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Concentration versus number of particles in the assessment of air pollution with particulate matters

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Abstract
In this paper, an assessment study was performed regarding air pollution with particulate matters including submicron particles. The evaluation of the contamination level was performed at a textile production unit in Pascani, Romania, which produces polyester knitwear. In the study, automatic determinations of total suspended particulate matters (TSP), PM 10, PM 2.5 and PM 1 (particle with nominal diameter <10 µm, <2.5 µm and <1 µm), and submicron particulate matters (0.25, 0.35, 0.50 and 0.70) were performed both outdoor, in the ambient air, and indoor (workplace) in the area of the knitting machines. The correlation between the mass concentrations of submicronic particles (µg/m^3) and the numerical concentrations (number of particles/m^3) was study, too, for establish the most appropriate expression of the air pollution level with particulate matter.
The results of the performed tests showed a level of ambient air pollution with particulate matters that exceed the limit values in the case of PM 2.5 and PM 10, the total suspended particulates still falling within the limits established by law. Likewise, in the case of workplace air, the level of inhalable particulate matters (particles with nominal diameter <100 µm), the concentration is below the limit values.
Regarding the way of expressing the concentration of air particles, in µg/m^3 or in no. particles/m^3 the tests indicated better representativeness of the pollution level if the concentration in µg m^3 is expressed for the dimensional fractions with diameter ≥ 1 µm and in no. particles/m^3 for particles with a diameter of ≤1 µm.

Keywords: *ambient air pollution, particulate matter, textiles, workplace air*

INTRODUCTION

The investigation of complex material particles in the environment is particularly important.
Each type of particle, of various sizes and physicochemical properties acts differently on the body. Small particles, especially submicron ones, penetrate easily and can accumulate in the respiratory system causing serious health problems ranging from asthma to lung cancer [1-3].
The impact of inhalable particulates on human health is closely related to several factors such as: dimensional distribution, composition and mass of particulate matters [3-5].
On the other hand, the composition and size of submicronic particulate matters varies depending on the sources of contamination, climate and space. They are emitted into the atmosphere as primary particles or, they can be generated as secondary particulate matters from precursors in a state of gaseous aggregation or as new particles as a result of photochemical reactions [6, 7].
Submicronic particulate matters have a specific surface area and a higher reactivity than PM10 and PM2.5, thus allowing the adsorption of large amounts of hazardous metals and organic compounds per unit mass. The major element in the composition of submicronic particulate matters studies reveals, is elemental carbon and in smaller quantities are found organic compounds, metal oxides, sulphate and nitrates [7-10].

Based on the information provided by the air quality monitoring stations belonging to the National Air Quality Monitoring Network (RNMCA) Romania, in the big cities, Bucharest, Iasi, Cluj, Timisoara and not only, the daily limit values for the protection of the population for PM 10 [11] of 50µg/ m^3 are frequently exceeded, as the daily limit values for PM 2.5, 35µg/m^3 [12]. For the dimensional fractions with a nominal diameter less than 2.5 µm, no limit values are established in the ambient air, being included in the health impact studies in the class of inhalable particulate matters [13].

An essential feature of submicronic particles is the dynamics of submicron particulate matters, and their rapid evolution, starting especially from their smallest fractions (<20 nm). These particles move under Brownian motion with diffusion-based motion through concentration gradients, so in situations where there are higher numerical concentrations near the emission sources, the submicronic particles easily collide with adjacent particles when they coagulate into larger particles, or are deposited on the available surfaces. In addition, the coagulation and condensation of semi-volatile organic compounds on the surface of the particles are the main causes of the increase in particle size.

Consequently, submicronic particles have very short atmospheric lifetimes, usually about few hours, and their concentrations decrease rapidly with increasing of distances from emission sources [14-16].

The most commonly terms used for particulate matters characterization (PM) are numerical concentration and mass concentration. An issue of wide interest, currently being debated, refers to the representativeness of the expression of the measurement results, respectively in mass/m^3 or number of particles/m^3 [17-18].

In this context, the purpose of this paper was not only the assessment of the level of ambient air and workplace pollution with dimensional particulate matters fractions in a textile unit, which produces polyester knitwear but also the establish the most appropriate expression of the air pollution level with particulate matter, in mass concentrations (µg/m^3) or in numerical concentrations (number of particles/m^3).

EXPERIMENTAL PART

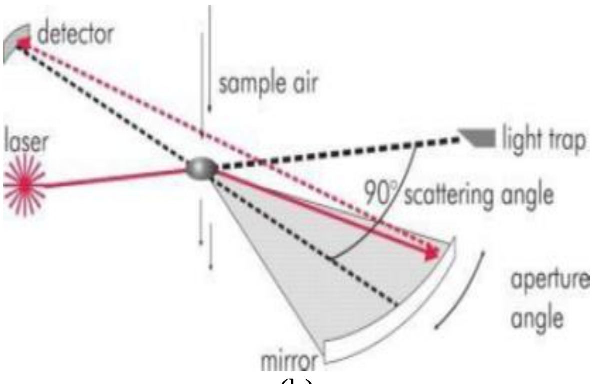
Location and planning of the case study

The case study was performed in a textile unit in Pascani, which produces polyester knitwear and the measurements were performed in October and November 2021, both indoor, in a production hall in the area of knitting machines and outdoor, in ambient air. In the study were determined the following dimensional fractions of particles: total particulate matters, PM10, PM2.5 and submicronic particles with nominal diameter less than 0.70µm, 0.50 µm, 0.35 µm and 0.25µm.

Methods and equipment

The measurements were performed with a "scattered light" automatic analyser type Aerosol (Mini-LAS) 11-E Laser Spectrometer (Fig. 1) both in mass concentrations (µg/m^3) and in numerical concentrations (number of particles/m^3).

(a)



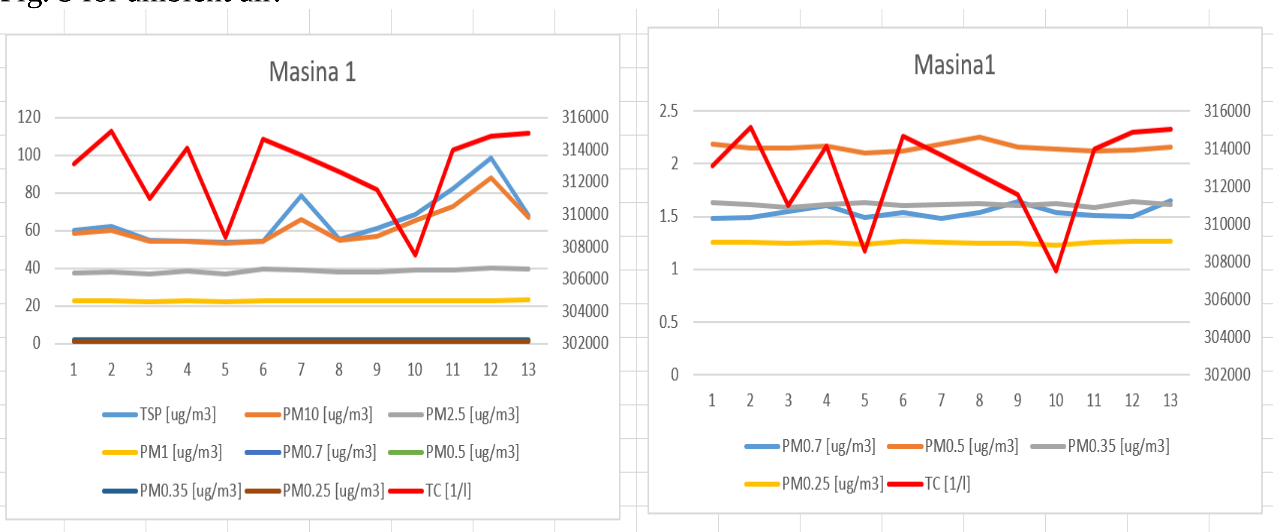
(b)

Fig. 1. Automatic analyser Mini-LAS 11-E (a) and its operation principle (b)

The principle of the method is the crossing of a ray of light through the air sample containing particulate matter. The intensity of the scattered light is dependent on the intensity, wavelength and polarization of the incident light, the angle at which the intensity of the scattered light is measured, the size and shape of the particles and the refractive index of particles in which light diffuses.
In a certain field, there is a linear relationship between the intensity of light scattered at a certain angle and the concentration of particles in the air. The linear relationship between the intensity of the scattered light and the concentration of the particles supposes a constant of the other factors. Scattered light detectors typically are use in a scattering angle of 150 degrees.
The measurement, based on the "scattered light" method with laser, reliably counts each individual particle – into a wide range of sizes between 0.25 and 32 µm and classified into 31 separate channels.
Measurement and storage of data was done in real time via data communication interfaces.
For the characterization and statistical analysis of the data series SPSS 20.0 software was used.

RESULTS AND DISCUSSION

The variation, in time, of the mass concentrations and of the number of particles for the determined dimensional fractions of particulate matters are represented in Fig. 2 for the workplace air and in Fig. 3 for ambient air.



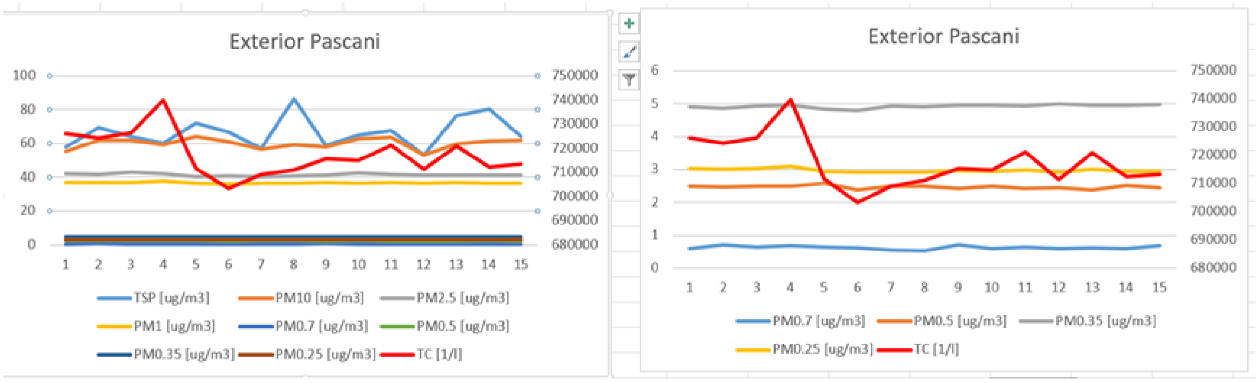
(a) (b)

	N	Minimum	Maximum	Mean	Std. Dev.	Skewness	Kurtosis
TSP	13	53.9	98.5	65.7	13.6	1.405	1.579
PM10	13	53.5	87.9	62.1	9.87	1.659	2.998
PM2.5	13	37.0	40.2	38.6	0.949	-0.146	-0.671
PM1	13	22.3	23.2	22.8	0.232	-1.067	1.546
PM0.70	13	1.48	1.65	1.53	0.058	0.939	-0.212
PM0.50	13	2.10	2.25	2.15	0.038	1.029	1.772
PM0.35	13	1.59	1.64	1.61	0.015	0.197	-0.626
PM0.25	13	1.23	1.27	1.25	0.012	-0.844	0.509
number	13	307496	315146	312756	2472	-1.168	0.454

(c)

Fig. 2. Variation of mass concentration and number of particles on dimensional fractions (a, b) and the main characteristics of the data series for the workplace air (c)

The main characteristics of the data series are also presented: average, standard deviation, extreme values (minimum and maximum), but also values for skewness and kurtosis. The characteristic parameters of the data series are expressed in µg/m^3 and, respectively, number of particles/m^3.



(a) (b)

	N	Minimum	Maximum	Mean	Std. Dev.	Skewness	Kurtosis
TSP	15	53.3	86.6	66.6	9.21	0.737	0.158
PM10	15	53.1	63.9	59.9	3.07	-0.840	0.235
PM2.5	15	40.5	42.9	41.4	0.765	0.713	-0.306
PM1	15	36.0	37.8	36.7	0.432	1.026	1.916
PM0.70	15	0.54	0.71	0.63	0.052	-0.066	-0.770
PM0.50	15	2.38	2.59	2.46	0.053	0.306	0.962
PM0.35	15	4.80	4.99	4.91	0.050	-1.151	1.072
PM0.25	15	2.91	3.10	2.97	0.053	0.991	0.461
number	15	703392	739753	717414	9086	0.956	1.262

(c)

Fig. 3. Variation of mass concentration and number of particles on dimensional fractions (a, b) and the main characteristics of the data series for the ambient air (c)

Analysing the obtained results, it can be ascertained the presence both in the ambient air and in the workplace air of a wide range of dimensional fractions; in the case of fractions with diameters larger than 1µm, the mass concentrations are located in the same fields both in ambient air and in workplace air, very slightly larger in ambient air, especially for PM1 and PM2.5. Submicron particles, however, are found in higher mass concentrations in the ambient air than in the workplace air. If we analyse the situation but taking into account the concentration expressed in number of particles/m^3 we find that, on average, the concentration in the ambient air is 2.3 times higher than in workplace air. We can appreciate in this case that the contribution of submicron particles is very significant if we express them in number of particles/m^3, and, almost insignificant if we express it in mass concentration.

In these conditions we ask ourselves the question: how is it more correct to express the concentration of particulate matters in the air, in µg/m^3 or in number of particles/m^3?

From the information obtained in this study we can say that, depending on the dimensional fractions of interest we can express the level of air pollution with particulate matters in mass concentration for particulate maters with a nominal diameter > 1µm and in number of particles/m^3 for submicronic PM.

The expression of the level of particulate matters pollution > 1 µm in the form of mass concentration also results from the need to report to the limit values from the environmental and occupational health legislation in force expressed in µg/m^3 (Table 1).

Table 1. Limit values for ambient air particulate matters and for workplace air

Particulate matters	Daily limit value, µg/m^3	
	Ambient air	Workplace air
Inhalable PM	-	10000 [20]
PM 2.5	35 [12]	-
PM10	50 [11]	-
TSP	150 [19]	-

From the point of view of reporting to limit values, in this study, we find that the level of the particulate matters concentration in the ambient air is below the limit value for TSP, but it exceeds the limit values for PM10 by 20% and for PM2.5 by 17%. In the case of inhalable particulate matters limited by the legislation at workplace [20] the level of pollution is below the limit value.
Additional information on the most appropriate form of expression of the particulate maters concentration in the air can be obtained by statistical correlation analysis applied to the data series of mass concentration and number of particles/m^3. Considering the values obtained for the skewness and kurtosis (Figures 2 and 3) which indicate a distribution that deviates from normality, we will use in the analysis the Spearman correlation coefficients; the values of the Spearman correlation coefficients are found in Table 2 for the workplace air and in Table 3 for the ambient air.

Table 2. Spearman correlation coefficients for workplace air

	TSP	PM10	PM2.5	PM1	PM0.70	PM0.50	PM0.35	PM0.25	Number
TSP	1.000								
PM10	0.977**	1.000							
PM2.5	0.576*	0.630*	1.000						
PM1	0.679*	0.729**	0.719**	1.000					
PM0.70	-0.199	-0.172	0.093	0.011	1.000				
PM0.50	-0.011	-0.003	-0.155	0.082	0.057	1.000			
PM0.35	0.050	0.084	0.039	-0.187	-0.452	0.107	1.000		
PM0.25	0.292	0.424	0.705**	0.517	-0.012	-0.012	-0.061	1.000	
Number	0.286	0.404	0.598*	0.640*	-0.006	0.724	0.825	0.892**	1.000

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

Table 3. Spearman correlation coefficients for ambient air

	TSP	PM10	PM2.5	PM1	PM0.70	PM0.50	PM0.35	PM0.25	Number
TSP	1.000								
PM10	0.556*	1.000							
PM2.5	-0.213	0.109	1.000						
PM1	-0.056	0.178	0.783**	1.000					
PM0.70	-0.102	0.330	0.242	0.562*	1.000				
PM0.50	0.219	0.192	-0.122	-0.075	-0.440	1.000			
PM0.35	-0.343	-0.274	0.272	0.098	0.124	-0.261	1.000		
PM0.25	-0.058	0.173	0.750**	0.977**	0.527*	-0.045	0.075	1.000	
Number	-0.100	0.166	0.634**	0.983**	0.715*	0.694	0.858**	0.976**	1.000

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

The Spearman correlation coefficient (q) can take values between -1 and +1; positive values indicate a direct/positive correlation and negative values an inverse/negative correlation.
The degree of association/correlation between the variables is established depending on the value of the coefficient, as follows:

i) q ϵ [0; 0.2] → very weak correlation,
ii) q ϵ [0.2; 0.4] → weak correlation,
iii) q ϵ [0.4; 0.6] → moderate correlation,
iv) q ϵ [0.6; 0.8] → good correlation,
v) q ϵ [0.8; 1) → very good correlation,
vi) q = 1 → perfect correlation.

Analysing the results obtained following the statistical correlation analysis, we find a good and very good direct correlation between the mass concentration and the one expressed in number of particles/m^3, q ϵ [0.6; 0.9], for dimensional fractions with diameter ≤1 μm. For the dimensional fractions with diameter ≥1 μm the correlation is weaker, with the tendency to decrease with the increase of the particle diameter both in the ambient and at the workplace air.

CONCLUSIONS

The tests performed revealed the presence of particulate matters both in the ambient air and in the workplace air in a wide range of sizes and concentrations. Compared to the limit values in the environmental legislation in force, there was an exceeding of the daily limits for PM 2.5 and PM10 and a compliance with the limits for TSP; in the case of workplace, concentration of inhalable particulate matters falls within limits. For submicron particulate matters, however, the lack of limit values in the legislation does not allow an interpretation of the impact on the environment.

Regarding the way of expressing the concentration of particulate matters from air, in $\mu g/m^3$ or in number of particles/m^3 the tests indicated a better representativeness of the pollution level if the concentration in $\mu g/m^3$ is expressed for the dimensional fractions with diameter ≥ 1 µm and in number of particles/m^3 for particles with a diameter of ≤ 1 µm, their contribution to the mass of particulate matters being reduced, but their presence in large numbers in the air can induce a harmful impact on the health of the population.

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