data file. Alarm limits can be set for these parameters.

Specifications

- Extracted sample temperature can be from -20 °C to room temperature (non-condensing)
- 0-100% RH
- No sample conditioning needed
- Time response 1 s – 60 min
- Max data storage time 1 year
- Measured ultrafine particle size range from 10 nm and up
- Modulating trap voltage to provide mean particle size information for data calculation
- Total ultrafine particle mass, total ultrafine particle number and LDS measurement simultaneously from 10 nm and up.
- modulating trap voltage providing size information to the sensor for data calculation.
- No sample conditioning needed
- Low maintenance need
- Concentration range for particle number 300 $1/cm^3$ up to $6*10^8$ $1/cm^3$
- Concentration range for particle mass 1 $\mu g/m^3$ up to 200 mg/m^3
- Dimensions 165 x 200 x 340 mm, weight 7 kg
- Clean air flow generated and monitored with internal pump and flowmeter
- Sample flow generated and monitored with internal pump and flowmeter. Measurement result is flowrate corrected (sensor loading, and altitude effects eliminated)
- Built in data storage 1 GB, flash memory
- Connections USB to Stick, analog V (0-10 V) or mA (4-20 mA). Range adjustable by the user. Modbus over Ethernet, wireless 3G/4G modem, radio modem, cloud service
- Operating voltage AC 100-240 V or DC 24 V, 2,7 A (power supply included in the shipment)
- Continuously self-diagnosed for trap voltage, corona voltage, corona current, and sensor impedance, both trap insulator and main insulator. Impedance indicates sensor loading and possible cleaning need/water condensation.

Pegasor AQ™ Indoor Strengths

Pegasor AQ Indoor™ has been designed for affordable aerosol concentration measurement from remote location to densely populated urban areas. Competing devices are typically labor consuming and require frequent service and dangerous consumables such as Condensation Particle counter (CPC) needs butane as working fluid and Beta Gauge needs radioactive source for the detection. TEOM collection filter needs to be changed frequently. Pegasor AQ Indoor™ is measuring well defined aerosol concentration with no interference nor material dependence in the aerosol itself. E.g. filter measurement of indoor air PM concentration can sometimes be problematic because used filter media may react with gaseous compounds contained in the air. CO_2 concentration and relative humidity may give further insight to the results.

Modulating Trap Voltage

Pegasor AQ Indoor™ has been designed for affordable and long-term indoor air aerosol concentration measurement without any user attention. Pegasor AQ Indoor™ is measuring well

defined aerosol concentration with no interference nor material dependence in the aerosol itself. E.g. filter measurement of urban indoor air PM concentration can sometimes be problematic because used filter media may react with gaseous compounds contained in the indoor air. Pegasor AQ Indoor has so called modulating trap function. This function provides particle size information for data calculation thus getting very exact concentration data for all measured quantities separately.

Measurement Data

Pegasor AQ indoor™ has been used to monitor indoor air emissions in the office environment (fig.4.). Particle number concentration in the indoor air is clearly higher when there is a particle emission source active in the room than the background air.

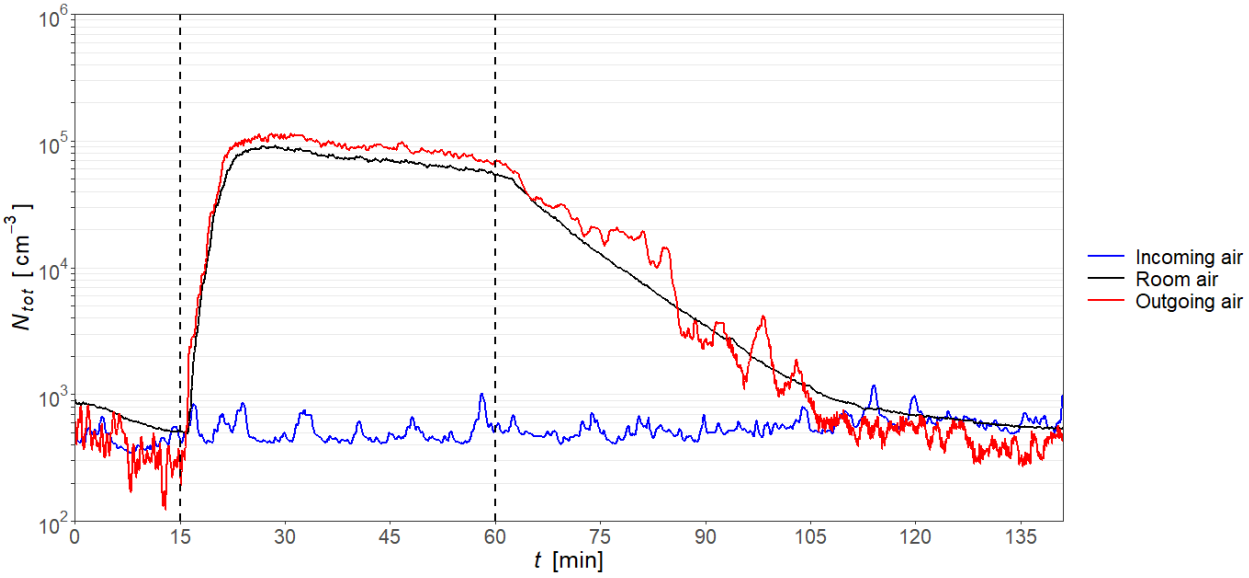

Fig. 4. *Ultrafine particle concentration in an office. Background concentration is increased three orders of magnitude when there is a particle emission source active in the room. In this case, the ultrafine particle levels to come back to the level of the background takes about 1 hour. Source: Finnish Institute of Occupational Health, 2019.*

Summary

Pegasor AQ Indoor™ offers the user fast and continuous ultrafine particle concentration (number, surface area and mass) measurement as well as LDSA measurement. Pegasor AQ Indoor™ measures ultrafine particle number concentration, surface area concentration, mass concentration and LDSA simultaneously from 10 nanometers and up.

Pegasor AQ Indoor™ does not require any external sample conditioning for example for temperature and humidity. Sample taken to the Pegasor AQ Indoor™ can have temperatures from -20°up to room temperature (non-condensing) and 0-100 RH.

Normally data is transferred to a USB memory stick, Modbus over Ethernet, wireless 3G/4G modem or radio modem. Pegasor AQ Indoor™ has extensive self-diagnosis and it informs the user on abnormalities and of any action needed to be done in order to keep the sensor data reliable and accurate.

Scientific Publications

- L. Ntziachristos et al., (2009), ' A New Sensor for On-Board Diagnosis of Particle Filter Operation – First Results and Development Potential, FAD Conference, Dresden, November 4-5.2009.
- T. Lanki et al., (2011), 'An electrical sensor for long-term monitoring of ultrafine particles in workplaces', *J. Phys.: Conf. Ser*. **304** 012013.
- L. Ntziachristos et al., (2011), 'Exhaust Particle Sensor for OBD Application', SAE Paper 2011-01-0626.
- M. Besch et al., (2011), 'Assessment of novel in-line particulate matter sensor with respect to OBD and emissions control applications', Proceedings of the ASME 2011 Internal Combustion Engine Division Fall Technical Conference, ICEF2011 October 2-5, 2011, Morgantown, West Virginia, USA, ICEF2011-60142.
- L. Ntziachristos et al., (2013), 'Application of the Pegasor Particle Sensor for the Measurement of Mass and Particle Number Emissions', SAE Int. J. Fuels Lubr. 6(2):521-531, 2013, doi:10.4271/2013-01-1561.
- Amanatidis, S et al., (2013). "Applicability of the Pegasor Particle Sensor to Measure Particle Number, Mass and PM Emissions," SAE Technical Paper 2013-24-0167, 2013, doi:10.4271/2013-24-0167.
- M. Maricq, (2013), 'Monitoring Motor Vehicle PM Emissions: An Evaluation of Three Portable Low-Cost Aerosol Instruments', Aerosol Science and Technology, 47:5, 564-573.
- S. Amanatidis et al., (2014). 'Use of a PPS Sensor in Evaluating the Impact of Fuel Efficiency Improvement Technologies on the Particle Emissions of a Euro 5 Diesel Car'. SAE Technical Paper 2014-01-1601.
- Chung, MC et al. "Comparison study on characteristics of nanosized particle number distribution by using condensation particle counter calibrated with spray and soot type particle generation methods". In: International Journal of Automotive Technology 15.6 (2014), pp. 877–884.
- Tarabet, L et al. "Experimental investigation of DI diesel engine operating with eucalyptus biodiesel/natural gas under dual fuel mode". In: Fuel 133 (2014), pp. 129–138.

- Rostedt, Antti et al. “Characterization and response model of the PPS-M aerosol sensor”. In: Aerosol Science and Technology 48.10 (2014), pp. 1022–1030.
- Järvinen, A et al. “Monitoring urban air quality with a diffusion charger based electrical particle sensor”. In: Urban Climate 14 (2015), pp. 441–456.
- Amanatidis, Stavros, Matti Maricq, et al. “Measuring number, mass, and size of exhaust particles with diffusion chargers: The dual Pegasor Particle Sensor”. In: Journal of Aerosol Science 92 (2016), pp. 1–15.
- Ruzal-Mendelevich, Michal, David Katoshevski, and Eran Sher. “Controlling nanoparticles emission with particle-grouping exhaust-pipe”. In: Fuel 166 (2016), pp. 116–123.

Conference Presentations

- J. Tikkanen et al., (2011), ‘Pegasor Particle Sensor (PPS-M) for Raw Exhaust PM Measurement’, 21st CRC Real World Emissions Workshop, March 20-23, 2011, San Diego, USA.
- Marc Besch et al., (2011), ‘In-Use NTE PM Measurement Methodology using an In-Line, Real-Time Exhaust PM Emissions Sensor’, 15th ETH Conference on Combustion Generated Nanoparticles, June 26-29, 2011, Zürich, Switzerland.
- F. Gensdarmes et al., (2011), ‘Evaluation of Pegasor PPS Response Time for Real Time Aerosol Concentration Measurements’, EAC 2011, September 4-9, 2011, Manchester, UK.
- L. Ntziachristos et al. (2012), ‘Mass Calibration of a Novel PM Sensor’, 22nd CRC Real World Emissions Workshop, March 25-28, 2012, San Diego, USA.
- M. Besch et al., (2012), ‘On-Road Particle Matter Emissions Assessment from a Compliant HD Diesel Truck While Driving Across the US’, 22nd CRC Real World Emissions Workshop, March 25-28, 2012, San Diego, USA.
- J. Karim et al., (2012), ‘Preliminary Investigation of the Correlation between In-Use Diesel Engine PM Emission Rates and Opacity’, 2012 PEMS Conference and Workshop, March 28-30, 2012, Riverside, USA.
- Beck, H. et al., (2012), ‘Correlation between Pegasor Particle Sensor and Particle Number Counter Application of Pegasor Particle Sensor in Heavy Duty Exhaust’. 16th ETH Conference on Combustion Generated Nanoparticles, June 24-27, 2012, Zürich, Switzerland.
- Ntziachristos, L., (2012), ‘Calibration and performance of a novel particle sensor for automotive application’, EAC - 2012, European Aerosol Conference, Granada, 2-7 Sept. 2012, Spain.
- Ntziachristos, L, S Amanatidis, A Rostedt, K Janka, et al. “Optimization of the Pegasor Particle Sensor for Automotive Exhaust Measurements”. In: 23rd CRC Real World Emissions Workshop, San Diego, CA. 2013.
- J. Tikkanen et al, (2013). ’Dilution Artifacts. A Significant Source of Error from Absolute Concentration and Possibly Difficult to Reproduce. PMP vs. Raw Exhaust’, 17th ETH-

Conference on Combustion Generated Nanoparticles, June 23th – 26th 2013, Zürich, Switzerland.

- M. Besch et al., (2014), ' Off-cycle light-duty diesel vehicle emissions under real-world driving conditions', 24th CRC Real World Emissions Workshop, March 30 -April 2, 2014, San Diego, California.
- Tanfeng C et al., (2014), ' Comparison of the SEMTECH ECOSTAR CPM to AVL 483 MSS, AVL 489 APC, and CVS gravimetric PM', 2014 PEMS Conference and Workshop, April 3-4, 2014, Riverside, California.
- D. Booker, (2014). Challenges and Solutions for Light Duty Real-World PEMS Testing under the auspices of the European RDE/LDV Program', 2014 PEMS Conference and Workshop, April 3-4, 2014, Riverside, California.
- Stavros Amanatidis et al., (2014),' Estimation of the mean particle size by sampling in parallel with two Pegasor Particle Sensors', 18th ETH-Conference on Combustion Generated Nanoparticles, June 22th – 25th 2014, Zürich, Switzerland.
- Delhaye, D et al. 'The MERMOSE project: characterization of particulates emissions of a commercial aircraft engine: from morphology to chemical composition'. In: International Aerosol Conference 2014. 2014.
- Chen, J and H Ye. 'On-Road Diesel Truck Emissions Measurement and Inventory Development in Chengdu City of China'. In: AGU Fall Meeting Abstracts. Vol. 1. 2014, p. 3159.
- ZHANG, Qi-Jun et al. 'On-road Emission Characteristics of Logistics Transportation Vehicles in Chengdu'. In: International Conference on Social Science. 2014.
- Saukko, E et al. 'Expanded Capabilities of Dual Pegasor PPS-M Sensor in PEMS Measurements Beyond PN, PM and Particle Size'. In: 6th International PEMS Conference, Riverside, CA, USA. 2016.

References

[1]. https://www.epa.gov/indoor-air-quality-iaq/indoor-particulate-matter