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INDOOR POLLUTION:
$PM_{2.5}$ AND PM_{10} FROM CIGARETTE SMOKE

This work is aimed to establishing the temporal and spatial dispersion of PM_{10} and $PM_{2.5}$ particulate matter fractions generated by cigarettes smoking in an indoor ambient. To this purpose, PM_{10} and $PM_{2.5}$ concentrations were collected with a mobile instrument positioned in a room accommodating a smoking machine.

In the last years air quality in domestic or working environments was the subject of many studies aimed at establishing the risks due to the exposure to high indoor pollution levels. It is known that the increase of many respiratory health problems, as asthma or allergies, are strictly related to changes in indoor air quality [1]. Tobacco smoking can significantly contribute to the concentration of most important indoor pollutants as NO_x, CO, VOCs [2] and particulate matter [3], so it is a potential danger for smokers and for those who are somehow exposed to it. The emission due to tobacco smoke is usually subdivided in two different streams: Main Stream smoke, that is the emission filtered by smoker respiratory apparatus and exhaled from smoker lungs, and Side Stream, that is puffs from cigarette combustion; these fractions contain different concentrations of same compounds [4]. Moreover the side stream constitutes the major contribution to tobacco smoke [5] specially for particulate matter production, as the smokers respiratory apparatus absorbs main part of pollutants, with very severe consequences for their self. So the presence of smokers in an indoor environment can significantly affect the local air quality and determines the exposure of other peoples to high pollutant levels [6]; this is the reason why it is important to estimate the impact of smoker activity on pollutants concentration levels and on their temporal and spatial dispersions. In a previous paper [7] we also discussed the use of photoactive paints for particulate matter degradation with the aim of testing new strategies for indoor air quality improvement. In this work smoke activity was simulated by means of a smoking machine. Actually this instrument works in a standardized way differently by that of human smokers: the advantage associated with the use of a smoking machine is the measurement reproducibility due to parameters control of both the main stream and side stream fluxes.

Material and methods

Particulate matter measurements were carried on by means of a DustScan Aerosol Monitor, a mobile continuous analyzer, based on light scattering principle. That instrument operates in compliance with many European standard and regulations, as FCC CFR 47 Part 15 Digital Device and the European Community Directive 89/336/EEC; moreover instrument calibration was performed by constructor (Rupprecht & Patashnick, NY USA) according to accepted industry methods using equipment, procedures and standards that are traceable to NIST and ASTM.

The smoking machine apparatus was designed for controlling the main stream virtually inhaled by smoker and the side stream emitted from cigarette combustion; it consists of a glass chamber where twenty lodgings for cigarettes are positioned. Moreover the glass chamber presents two independent aspiration apparatus: one for the main stream, collected in specific bags, and the other for the side stream, separately aspired.

For this work we are interested in monitoring the particulate matter in the side stream.

For this reason the second aspiration apparatus was excluded, opening the lateral window of the chamber: in that manner side stream diffuses in the laboratory where it can be registered. Measurements were performed in a room (30 m^2) at the ground floor of the Chemistry Department of "Federico II" University of Naples. The room presents a window facing toward a garden and a door facing a corridor. Both were closed during the experiments: so we can assume that the air flow from/out the corridor and garden was not significant. A centralized air conditioning system is present; measurements was carried on taking care that the conditioning system works in the same manner during all measurements. The window was regularly opened for 1 h every morning before measurements. The room was at a pressure of 1,003-1,023 millibar, temperature of 20 °C and humidity of 30-40% during all the experiments. The room plant and the position of instruments are sketched in Fig. 1.

$PM_{2.5}$ and PM_{10} particle concentrations in the side stream, were measured, simulating the presence of one or three smokers. The Dust Scan monitor was positioned close to the smoking machine (position "instrument 1" in Fig. 1), at a distance of 50 cm. Measurements were repeated at a distance of 1.5 meters from the smoking machine (position "instrument 2" in Fig. 1), in order to determine concentration dependence on space. These distances are those typical between people conversing in the same room, so that they can be considered representative of many situations occurring in the real life.

It is possible to choose the operational parameters for the smoking machine, that is the aspiration volume, aspiration time, aspiration pause and ventilation coefficient depending on the application of interest. Particularly opening percentage in cigarette filter determines a different ventilation condition generating

Tab. 1 - Parameter values for simulating low (ISO) [8], medium (Massachusetts) [9] and intensified (Canada) [10] smoking conditions

	Aspiration Volume (mL)	Aspiration Time (sec)	Aspiration pause (sec)	Ventilation (%)
ISO	35	2	60	100
Massachusetts	45	2	30	50
Canada	55	2	30	0

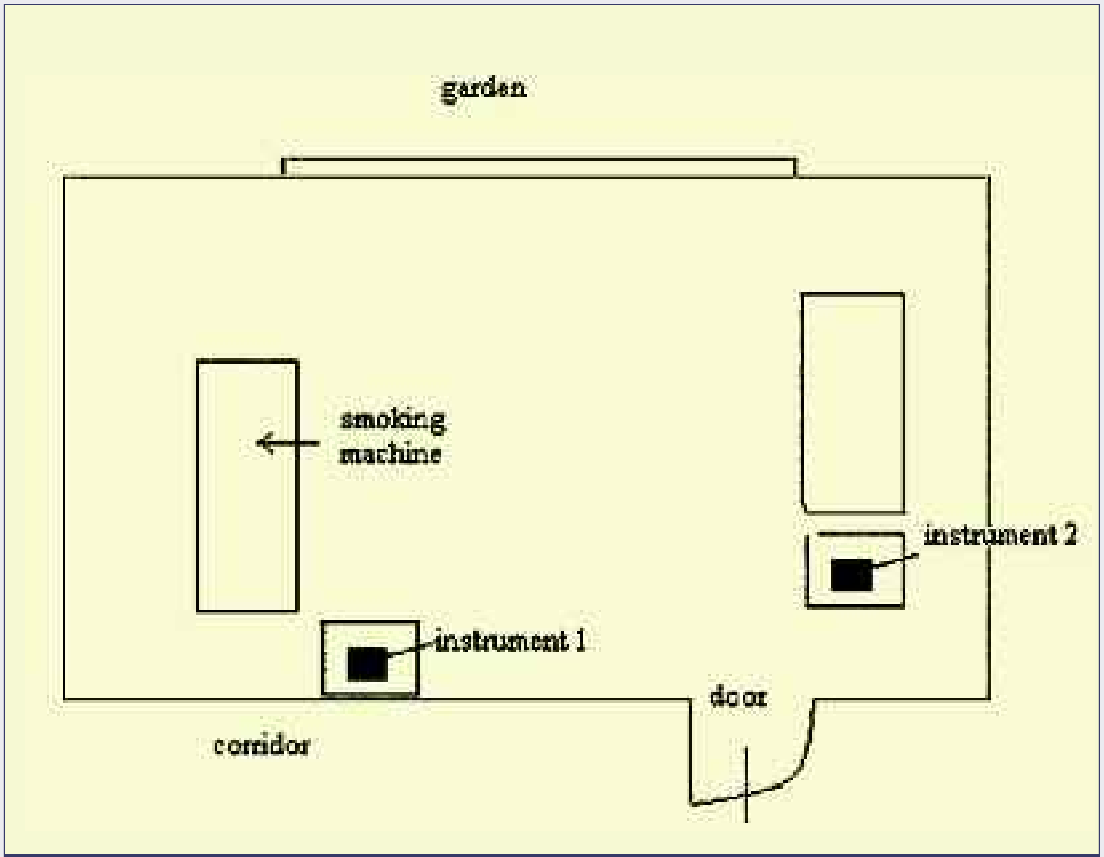

Fig. 1 - Smoking laboratory and position of instruments

SCIENCE & TECHOLOGY

Tab. 2 - Data collected as blanks from the smoking laboratory

	$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	$PM_{2.5}/PM_{10}$
Mean concentration	6±1	8±2	0.75

Tab. 3 - Selected parameters for case studies

Case label	Cigarettes Number	Smoking modality	Distance from smoking machine (m)
1	1	ISO	0.5
2	3	ISO	0.5
3	3	Mixed	0.5
4	1	ISO	1.5
5	3	ISO	1.5

different pollutant concentration levels in smoker mouth and in his lungs. Standard values for these parameters are reported in Tab. 1.

Results and discussion

In Tab. 2 data collected as blank are reported; data consist of $PM_{2.5}$ and PM_{10} concentrations, and $PM_{2.5}/PM_{10}$ ratio measured during night time (that is with smoking machine switched off and laboratory closed). Every experiment was repeated three times, in order to ensure reproducibility.

Particulate matter measurements were performed to estimate the contribution of every smoker (that is every cigarette) close to, and away from, the smoker itself; these measurements were repeated with one and three cigarettes; in the case of three cigarettes, the presence of several smokers was simulated using only ISO modality [8] (see Tab. 1) and after using all different smoking modalities, as reported in Tab. 3.

Concentration profiles

For this study, we considered conditions listed in Tab 3.

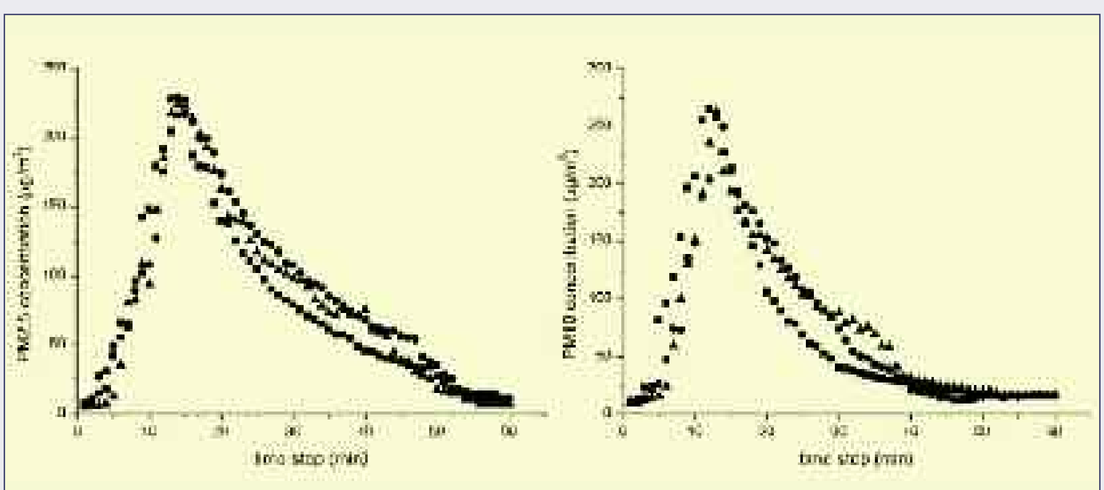

Fig. 2 - Concentration profiles for $PM_{2.5}$ (on the left) and PM_{10} (on the right), case 1

As an example temporal profiles for $PM_{2.5}$ and PM_{10} concentrations collected for case 1 and case 5 are presented in Fig. 2 and 3; on x-axis is represented time step from cigarette ignition, expressed as minutes (the entire measure was as long as sixty minutes for case 1 and ninety minutes for case 5).

Data on $PM_{2.5}$ and PM_{10} concentrations are reported in Tab. 4. All measurements were repeated three times, as in the case of blank measurements, to ensure results reproducibility; so values obtained for each measurement are reported.

Parameters in the Tab. 4 are:

1) peak value, that is the maximum value reached during the measurement, expressed as μg/m³;

2) baseline concentration before ignition, that is the mean concentration before cigarette ignition, expressed as μg/m³;

3) baseline concentration after cigarette extinction, that is the mean concentration of the final plateau, expressed as μg/m³;

4) mean baseline increase, that is the difference, in percentage, between the baseline concentration after and before measurement.

Comparing $PM_{2.5}$ peak values, it results a greater concentration when the monitoring instrument is close to the smoking machine, indicating that dilution effects exerts an influence, though not relevant; in fact concentration drops from 227 to 191 μg/m³ for cases 1 and 4, respectively.

When using three cigarettes and when monitoring instrument is close to the smoking machine (case 2), pick values was so high (409 μg/m³) to saturate the signal registered by the monitoring apparatus; same situation is registered in case 3 and 5.

Apparently this can suggest that dilution effects are not sufficient to reduce so high values; really it is probable that concentration levels would be different without instrument saturation.

In case 1, the baseline increase is very high (from 6 to 12 μg/m³, approximately); in case 2 it is considerable (from 10 to 15 μg/m³, approximately) but lower than the former, indicating a nonlinear effect between concentration increase and cigarettes number. This means that with more cigarettes (cases 2, 3, 5), due to the increased particles production, the aggregation effects and so ground deposition are more relevant. A difference is registered in case 3, with the highest baseline increase among cases with three cigarettes; that is associated to the different smoking modalities, particularly because in this case we use intensified smoking conditions.

For PM_{10}, maximum concentration was registered for cases with three cigarettes. In all cases, the baseline increases after cigarette extinction, stay high for a long time, as in the case of $PM_{2.5}$; the greatest increase corresponds to the case of one cigarette close to the smoking machine as for $PM_{2.5}$. Regarding baseline increase registered for $PM_{2.5}$, PM_{10} presents smaller values; this can be associated with ground deposition effects for heavier particles; moreover precipitation of great particles can favor $PM_{2.5}$ precipitation with a dragging effect.

Moreover, PM_{10} concentration is higher that $PM_{2.5}$ concentration in case 1; in the other cases values are very similar due to instrument saturation (for case 2, 3, 5) or small dilution effects (for case 4).

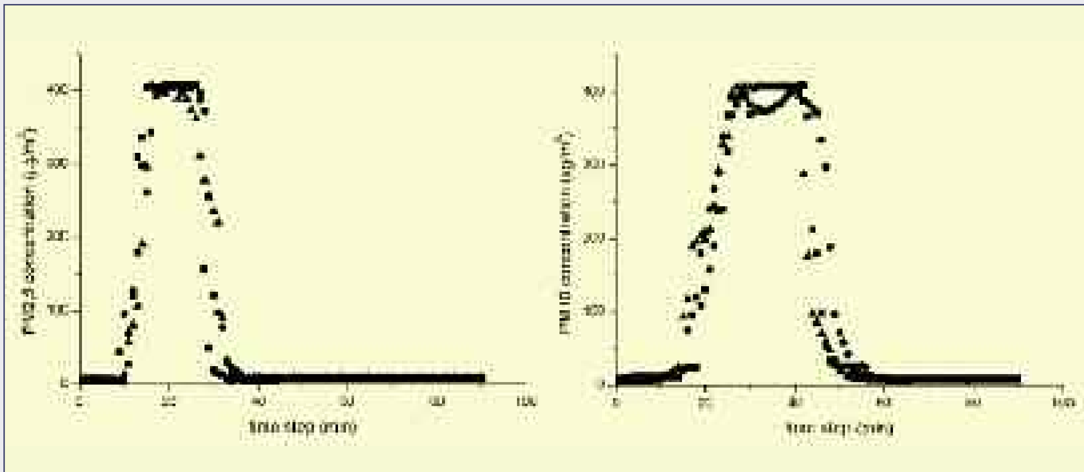

Fig. 3 - Concentration profiles for $PM_{2.5}$ (on the left) and PM_{10} (on the right), case 5

Tab. 4 - Data for $PM_{2.5}$ and *PM_{10}* collected in the smoking machine room. Data from all experiments are reported for each parameter

Case label	1	2	3	4	5
Peak value (μg/m³)	227 *265*	401 *406*	407 *410*	191 *189*	408 *408*
	229 *261*	409 *412*	408 *409*	191 *189*	405 *409*
	224 *263*	409 *410*	408 *409*	192 *195*	408 *406*
Baseline concentration before s ignition (μg/m³)	6 *10*	9 *9*	8 *7*	5 *7*	5 *8*
	7 *10*	12 *13*	8 *9*	5 *7*	5 *6*
	5 *10*	10 *15*	8 *8*	6 *7*	5 *6*
Baseline concentration after extinction (μg/m³)	11 *16*	11 *16*	10 *12*	17 *12*	7 *9*
	14 *15*	13 *13*	17 *12*	15 *9*	8 *7*
	12 *17*	20 *15*	14 *14*	12 *10*	8 *7*
Mean baseline increase	107%	43%	71%	100%	44%
	60%	*28.2%*	*60%*	*47%*	*15%*

Concentration increase and decrease

Data corresponding to concentration increase and decrease were fitted by means of least squares method with the exponential curve:

$$C(t) = C_0 + Ae^{(t-t0)/\tau} \qquad (1)$$

where A is the pre-exponential factor, τ is the time constant, positive for the increasing branch and negative for the decreasing branch, and C_0 is the baseline value. For the increasing branch, data was fitted from cigarette ignition to the maximum value; in the cases with a plateau, fitting was stopped at the first plateau value. For decreasing branch, data was used from the maximum value, or last plateau value, until the last recorded value.

These calculations aimed to associate a process rate to increasing and decreasing curves; for that reason, only the pre-exponential factor and the time constants, indicating the process rate, are reported in Tab. 5.

For $PM_{2.5}$ fraction, cases 1 and 4 (one cigarette) show the slowest increasing rate, with a time constant of approximately 10 minutes. Cases 2 and 3 (three cigarettes) present increasing processes faster than cases 1 and 4, but slower than case 5.

However cases 2 and 3 present a different behavior, attributable to different smoking modality, particularly volume aspiration and aspiration time. Cases with instrument away from smoking machine present faster increase process, because when PM monitor is close to the smoking machine, it records particulate matter gradually, during the emission. When the PM monitor is away from smoking machine, it records the entire PM mass produced by source and arrived to it, so the increase results faster.

For decreasing curves, the fastest processes are those corresponding to cases 3 and 5, that is with three cigarettes and the instrument positioned close to and away from the smoking machine.

This indicates that differences in time and number of aspirations can significantly influence the behavior of the temporal profile.

It can be noted that $PM_{2.5}$ and PM_{10} fractions present a different behavior in decreasing processes: particularly $PM_{2.5}$ presents a steeper decreasing curve but an irregular behavior differently by PM_{10} for which increasing and decreasing behavior are the same.

Conclusions

In this work we simulated the presence of one or more smokers in a limited ambient in order to study the influence of smoking activity on indoor air quality, more precisely on particulate matter concentration.

$PM_{2.5}$ and PM_{10} fractions were determined; data were also used to study the temporal and spatial variations of particulate matter concentration. These experiments confirmed that the influence of a smoker can be significant on the indoor air quality; the presence of one smoker can determine a considerable increase of concentration values, persisting for a long time (nearly 1 hour).

Tab. 5 - Parameters for $PM_{2.5}$ and *PM_{10}* increasing and decreasing rate

Case label	1	2	3	4	5
Pre-exponential factor (µg/m³) for increasing branch (A)	80.1±78 *84.8±44*	54.4±22 *298±145*	123±74 *53.1±30*	13.4±4 *5.5±1.3*	4.28±2 *10.6±3*
Time constant (min) for increasing branch	9.9±1.8 *8.7±2.3*	6.3±1.0 *10.5±3.2*	5.9±1.8 *4.0±0.9*	9.2±0.9 *10.6±0.7*	3.5±0.4 *7.0±0.6*
Pre-exponential factor (µg/m³) for decreasing branch (A)	4,660±16 *744±40*	2,430±247 *101±40*	$1.33\times10^5\pm 2.8\times10^4$ *$1.99\times10^4\pm 4.9\times10^3$*	$1.7\times10^5\pm 8.04\times10^4$ *$6.15\times10^2\pm 42$*	$1.01\times10^6 \pm 4.22\times10^5$ *$2.32\times10^6\pm 1.53\times10^5$*
Time constant (min) for decreasing branch	-21.2±1.4 *-11.5±0.5*	-11.5±0.7 *-29.0±3.6*	-2.9±0.1 *-3.5±0.2*	-5.8±0.4 *-46.6±8.6*	-3.3±0.2 *-4.8±0.3*

In the case with three cigarettes the influence on concentration levels was so high to saturate the signal registered by the monitoring apparatus, i.e. as high as 400 µg/m³ for both PM_{10} and $PM_{2.5}$. These values were reached also in the cases with the monitoring instrument positioned away from the smoking machine.

Only for case 1, the $PM_{2.5}$ maximum concentration value was significantly lower than PM_{10} maximum concentration; in all other cases they were very similar showing that a great amount of particulate matter generated by smoking activity is constituted by the $PM_{2.5}$ fraction.

Temporal profiles obtained from these two fractions are not similar, meaning that the physical and chemical processes act differently on nucleation/condensation/deposition effects, even at the small distances as those taken into consideration in this study.

Aeration system seems not be sufficient to control concentration levels in a closed environment, even in the presence of only one smoker; moreover the distance from the smoker cannot be sufficient to experiment a reduced concentration level, determining an hazardous exposition also for people away from the smoker but in the same room.

Acknowledgments: The authors would like to thank the British and American Tobacco Italy SpA for its financial support and for the smoking machine usage.

Moreover this work has been supported by the 'Centro Regionale di Competenza Analisi e Monitoraggio del Rischio Ambientale' (AMRA), Campania Region, Italy.

Fig. 4 - Smoking machine

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RIASSUNTO

Inquinamento indoor: $PM_{2.5}$ e PM_{10} da fumo di sigaretta

Questo lavoro ha lo scopo di studiare le dispersioni spaziali e temporali delle frazioni di polveri $PM_{2.5}$ e PM_{10} generate dalla combustione di sigarette. Pertanto sono state registrate, a mezzo di uno strumento mobile, le concentrazioni di $PM_{2.5}$ e PM_{10} prodotte da una smoking machine.