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# THE PARTICULATE MATTER IN THE WORKING ENVIRONMENT OF THE DIGITAL PRINTING MACHINE DETECTED BY STATIONARY AND PERSONAL METHODS

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Abstract: *Particulate matter (PM) emitted during the digital printing process is potentially dangerous in the sense that it penetrates deep into the operator's lungs. The mass concentration levels of $PM_1$, $PM_{2.5}$, and $PM_{10}$ particles emitted in the working environment of digital machines were measured after applying two sampling methods, spatial and individual. A sensor sampler with an optical particle counter was used for the spatial method, while a personal sampler of particulate materials was applied for the individual process. The paper's primary goal is to assess the comparability of the concentration of PM particles obtained by different sampling methods.*

Key words: particulate matter, digital printing, sensor, optical and gravimetric analysis

## 1. INTRODUCTION

The indoor air quality can be affected by various harmful contaminants such as carbon monoxide, carbon and nitrogen dioxide, hydrogen sulfide, sulfur dioxide, ammonia, formaldehyde, volatile organic compounds (including benzene, toluene, xylene, etc.), ozone, and PM (Adamović et al., 2022). PM is the most significant pollutant produced by industrial activities (Simões Amaral et al., 2015). To accurately assess the impact of these particles in the working environment, it's essential to determine their concentration and geometric characteristics (Ilić et al., 2014, Ilic Micunovic et al., 2024).

The analysis of PM is a complex process that requires the proposal of different analytical methods depending on the specific requirements and objectives of the research. PM measurement methods are divided into concentration methods such as gravimetric, optical, and microbalance and size distribution methods (microscopical, impaction, diffusion, charging, and complete systems). The gravimetric analysis provides basic quantitative information, while spectroscopy, electron microscopy, and microbalance analysis offer deeper insights into particles' chemical and physical composition. Combining these methods can enable a comprehensive view of the distribution, sources and potential impacts of PM on health and the environment (Simões Amaral et al., 2015).

Gravimetric analysis is a traditional method used to measure the total mass of particulate matter (PM) collected on a filter. This method involves passing air through a filter to trap particles, and then measuring the mass of the particles before and after sampling. Gravimetric analysis is widely used due to its simplicity and accuracy, but it does not provide information on the chemical composition or particle size. For more detailed information regarding these aspects, electron microscopy is recommended (Simões Amaral et al., 2015).

During optical analysis, PM particles are illuminated with a beam of light, during which light is reflected (scattered) from them in all directions while part of the light is absorbed. Optical instruments used to measure the concentration of particles can be based on the principles of light scattering, absorption and extinction (Simões Amaral et al., 2015).

The paper presents the quantitative mass concentration levels of $PM_1$, $PM_{2.5}$, and $PM_{10}$ particles emitted in the working environment of ink jet digital printing machines. In the spatial method, the particles' mass concentration was detected by optical analysis with a sensor sampler. In contrast, in the individual process, the particles' mass concentration was quantified by gravimetric analysis with the personal sampler. The paper further examines the similarities and differences between the concentrations of PM detected with spatial and personal sampling.

## 2. METHODS

### 2.1. Digital printing environment

The research took place at the printing laboratory of the Department of Graphic Engineering and Design at the Faculty of Technical Sciences in Novi Sad, Serbia. PM mass concentration levels were measured near the ink jet digital printing machine, model LEC-540 (Roland, Japan).

### 2.2. Analysis of particulate matter

The spatial method, an essential technique in air quality assessment, involves sampling particulate materials in the air using a static sensor sampler. Its strategic positioning at fixed locations is beneficial. In contrast, the individual sampling method, crucial in assessing workers' exposure, is equally important. Placing a personal sampler near the operator's breathing zone ensures occupational health and safety (Ilić Mićunović, 2018).

#### 2.2.1. Sensor sampler

PM particle mass concentration levels were continuously monitored using an optical particle counter OPC-N2 (Alphasense, United Kingdom) sensor sampler. The sensor device is a portable and precise PM monitor known for measuring PM mass concentrations (µg/m$^3$) with high accuracy and real-time data collection. The sensor was strategically placed where significant operator exposure was expected (Adamović et al., 2023).

#### 2.2.2. Personal sampler

The EGO PLUS TT (Zambelli, Italy) personal sampler was used to collect PM particles with a diameter of less than 10 µm. The device consists of a display setting, a conical nozzle equipped with a filter, and a silicone hose. The membrane filters used were ME 27 (KEFO, Slovenia), made from a mixture of cellulose esters with a pore size of 0.8 µm and a diameter of 25 mm. The filter's effective diameter for collecting particles was 22 mm, and it had an effective surface of 380 mm$^2$. When using a conical attachment for measuring inhalable fractions of PM particles, the manufacturer recommended an airflow rate of 3.5 l/min (Zambelli, Italy). The sampling time was 30 minutes, and measurements were taken within the printing technician's breathing zone, placed on the upper part of the chest (Ilić et al., 2014, Ilic Micunovic et al., 2024).

The mass concentrations of particles with diameters less than 10 µm in the indoor air of digital printing machines were determined using the standard gravimetric measurement method (SRPS EN 12341:2023). To sample PM, a personal sampler collected PM using filter paper placed on the duraluminum filter holder of the sampler. The masses of the filter papers before and after one hour of sampling were measured on an analytical balance, model ABJ-120 (Kern, Germany) with an accuracy of ±10$^{-4}$ g. It's worth noting that the filter papers were only touched with a material called pancetta (Adamović et al., 2022).

The mass concentration levels (quantity) of PM particles with a diameter of less than 10 µm in the indoor air near the digital printing machine were determined according to the Equation (1) (SRPS EN 12341:2023, Adamović S. et al., 2022):

$$Q_{PM} = \frac{m_2 - m_1}{V} \cdot 10^6 \qquad (1)$$

where:

- $Q_{PM}$ is the quantity of particles less than 10 µm (µg/m$^3$),
- $m_1$ and $m_2$ are the masses of the filter paper before and after sampling (g), respectively, and
- V is the volume of air being passed through the device for 30 min (101,6 m$^3$).

## 3. RESULTS AND DISCUSSION

The mass concentrations of $PM_1$, $PM_{2.5}$, and $PM_{10}$ particles were measured with the sensor sampler before machine operation. The readings showed that there were 2.4 µg/m$^3$ of $PM_1$, 3.2 µg/m$^3$ of $PM_{2.5}$, and 3.7 µg/m$^3$ of $PM_{10}$ particles in the air before the machine operation. These values indicate that some particle concentration remained in the air after ventilation and that particles from outside migrated into the indoor air of the printing laboratory, which is not isolated from the outside environment. To obtain accurate mass concentrations for the tested machine, the detected mass concentrations of PM particles were adjusted by the detected zero value. Figure 1 illustrates the concentration levels of $PM_1$, $PM_{2.5}$, and $PM_{10}$ particles during 30 minutes of monitoring using a spatial sampling method with the sensor sampler, showing 8 values with a reading frequency of 4 minutes (Adamovic et al., 2022).

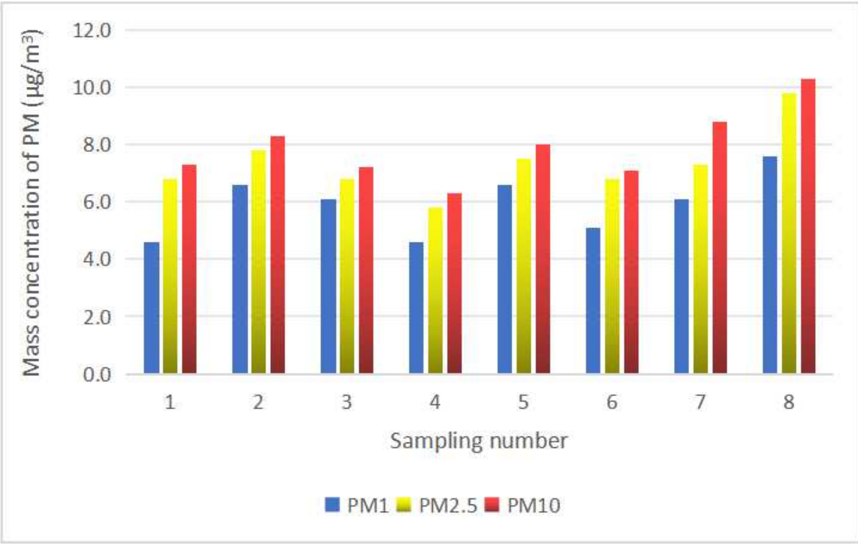


*Figure 1: Concentration levels of $PM_1$, $PM_{2.5}$, and $PM_{10}$ particles detected by spatial sampling with sensor sampler*

The spatial sampling method detected concentrations of $PM_1$ particles in the range of 4.6 to 7.6 µg/m$^3$ for 30 minutes. The concentrations did not grow exponentially, but a 39.5% increase was observed from the 1$^{st}$ to the 8$^{th}$ sampling.

Over a 30-minute monitoring period using a sensor sampler, $PM_{2.5}$ particle concentrations ranged from 5.8 to 9.8 µg/m$^3$. There was a 40.8% increase in concentrations from the lowest (detected in the 4$^{th}$ sampling) to the highest value (detected in the 8$^{th}$ sampling).

The mass concentrations of $PM_{10}$ particles during the same 30-minute monitoring period ranged from 6.3 to 10.3 µg/m$^3$. An increase of 38.8% was observed from the lowest concentration (detected in the 4$^{th}$ sampling) to the highest (detected in the 8$^{th}$ sampling).

After using the personal sampling method, the mass of the filter paper before and after 30 minutes of sampling was 0.0254 and 0.0374 g, respectively. Based on the measured masses and the volume of air passing through the device in 30 min (formula 1), the quantity of PM particles with a diameter smaller than 10 µm was 118.11 µg/m$^3$.

The results indicate that the mass concentration obtained by personal sampling is 5.6 times higher (an 82% increase) than the cumulative value (21.1 µg/m$^3$) of $M_1$, $PM_{2.5}$, and $PM_{10}$ detectable particles with a sensor sampler.

It's important to note that spatial and personal sampling methods may not always produce comparable results. The measurements using personal samplers tend to demonstrate a higher concentration than spatial ones. This has practical implications for air quality monitoring, as it suggests that personal samplers may be more effective in detecting pollutants in certain situations (Ilić Mićunović, 2018). Due to their light weight, size, and the fact that they do not require calibration, passive samplers are preferred over active air pump sensor samplers (Simons et al., 2017).

## 4. CONCLUSIONS

The results based on spatial sampling indicate that the detected mass concentrations decrease in the following order: $PM_{10} > PM_{2.5} > PM_1$. The concentrations of $PM_{10}$ particles are higher than those of $PM_1$ particles by 15.3% to 37.0% and more than 4.2% to 17% higher than $PM_{2.5}$ particles. Additionally, concentrations of $PM_{2.5}$ particles are higher than those of $PM_1$ particles by 10.3% to 32.4%. Also, the cumulative value of $PM_1$, $PM_{2.5}$, and $PM_{10}$ detectable particles with a sensor sampler was 82% lower than the value detected by the gravimetric analysis after the personal sampler.

In future research, the focus will be on improving methodology and incorporating new methods. For example, using scanning electron microscopy, particles can be characterized by their morphological and size distributions. Drying the filters to a constant mass will eliminate the influence of moisture, leading to more accurate results through gravimetric analysis. Analyzing and optimizing the printing process can enhance the result correlations. Identifying the best position for the devices is crucial for minimizing discrepancies between results obtained from different methods.

## 5. ACKNOWLEDGMENTS

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