METROLOGY SYMPOSIUM

DIGITALIZATION AND AUTOMATION IN MASS METROLOGY

Third Edition: Future and New Solutions

RADWAG

ČESKÝ METROLOGICKÝ INSTITUT

Robotic weighing systems used for weighing environmental samples

METROLOGY SYMPOSIUM

DIGITALIZATION AND AUTOMATION IN MASS METROLOGY

Third Edition: Future and New Solutions

Presenters

Sławomir Janas, PhD.

Radwag Metrology Research
and Certification Center

Artur Krystosik

Export Department

Application Areas for Balances
and Weighing Systems for Filter Mass Measurement

Process character

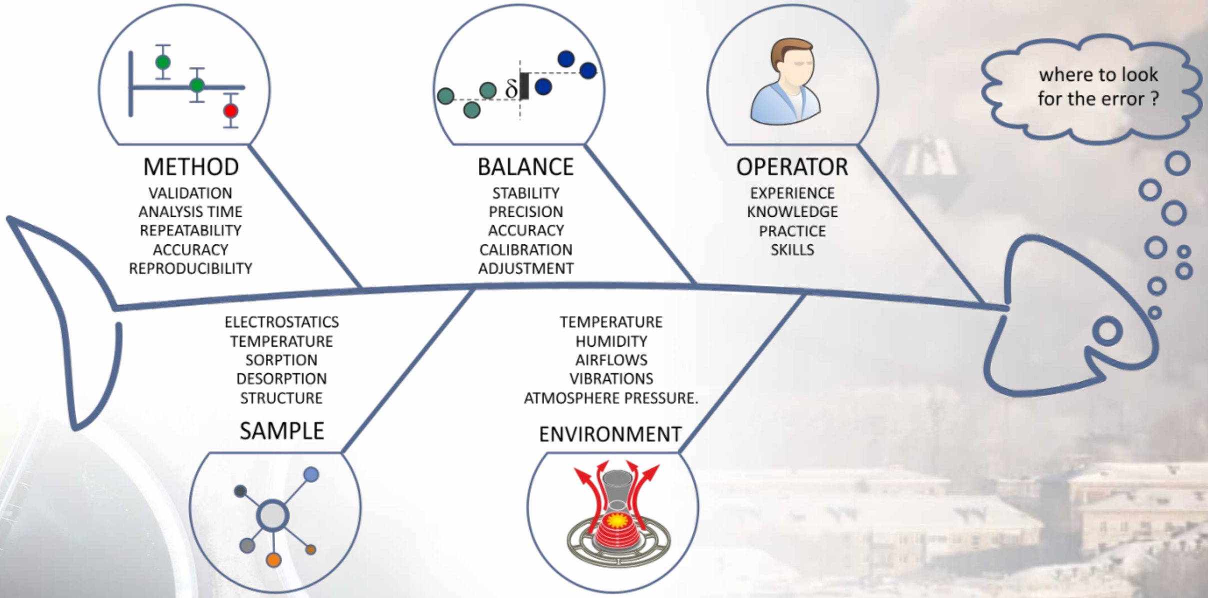
- Registration of filter mass changes during chemical and physical processes.
- Testing the stability of objects mass over time.
- Improvement of research methods based on continuous/periodical registration of changes in the tested object mass.

Installation site

- Research and development centres
- National laboratories monitoring air quality (NAAQS)
- Universities
- Automotive laboratories
- Commercial air quality monitoring units (B2B, B2C)

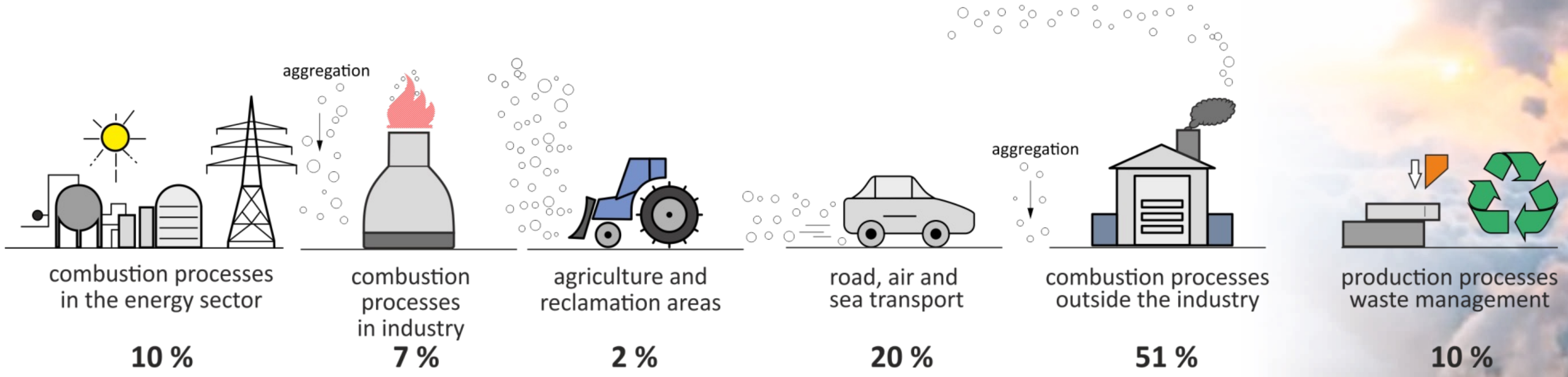
Preface

Nowadays, many devices are used intuitively, without the need for a thorough analysis of how they work. The simple mass measurement process depends on many factors that may have a significant impact on the accuracy of the analysis. This also applies to measurements related to environmental protection.



Ambient air quality
National Air Quality Index

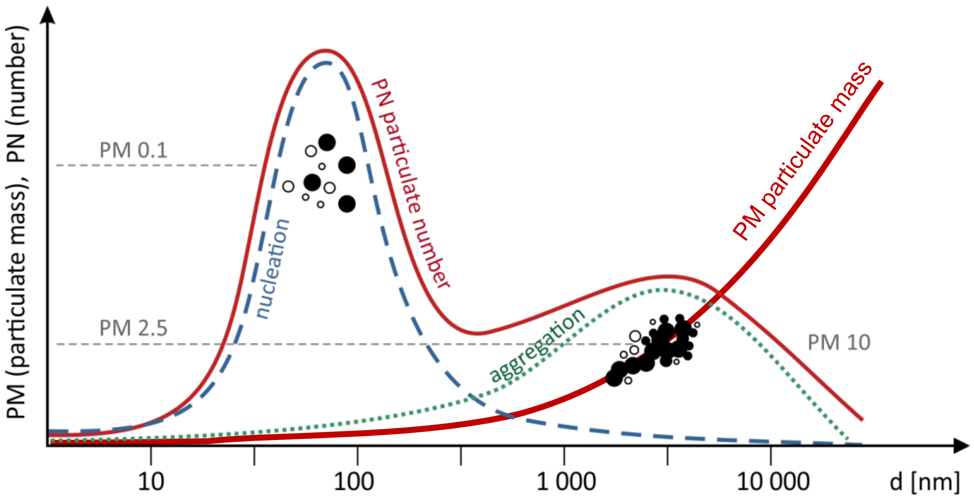
There are many sources that generate pollution.
These are natural sources (fire, volcanic eruption) and anthropogenic sources related to human activity.



Automotive industry - particulate emissions

Fact: currently, approximately 1.2 billion vehicles are on the world's roads, most of them in China, the USA and Europe. In the future, the greatest growth is expected in Asia and Latin America.

Emission tests can be performed in real conditions using RDE tests, (Real Driving Emission)

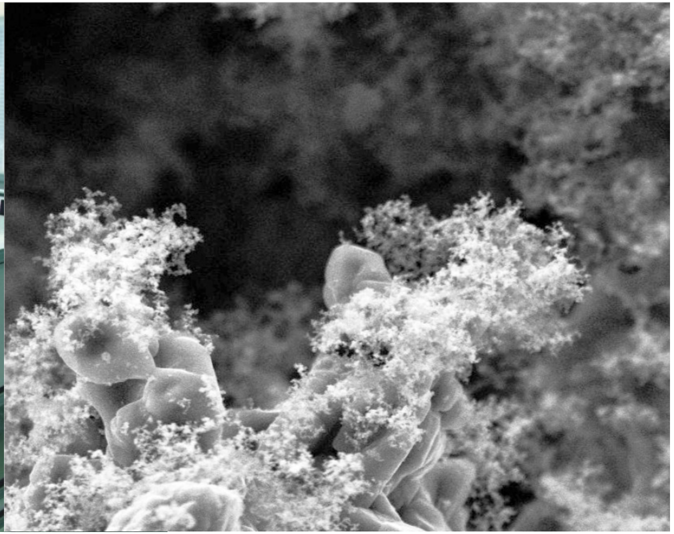


The process of fuel combustion in an internal combustion engine

Automotive industry - particulate emissions

Tests can be performed in the laboratory using WLTP tests (Worldwide Harmonized Light-Duty Vehicles Test Procedure).

Exhaust gas emission test station Source: BOSMAL Automotive Research and Development Institute.



Scanning electron micrograph of diesel engine particulate matter captured in the pore of a ceramic wall-flow filter.
Source:
https://www.flickr.com/photos/cambridgeuniversity-engineering/5862356585

Particulate emissions - exhaust gas components

L.p	Chemical sign	Name
1	N_2	Nitrogen
2	O_2	Oxygen
3	H_2O	Water
4	CO_2	Carbon Dioxide
5	CO	Carbon Monoxide
6	HC	Hydro-Carbons +
7	CH_4	Methane
8	C_2H_5OH	Ethanol
9	HCHO	Formaldehyde
10	CH_3CHO	Acetaldehyde
11	NO	Nitro Oxide
12	NO_2	Nitro Dioxide
13	N_2O	Laughing Gas
14	NH_3	Ammonia
15	SO_2	Sulfur Dioxide
16	H_2O @ SO_4^-	Water sulfate associated
17	OC	Organic Carbons
18	SO_4^2	Sulfate
19	NO^3	Nitrates
20	EC	Elemental Carbons
21	Ash	Ash from fuel
22	Ash	Ash from lube oil
23	others	Additive components
24	others	Engine abrasion, metal, ..

Mass measurement method

The weight method involves determining the difference in filter weight before and after the test, taking into account the filter conditioning period (temperature / humidity).

The accuracy of filter mass measurement depends only on the measurement precision.
For this reason, it is recommended to use automatic or robotic measurement systems, such as **RMC 2.5Y.FC**

What do we actually measure?

Mass measurement involves determining the force with which the sample is attracted by the Earth. When the sample mass is small, the weighing system must be super accurate.

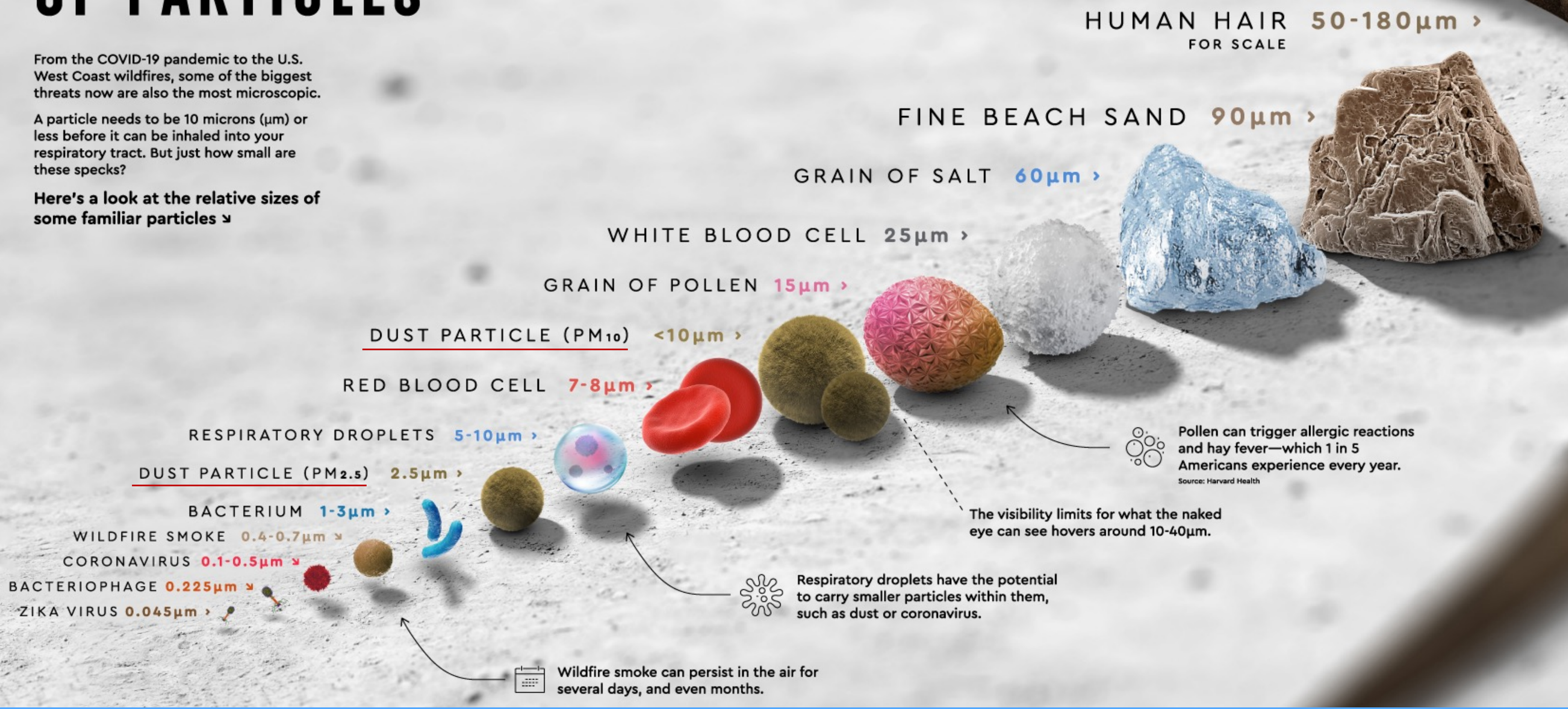
THE RELATIVE SIZE OF PARTICLES

Source:
https://www.visualcapitalist.com/visualizing-relative-size-of-particles/

From the COVID-19 pandemic to the U.S. West Coast wildfires, some of the biggest threats now are also the most microscopic.

A particle needs to be 10 microns (µm) or less before it can be inhaled into your respiratory tract. But just how small are these specks?

Here's a look at the relative sizes of some familiar particles ↘



How to choose the optimal measurement system?

EXTERNAL STABILITY CONDITIONS

INTERNAL
Outside the device
Not required

NUMBER OF FILTERSWHICH WILL BE WEIGHED

Few	1 - 5
Medium	~20
A lot of	> 50

ACCURACY AND PRECISION MEASUREMENT

d	St. dev
0.1 µg	~ 0.5 µg
1 µg	~ 2.0 µg

COMPATIBILITY WITH REQUIREMENTS

Air quality
automotive
Other’s

Robotic and automatic weighing systems

APPLICATION

RB 2.5.Y.F

Robotic Weighing System

The **RB 2.5Y.F** filter robot is a professional-class measuring device ensuring full automation of filter mass measurement. The robot is based on MYA 5Y microbalance mechanism that guarantees unrivalled repeatability and redability of d= 1 µg. The device enables weighing up to 1020 filters with 47 mm diameter.

- Maximum capacity [Max]: **2.1 g**
- Readability [d]: **1 µg**
- Verification unit [e]: **1 mg**

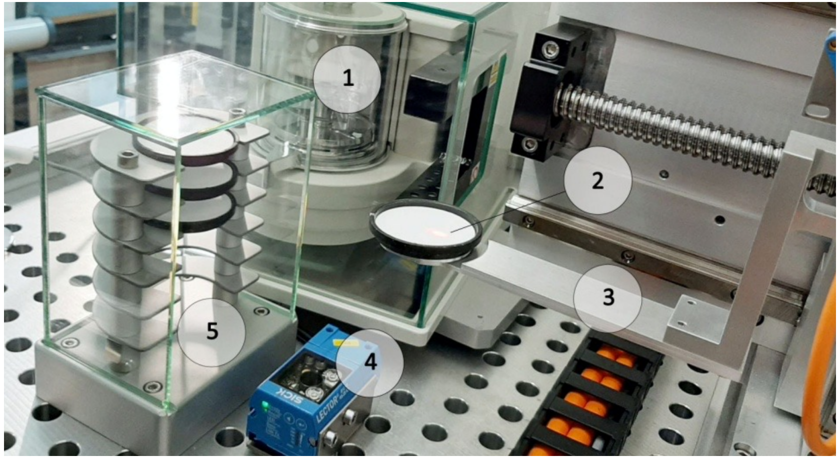
Compatibility
EN 12341:2024. Ambient air - Standard gravimetric measurement method for the determination of the PM10 or PM2,5 mass concentration of suspended particulate matter.

US EPA 40CFR 1065 - Engine-testing procedures
US EPA 40 CFR parts 50 - National primary and secondary ambient air quality standards

RB 2.5.Y.F

Weighing proces

In the warehouse (6), each filter was placed in an antistatic holder. Then, the robotic arm (3) took the filter (2) and transported it to the weighing chamber of the microbalance (1). The filter moved over the QR code reader (4) and was registered in the master system as the currently weighed sample. The weighing chamber of the microbalance (1) was opened automatically and the robotic arm placed the filter on the microbalance pan. Then the weighing chamber was closed to precisely determine the filter mass. After weighing was completed, the microbalance chamber was opened and the robotic arm returned the filter to the warehouse. The reference filter and mass standard storage (5) would be used periodically to investigate potential drifts in the sensitivity of the robotic system and the impact of environmental conditions on the variability of the reference filter mass.

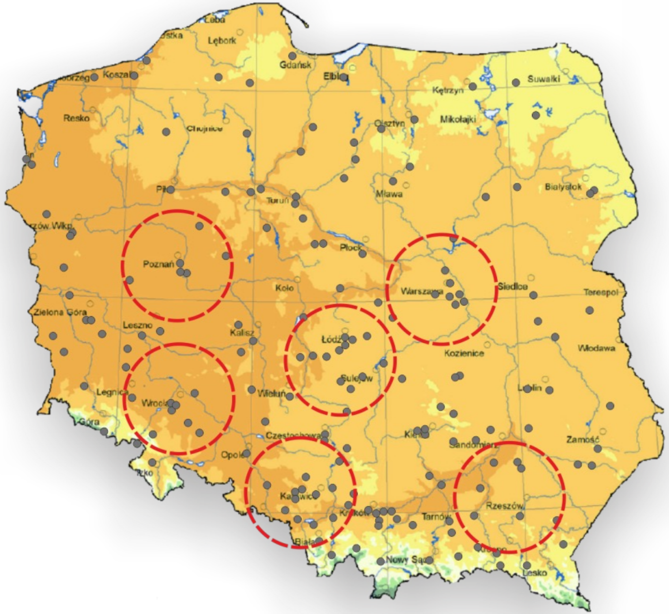


RB 2.5.Y.F

Implementation

Purchase of an automatic system RB 2.4Y for weighing of filters used for sampling of particulate matter PM 10 / 2.5

European Funds Programme - Operational Programme Infrastructure and Environment 2014 – 2020



Particulate matter collection stations PM 2.5, PM 10 in Poland
Sampling using the automatic method

RB 2.5.Y.F

Science research

PM immission tests according to EN 12341:2014 using the RB 2.4Y.F robotic weighing system

Purpose of the research

Comparison of concentration results determined when measuring filter mass using the manual (microbalance) and automatic methods (RB 2.4Y). Sampler: 4 LVS type collectors with PM1, PM2.5, PM10 heads, located in 4 different locations

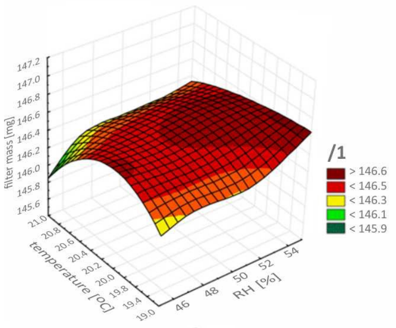
No of measure point	Type of Measurem.	Location coordinates		Altitude [m]	Localization	PM type	Sampler tape
		Latitude (φ)	Longitude (λ)				
1	automatic	50°18'53"N	18°46'17"E	254	Zabrze, Marii Skłodowskiej-Curie 34	PM_1, $PM_{2,5}$	low-volume sampler PNS-15 (Atmoservice)
2		50°5'24"N	18°12'58"E	190	Racibórz-Szkoła Wojska Polskiego	$PM_{2,5}$	low-volume sampler μPNS LVS15 (Umwelttechnik MCZ)
3		49°58'36"N	19°48'49"E	210	Skawina, A. Mickiewicza 27	PM_{10}	low-volume sampler μPNS LVS16 (Umwelttechnik MCZ)

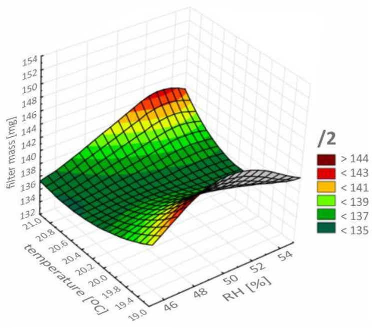
RB 2.5.Y.F

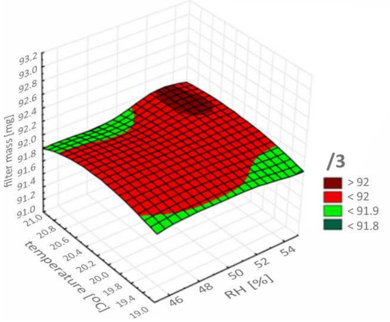
Science research - results

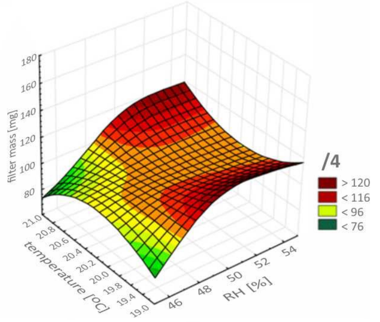
Dependence of changes in filter mass in relation to variable conditioning conditions in the range of humidity 50±5% and temperature 20±1°C

m_{QMA}	$\rightarrow$	m_{QMA}	+ 0.003RH	+	0.015T	/1
$m_{GF/A}$	$\rightarrow$	$m_{GF/A}$	+ 0.018RH	+	0.055T	/2
m_{PTFE}	$\rightarrow$	m_{PTFE}	+ 0.186RH	–	1.473T	/3
m_{NL}	$\rightarrow$	m_{NL}	+ 2.242RH	–	2.90T	/4
m_{PC}	$\rightarrow$	m_{PC}	+ 0.004H	–	0.046T	/5

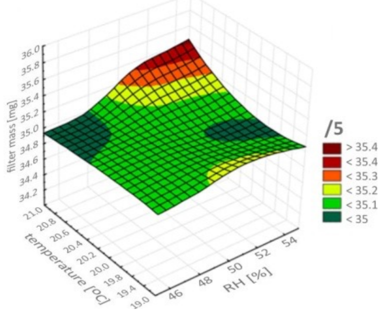








Legend: RH – relative humidity (coefficient when RH increases by 1%)
T – air temperature (coefficient when T increases by 1oC)
PTFE – PTFE (polytetrafluoroethylene), type PM2.5
PTFE W/PPNL – polyamide membrane (nylon), type NL 16
Cyclopore PC – polyester membrane (polycarbonate) CycloporeTM Polycarbonate
QMA 4.7CM 100/PK – quartz fiber type QMA 4.7CM 100/PK
GF/A 4.7CM 100/PK – glass fiber type GF/A 4.7CM 100/PK



Source: Widziewicz-Rzońca K, Janas S, Błaszczak B et al. Advancing the understanding of pm filter mass stability: unveiling the influence of humidity and temperature. Scientific Reports of Fire University. (2023);1(88):7-26. https://doi.org/10.5604/01.3001.0053.9741

RB 2.5.Y.F

Conclusion

The RB 2.4Y.F Filter Robot Assembly enables the maintenance of stable relative humidity and air temperature conditions, the fluctuations of which do not exceed the range permitted by the requirements of the EN 12341:2024 standard.

As the concentration of dust collected on quartz fiber filters increased, the difference in mass deviation values between manual and automatic measurements decreased. However, these differences were not statistically significant at the significance level of $p < 0.05$.

It has been shown that the variability of conditioning conditions (temp/rel. hum.) influences the size of filter mass deviations. The average mass deviations of the filters were:

- 146±0.32 mg (quartz fiber filters);
- 135.59±3.19 mg (PTFE filters);
- 91.91±0.51 mg (glass fiber filters);
- 101.09±7.13 mg (polyamide membrane – nylon);
- 35.22±0.75 mg (polyester-polycarbonate membrane).

Statistically significant ($p < 0.05$) differences in PM mass measurements using manual and automatic methods were detected for the PM2.5 fraction collected in Racibórz and for the PM10 fraction for the site in Skawina. However, the detected differences in percentage terms were very small and did not exceed 0.12 µg/m³ and 0.29 µg/m³.

RMC .FC / UMA FC Series Devices

Dedicated filter container
Better measuring precision = detection of even the smallest variations in filter weight

BENEFITS

Transportation / Storage / Acclimatization / Draft shield
Faraday antistatic cage / Safety and cleanliness of the filter/ Accurate weight

MEASUREMENT

sd = 0.3 µg

RMC 2.5.Y.FC

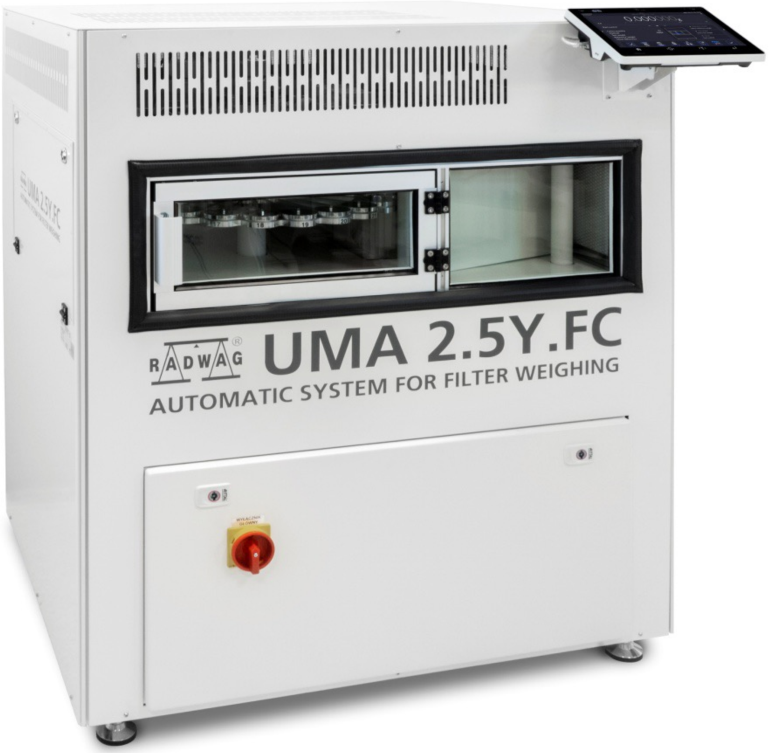
Robotic Weighing System

The **RMC series automatic system** is a professional measurement system designed to measure the mass of filters or other objects with an accuracy of 0.1 µg or 1 µg. Stable temperature and humidity conditions are maintained inside the device - conditioning. The all filters are stored in steel containers, which allows for a measurement precision of ~ 0.3µg.

- Maximum capacity [Max]: **2.1 g**
- Readability [d]: **0.1µg or 1 µg**
- Verification unit [e]: **1 mg**
- Filter: **156 pcs.**

Compatibility
EN 12341:2024. Ambient air - Standard gravimetric measurement method for the determination of the PM10 or PM2,5 mass concentration of suspended particulate matter.

US EPA 40CFR 1065 - Engine-testing procedures
US EPA 40 CFR parts 50 - National primary and secondary ambient air quality standards.



UMA 2.5Y.FC

Automatic Weighing System

The **UMA** automatic system ensures conditioning and measurement of filter mass in accordance with the requirements of the EN 12341:2024 standard or under other defined conditions. The mass of each filter is quickly and accurately determined while maintaining high weighing precision guaranteed by a certified ultra-microbalance or microbalance installed inside the construction.

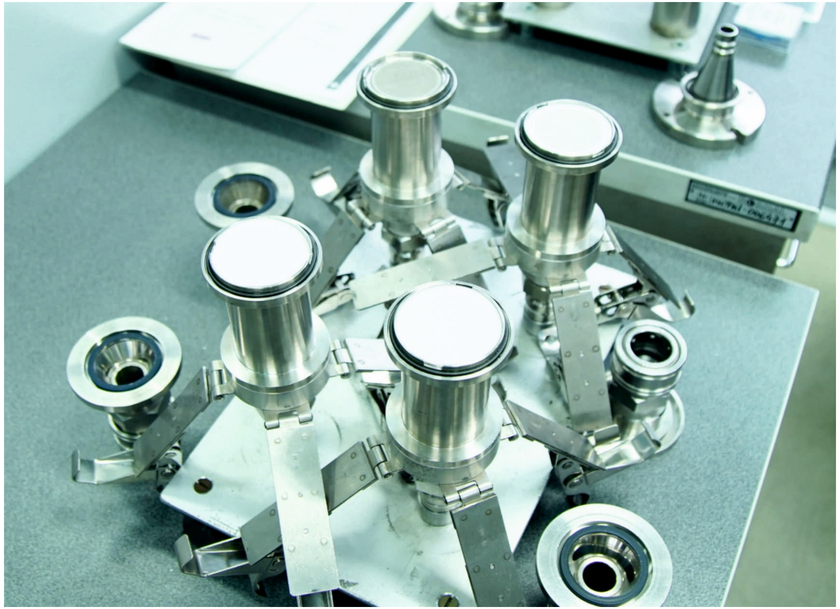
- Maximum capacity [Max]: **2.1 g**
- Readability [d]: **1 µg**
- Verification unit [e]: **1 mg**
- Filter: **24 pcs.**

Compatibility
EN 12341:2024. Ambient air - Standard gravimetric measurement method for the determination of the PM10 or PM2,5 mass concentration of suspended particulate matter.

US EPA 40CFR 1065 - Engine-testing procedures
US EPA 40 CFR parts 50 - National primary and secondary ambient air quality standards.

UMA 2.5Y.FC

Automatic Weighing System – **automotive research**



Preparing filters for testing
Source: BOSMAL Automotive Research and Development Institute

Weighing room – automatic and manual weighing system

UMA 2.5Y.FC

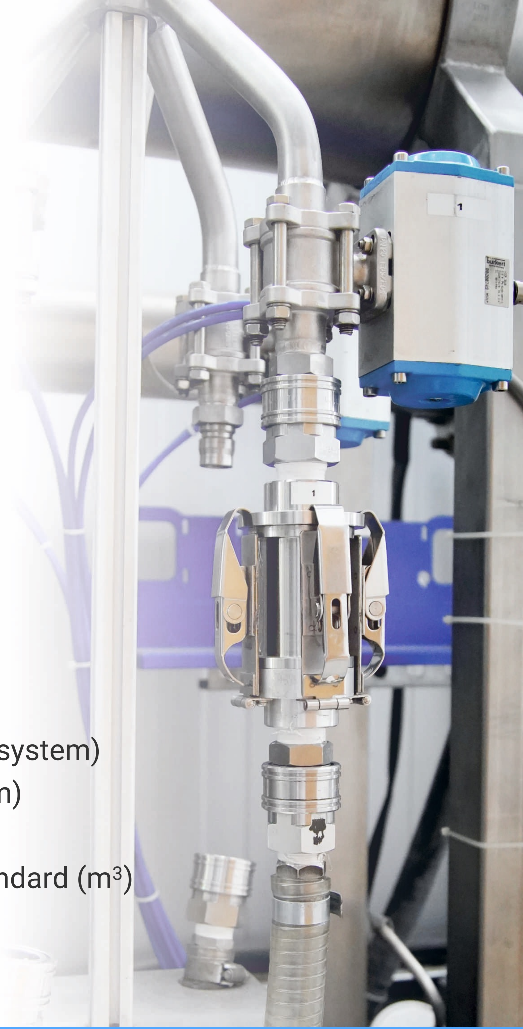
Automatic Weighing System – **automotive research, calculation**

$$PM_1 = \frac{(V_{mix} + V_{ep}) \times \boxed{P_e}}{V_{ep} \times d}$$

$$PM_2 = \frac{V_{mix} \times \boxed{P_e}}{V_{ep} \times d}$$

Legend

PM_1 – particulate matter emissions when exhaust gases were discharged outside the tunnel (AVL system)
PM_2 – particulate matter emissions when exhaust gases were returned to the tunnel (Horiba system)
V_{mix} – volume of diluted exhaust gas at standard conditions (m^3)
V_{ep} – volume of diluted exhaust gas flowing through the particulate sampling filter at condition standard (m^3)
P_e – mass of solid particles retained on the filter (mg),
d – distance traveled corresponding to the test cycle (km).



UMA 2.5Y.FC

Automatic Weighing System – **data analysis**

Measurement precision: standard mass

	MSE2.7S-000-DF – manual	UMA 2.4Y.F – automatic
	(mg)	(mg)
1	150,2548	150,2440
2	150,2545	150,2429
3	150,2553	150,2432
4	150,2553	150,2429
5	150,2549	150,2430
6	150,2550	150,2428
7	150,2550	150,2427
8	150,2548	150,2428
9	150,2545	150,2429
10	150,2545	150,2428
S	0,0003 mg	0,0004 mg

Measurement precision: filter QMA type, 47 mm

	MSE2.7S-000-DF – manual	UMA 2.4Y.F – automatic
	(mg)	(mg)
1	**102,1241**	102,0771
2	102,1215	102,0774
3	102,1232	102,0770
4	102,1197	102,0772
5	102,1176	102,0768
6	102,1156	102,0770
7	102,1152	102,0772
8	102,1163	102,0772
9	**102,1151**	102,0772
10	102,1173	102,0774
S	0,0034 mg	0,0002 mg

UMA 2.5Y.FC

Automatic Weighing System - research conclusion

From a metrological point of view, however, it is justified to use the automatic method due to much better measurement precision and reduced environmental impact by using the so-called filter container.

It should also be noted that the normative requirements regarding the scale used in particulate mass tests clearly specify the required measurement precision as at least 2 μg → EU 2017/1151.

This value should be verified for the filter weighing process and not for the mass standard, which allows for an objective assessment of the compliance of the weighing system with the requirements.

UMA 2.5Y.FC

Automatic Weighing System – **science publication**

Abstract

The aim of this study was to evaluate the accuracy and precision of measurements of an automatic weighing system used to assess the mass emission of particulate matter emitted by internal combustion engines. Thirty test cycles were carried out for cars equipped with spark-ignition and compression-ignition engines that met the Euro 4, Euro 5 and Euro 6 emission standards. Exhaust gas samples for analysis were taken according to EU 2017/1151 recommendations for driving cycles performed on AVL and Zöllner chassis dynamometers, AVL-CVS i60 LD LE and HORIBA-CVS 7400 S exhaust-gas collection systems, WLTC driving cycle according to EU 2017/1151, NEDC according to UNECE No. 83, RDE, RTS and TFL cycles, non-standard cycles of car manufacturers. The mass emission of particulate matter was measured using Teflon-coated glass filters of Pallflex® Emfab™ type TX40HI20WW, which ranged between 96 ÷ 102 mg. The mass of the filters was measured with a manual method using an MSE2.7S-000-DF scale manufactured by Sartorius and an automatic method using an UMA 2.4Y.F system manufactured by Radwag Wagi Elektroniczne. The mass measurement precision of the manual system for the mass standard was 0.0003 mg, and for the reference filter 0.0034 mg. The precision of the automatic system was 0.0004 mg and 0.0002 mg, respectively. For the reference filter, the measurement precision of the automatic system was more than 18 times better than that of the manual system. It was found that the mass of particulate matter emitted by internal combustion engines ranged between 0.01 mg ÷ 0.52 mg and that the emission of particulate matter ranged between 0.04 mg/km ÷ 2.46 mg/km. The maximum difference in particulate matter emission obtained with the manual and automatic systems was 0.10 mg/km. It was found that the use of the automatic system significantly influenced the ergonomics of the test process by greatly reducing the time taken to test changes in filter mass.

https://doi.org/10.4271/2022-01-1025

Manual weighing systems

MYA 5.5Y.F1

Microbalance

The F1 series microbalance enables quick and accurate measurements of the mass of filters with a maximum size of 160 mm. The aesthetic design with a viewing window ensures correct weighing in every case. The Digital Weighing Auditor function ensures supervision over the correct operation of the balance in all conditions.

- Maximum capacity [Max]: **5.1 g**
- Readability [d]: **1 µg**
- Verification unit [e]: **1 mg**

MYA 5.5Y.FA

Microbalance

The F.A series microbalance is a dedicated solution for the process of weighing filters with a maximum size of 70 mm. The automatically opening weighing chamber ensures ergonomics and speed of analysis. Measurement precision is ensured by a certified high-resolution weighing module. The Audit-trail, Digital Weighing Auditor and Environmental Module functions are the perfect solution for every laboratory.

- Maximum capacity [Max]: **5.1 g**
- Readability [d]: **1 µg**
- Verification unit [e]: **1 mg**

XA Balances

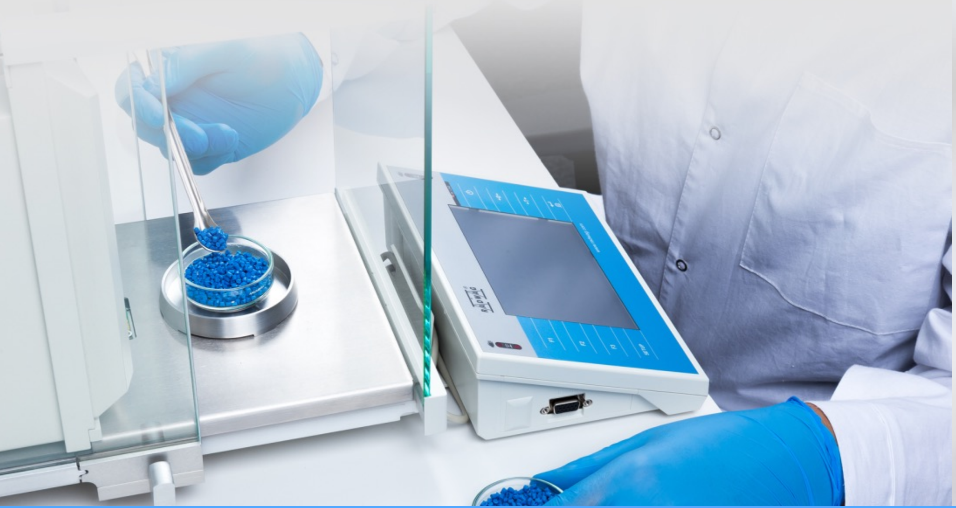
XA - Analytical balances

The **XA.5Y** series of analytical balances is a wide range of scales that can be used in any laboratory to measure the mass of filters used in filtration processes. Automatic adjustment combined with an innovative user interface is one of the best mass measurement solutions currently available on the market. OIML certification of scales is a guarantee of their high quality in every application.

- Maximum capacity [Max]: **520 g**
- Readability [d]: **0.01 mg**
- Verification unit [e]: **1 mg**

Manual system benefits

- Dedicated for small series of weighing daily
- Wireless communication
- Ergonomic chamber door and full view of the weighing chamber
- Data management security
- Optional anti-static solutions
- Mobile mechanical design
- Adaptable to other processes



Robotic system benefits

- 8 times faster than manual operation
- No human error
- No handling mistakes
- No calculation mistakes
- Unmatched repeatability
- Constant operation
- Remote control
- Saving time and money

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