

EXPERIMENTS TO ASSESS POLLUTION LEVELS IN THE TEXTILE MATERIALS PROCESSING INDUSTRY

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Abstract: Concerns about pollution, its extent, and its impact on the health of organisms and biodiversity have increased over the years. Managing and reducing the effects of pollution are critical issues for policymakers, industry stakeholders, the academic community, and researchers. The textile industry is a potential significant contributor to pollution, producing substantial amounts of wastewater, toxic dyes, and microplastics. Furthermore, it significantly contributes to greenhouse gas emissions due to the energy-intensive nature of manufacturing processes. This study presents the results of experiments conducted to assess the concentration of particulate matter in the air within a textile factory that processes synthetic polymers. Factors influencing particulate concentration levels at different times of the day, as well as the distribution of particles based on their chemical composition, are examined. Key findings from the particle measurements indicate that the highest concentration of particles occurs at the end of the shift (FS), with 0.3 µm particles showing the greatest presence across all time points (beginning of shift, end of shift, and after 16 hours). The particle concentrations follow a consistent pattern, with smaller particles (such as 0.3 μ m) generally outnumbering larger ones (like 10 μ m). The analysis of the particle composition using advanced techniques such as SEM, µRaman and TED-GC/-MS revealed that polyamide particles were consistently present, while polypropylene particles were only identified at the end of the shift due to limitations of the specific techniques. The particle sizes were predominantly smaller than 1.0 μ m, with irregularly shaped particles being the most common. The equivalent diameter of the particles is defined and calculated, with their classification based on this parameter. These findings underscore the need for improved air quality management and pollution control measures in textile production environments to mitigate health risks and environmental impacts.

Key words: pollution, airborne particle, syntetic polymers, silica filter, quartz filter, μ Raman, scanning, equivalent diameter, microplastics



1. INTRODUCTION

Nanoparticles, due to their extremely small size and high reactivity, can penetrate biological barriers and accumulate in human tissues and organs. This raises significant health concerns, especially through inhalation, ingestion, or skin contact. Studies have shown that certain types of nanoparticles can induce oxidative stress, inflammation, and even cellular damage, potentially leading to respiratory, cardiovascular, and neurological issues [1].

The progress made in atmospheric micro- and nanoplastic (MNP) research has seen significant advancements in the last decade. MNPs are released into the atmosphere as a result of an inadequate plastic collection system, resulting in plastic waste in the environment, which breaks down into small fragments through weathering [2]. The accumulation of MNPs in the atmosphere is additionally increased by the operation of wastewater treatment plants, the textile industry processing synthetic fibres, mechanical activities, strong winds, aerosols from the surface of seas, and wave breakage, which frequently transport them [3].



Fig. 1: Atmospheric Transport of Micro-Nanoplastics, Annual Potential Flow[2]

The spraying processes occurring at the sea surface are responsible for approximately 136000 tons of MNPs being blown annually from the water's surface into the air towards the shore (**Fig. 1**). Carried by the wind and waves, microplastics can travel over 1000 kilometres. Atmospheric MNPs are small in size and predominantly under 500 μ m. A significant portion of the particles is smaller than or equal to 10 μ m, the respirable particle size [4]. These particles fall within the size range that is of the most significant concern for biotic, ecosystem, and human health. Therefore, quantifying the amount of small MNPs that the atmosphere supplies to the ocean and the ocean-atmosphere exchange is important for global health.

Additionally, it is acknowledged that indoor air pollution (including plastic particles) can be up to 100 times greater than outdoor air pollution. Daily, a person inhales up to 130 small plastic particles, and the concentration of MNPs in all environments is continuously increasing [5]. MNPs act as carriers for organic and inorganic toxic substances, releasing organic toxins and accumulating in living organisms, supporting their unprecedented distribution in ecosystems [6]. Environmental organic and inorganic contaminants also interact and react with MNPs, potentially enhancing their transport to environmental compartments. Due to these processes, hydrophobic organic and metal pollutants can accumulate on MNPs, move with them, and interact with them to exacerbate their dangerous effects on biota [7]. Thus, MNPs disproportionately accumulate other environmental contaminants, suggesting that MNPs could function as vectors for harmful microorganisms. According to Zhag [8], the surface of polyethylene terephthalate, a type of microplastic, adsorbs microorganisms that are resistant to multiple antibiotics.



Regarding internal exposure, MNPs interact with the human body through mechanisms of adsorption, distribution, metabolism, and excretion. MNPs have been detected in sputum, lungs, liver, blood, urine, placenta, and breast milk. Elevated MNP levels in arteries correlate with cardiovascular diseases, suggesting links between high MNP exposure and health outcomes. Further research is crucial to elucidate the health effects of acute and chronic exposure to realistic concentrations of MNPs in sensitive and general populations [9].

This study presents results obtained by determining the concentration levels of airborne particles in number/m³ and μ g/m³ at three different times during the operations of a textile company processing polypropylene fibre, across three different environments: at the beginning of the work shift, at the end of the work shift, and after 16 hours, measns a 24 h cycle

2. MATERIALS AND METHODS

The study to evaluate the particle concentration levels in the air was conducted for a textile company that processes polypropylene and polyamide yarns with a linear density of 1100-1200 den to create strips with a width of 5-10 cm, intended for reinforcing textile items for packaging/transport. During the weaving process of synthetic yarns, particles or fibres can be produced due to several factors related to the properties of synthetic materials and the mechanics of weaving. Synthetic yarns, such as polypropylene and polyamide, are often smoother and have a higher friction coefficient compared to natural fibres. The friction between the yarns and between the yarn and the weaving machine components (like the loom or shuttle) can cause tiny particles or fibre fragments to break off. Additionally, during weaving, the yarn is subjected to tension and sometimes heat. The combination of these factors can cause a slight degradation of the fibres at the microscopic level, leading to the production of small particles. For example, if the synthetic fibres are not perfectly smooth or have surface imperfections, they may degrade when pulled under pressure or rubbed against other surfaces. Weaving machines often involve high-speed movements and complex mechanical actions, like interlacing the yarns. This can cause fraying, especially if the yarn is not properly processed or is too weak. The mechanical stress on the fibres can result in the release of tiny fibres or particles.

The determination of the particle concentration levels was carried out at three time points: the beginning of the workers' shift (BS), the end of the shift (FS), and after 16 hours (AH) in the proximity of the polypropylene workplace. The production room had natural ventilation. An online procedure was applied to determine the number of particles per cubic meter (particles/m³) in size fractions of 0.3, 0.5, 1.0, 2.5, 5.0, and 10 μ m, as well as the concentration (μ g/m³) of particles of 2.5 and 10 μ m using the TROTEC PC 220 device. The TROTEC device uses laser-based technologies (Class 3R laser, 780 nm) to count airborne particles. The primary principle behind these devices is based on detecting particles suspended in the air and measuring their size and concentration. Thirty determinations were carried out to determine the concentration, expressed in particles/m³ and μ g/m³.

A standard operating procedure has been established for collecting airborne particles using the following equipment: an internal capsule made of polyvinyl chloride (PVC) with a diameter of 37 mm, a hydrophobic filter attached to the PVC casing, and support plates within a two-piece filter cassette holder, also 25 mm in diameter; a Gilian Air Plus sampling pump with a flow rate of 1 to 3 L/min, equipped with flexible connection tubes; a microbalance with an accuracy of $\pm 0.001 \ \mu$ g; a static neutralizer (210Po); plastic tweezers; and a climate chamber maintaining a temperature of $20^{\circ}C \pm 1^{\circ}C$ and relative humidity of 50% ± 5 %. The pump was located about 60 cm away from the working area of the weaving machine, which is located about 90cm from the ground.



Quartz filters produced by SKC INC (USA), catalogue number 225-1824, were used for the experiments [10]. These 25 mm diameter quartz filters were heated to 800°C to eliminate traces of organics, contain no binders, and have a low metallic background. The filters have a thickness of 280 μ m and a pore size of 1.2 μ m. The 9 mm silicon wafer membranes are double-sided polished filters and produced by Smartmembranes with a thickness of 0.1 mm and a pore size of 1 or 10 μ m. For collection, an adaptation of the GilAirPlus pump holder was made to ensure the concentration of the airflow on the surface of the filter. The collection was carried out in a cascade, selectively for particles of 1 μ m and 10 μ m. [11].

Particles collected on Si filters were analyzed by scanning electron microscopy (SEM) and µRaman methods. SEM analysis is a powerful technique used in materials science, biology, chemistry, and other fields to study the surface structure, particle size and shape and partly composition of materials (EDX-SEM). It uses a focused beam of electrons to scan the sample and create high-resolution images. Raman analysis, or Raman spectroscopy, is a powerful and nondestructive technique used to study the vibrational, rotational, and other low-frequency modes of molecules. The technique is based on the Raman effect, which is the inelastic scattering of light by molecules, discovered by Indian physicist C.V. Raman in 1928 [12]. This analysis provides molecular-level information about a sample without the need for extensive sample preparation. The " μ " in μ Raman refers to the ability of the technique to focus on very small areas (micron-scale) of a sample, allowing for high spatial resolution. This makes µRaman ideal for studying heterogeneous materials, small features, or microscopic regions of interest within a sample. Unpolarized µ-Raman measurements were performed using a triple spectrometer 557 TriVista (S&I Imaging GmbH) in reflection geometry. Excitation was carried out with the 514.5 nm line of the DSS laser, with an output power level of approximately 100 mW. The laser was focused on the sample with a 100x/0.9 microscope objective with a working distance of 0.3 mm, having a spot size smaller than $2 \mu m$. The reflected laser light was rejected by an edge filter. The Raman spectrum was collected with a monochromator with a 1500 g/mm grating and a focal length of 750 mm. Spectrum acquisition was done with a 1024 x 256 Si-CCD cooled with liquid nitrogen.

Particles collected on quartz filters were analyzed by thermal extraction desorbtion-gas chromatography/mass spectrometry (TED-GC/MS). This is a powerful analytical technique combining thermal extraction, gas chromatography, and mass spectrometry to provide detailed and accurate information about the volatile compounds present in a variety of sample types. Its applications range from environmental monitoring to food quality control and forensic investigations. Here, the samples are heated from 25 to 600°C under inert nitrogen atmosphere. The decomposition gases were collected on a solid phase adsorber, desorbted in thermal desorbtion unit and focused by the cold injection system at -100 °C, before the molecules are separated in GC and detected in MS. Further information is given in [13].

3. RESULTS AND DISCUSSIONS

In Fig. 2a, 2b, the evolution of the number of particles/m³ and the concentration of particles $(\mu g/m^3)$ at the two selected times is presented.



Fig. 2: Evolution of the particle number a) BS time b) FS time

In Fig. 3a, 3b the evolution of the particle concentration of 2,5 and 10 μm ($\mu g/m^3)$ at the tow selected time is presented.



Fig. 3: Concentration $(\mu g/m^3) a)$ BS time, b) FS time

In **Table 1** and **Fig. 4** the evolution of the average, minimum, and maximum values of the number of particles/m³ at the selected times are presented.

Statistics		Number of particles/m ³							
		Particle type, µm							
Time		0.3	0.5	1.0	2.5	5.0	10.0		
BS	Min.	55723.0	16170.0	2255.0	352.0	43.0	25.0		
	Max	74821.0	22228.0	3104.0	488.0	101.0	56.0		
	Mean	66288.06	19894.2	2784.1	413.8	76.5	40.8		
	Std	3868.7	1275.4	190.7	35.1	12.1	7.0		
FS	Min.	62236.0	18487.0	2524.0	406.0	69.0	38.0		
	Max	103000.0	49825.0	4540.0	884.0	228.0	149.0		
	Mean	77476.5	24529.9	3503.4	587.4	133.3	82.9		
	Std	10.094.4	5535.0	536.0	119.0	41.6	28.9		
AH	Min.	56088.0	17343.0	2470.0	366.0	58.0	32.0		
	Max	97337.0	29913.0	3700.0	590.0	128.0	77.0		
	Mean	66792.9	20472.2	2968.1	452.7	87.4	49.4		
	Std	8639.3	2461.4	315.0	49.9	20.3	12.7		

Table 1: The evolution of the average, minimum, and maximum values





Fig. 4: Evolution of the particle average number/m³

Fig. 5: Evolution of the average concentration of the particle($\mu g/m^3$)

From the analysis of the data presented in the table 1 and figures 4 the following aspects result:

• 0.3 μ m Particles: The highest average count is observed at FS time (77,476.5/m³), significantly higher than at BS (66,288.06/m³) and AH (66,792.90/m³). Across all times, 0.3 μ m particles consistently have the highest counts, outnumbering the 0.5-10 μ m particles.

• 0.5 μ m Particles: FS time records the highest count (24,529.9/m³), followed by similar counts at BS (19,894.2/m³) and AH (20,472.2/m³). While still higher than 1.0-10 μ m particles, 0.5 μ m counts are lower than 0.3 μ m particles at all times.

• 1.0 μ m Particles: FS time again shows the highest count (3,503.4/m³), with BS (2,784.1/m³) and AH (2,968.1/m³) trailing behind. 1.0 μ m particles are consistently fewer than 0.3 μ m and 0.5 μ m particles but still exceed 2.5-10 μ m particles at all times.

• 2.5 μ m Particles: The highest count is at FS time (587.4/m³), with BS (413.8/m³) and AH (452.7/m³) showing lower levels. These particles have fewer counts than the smaller sizes (0.3 μ m, 0.5 μ m, and 1.0 μ m) but more than the 5.0-10 μ m particles across all times.

• 5.0 μ m Particles: FS time shows the highest count for 5.0 μ m particles (133.3/m³), with BS (76.5/m³) and AH (87.4/m³) showing lower levels. These counts are always lower than 0.3 μ m, 0.5 μ m, 1.0 μ m, and 2.5 μ m particles but consistently higher than the 10 μ m particles.

• 10.0 μ m Particles: FS time records the highest count (82.9/m³), with BS (40.8/m³) and AH (49.4/m³) values also lower. 10 μ m particles have the lowest count across all sizes and times.

The average values for all type of particle are quite similar at the time BS and AH.

In **Table 2** and **Fig. 5**, the average, minimum, and maximum values of the particle concentrations (μ g/m³) at the selected times are presented. The analysis shows that the highest concentration of 2.5 μ m and 10 μ m particles is found at AH time (51.3 and 258.4 μ g/m³, respectively). This increase in particle concentration may be determined by several factors, such as humidity and temperature, which can vary significantly from day to day, influencing particle dispersion. In the morning, when humidity is higher, dust particles may settle more quickly on surrounding surfaces. At 3:00 PM, higher temperatures or lower humidity may have favoured a longer suspension of particles in the air, which explains their higher concentration.

On the first day, at BS time, the environmental parameters were: T: 21.3°C and RH: 55.6%, at FS time T: 30.0°C and RH: 45.0%, and on the second day, at AH time, T: 25.0°C and RH: 45.8%. It is also possible that intensive cleaning of the machines or production area could have released particles that had accumulated over previous days. Additionally, cleaning activities in the morning, with equipment that stirs up more dust, could lead to an increase in the concentration of particles in the air.



Type of		BS	FS	AH
particle/Time				
2,5 µm	Min.	20.0	58.0	23.0
	Max	33.0	115.0	323.0
	Mean	23.9	78.2	51.3
	Std	2.41	13.4	61.1
10 µm	Min.	58.0	76.0	74.0
	Max	115.0	168.0	2287.0
	Mean	78.2	130.3	258.4
	Std	13.4	21.5	436.4

Table 2: The average, minimum, and maximum values

Mass spectra used for quantification of polypropylene and polyamide are presented in **Fig. 6**, and in **Table 3**, the mass of collected particles obtained by TED-GC/MS.

Samples	Polypropylene, µg	Polyamide, µg	Sum, µg
BS	Non detected	5,50	5,50
FS	1,53	2,98	4,51
AH	Non detected	7,14	7,14
Blank	Non detected	Non detected	0,0

Table 3: The mass of collected particles

Data analysis highlights the fact that polypropylene particles were identified only at FS time (1.53 μ g) and PA at all selected times (BS-5.50 μ g, FS-2.98 μ g, AH 7.14 μ g). Identification occurred via the PA marker caprolactam with m/z 113, 55 and 85. PP was detected by use of 2,4,6,8-tetramethylundec-10-ene (m/z 111, 69, 154, 210). The evolution over time of total amounts follows the same trend outlined above. The particle counting results above show many small particles but only small amounts for particles with 10 μ m. Since large particles have much more volume/mass compared to small particles, they contribute much more to the PP and PA mass detected with TED-GC/MS. Obviously, the PA particles reach the limit of detection and quantification of the TED-GC/MS instrument, while at BS and AH the mass of particles is too low for quantification.



Fig. 6: Mass spectra for PA (m/z 113) and PP (m/z 111) of particles collected on quartz filters

In Fig. 7a and 7b, SEM images for $10\mu m$ and $1\mu m$ particles collected with Si filters at FS time are presented and in Fig. 8a, the classification and evolution of equivalent diameter.





a. Si - 10µm

b. Si - 1μm Fig. 7: SEM for the particle of 10μm and 1μm



Fig. 8: a. particle classification; b. Evolution of equivalent diameter

All the samples indicate a high concentration of particles on Si filters and a lower concentration of fibres. The majority of the particles exhibit an irregular shape.

The particle classification by diameter follows the same trend as mentioned earlier, with a higher proportion of particles having a diameter smaller than $<1.0 \,\mu m$ compared to those in the 2.5-10.0 μm range. Since most particles are irregularly shaped, the equivalent diameter was calculated to better represent the distribution of particle sizes. The equivalent diameter is defined as the diameter of a sphere that has the same volume or area as the actual particle, even if the particle is not spherical. This diameter allows for a comparison of the particle's characteristics, such as cross-sectional area or volume, with those of a spherical particle. In all cases, the equivalent diameter of the collected particles is below 1.5 μm .

In **Fig.9** the Raman spectra of 1 and 10 μ m polypropylene and polyamide particles are presented. Polypropylene, a polymer with a typical Raman spectrum, exhibits several characteristic peaks. The vibrational modes commonly observed include: CH2 and CH3 groups, with -CH2- and -CH3 stretching and bending modes typically in the range of 1400 cm⁻¹ to 3000 cm⁻¹; CH2 wagging/bending around 1000-1300 cm⁻¹; and C-C stretching in the 800-1000 cm⁻¹ range. The amide functional group (-CONH-) gives rise to characteristic Raman peaks from its stretching and bending vibrations, with the Raman spectrum of polyamide (Nylon) showing peaks between 400-2900 cm¹.



The Raman spectra (**Fig. 9**) confirm the results obtained with TED-GC/MS regarding the chemical structure of the particles collected at the selected times, specifically identifying polyamide and, to a lesser extent, polypropylene.

This phenomenon may have the following causes:

• Polyamide (such as nylon) has a higher density (1.13 g/cm^2) and a structure that is more difficult to disperse in the air compared to polypropylene (0.9g/cm^2) . Although both are plastic materials, polyamide is more hygroscopic (meaning it absorbs more moisture), which can influence the behaviour of the particles in the air. These polyamide particles may remain suspended in the air for a longer period or may be more easily captured by collection systems.

• Polyamide has a higher melting point (220 $^{\circ}$ C) than polypropylene (160 $^{\circ}$ C), which may mean that during the processing, polyamide can solidify more quickly and form finer particles. These fine polyamide particles are easier to suspend in the air and can be more readily captured by collection systems.

4. CONCLUSIONS

• The study on particle concentration in the air at a textile company manufacturing polypropylene and polyamide yarns reveals significant insights into the airborne particles generated during the weaving process. Key findings from the particle measurements indicate that the highest concentration of particles occurs at the end of the shift (FS), with 0.3 μ m particles showing the greatest presence across all time points (beginning of shift, end of shift, and after 16 hours). The particle concentrations follow a consistent pattern, with smaller particles (such as 0.3 μ m) generally outnumbering larger ones (like 10 μ m).

• Environmental factors like temperature and humidity appear to influence particle concentration, with higher temperatures and lower humidity at the end of the shift contributing to a greater suspension of particles in the air. The cleaning activities in the morning and the presence of accumulated particles may also contribute to the elevated particle levels.

• Furthermore, the analysis of the particle composition using advanced techniques such as SEM, μ Raman and TED-GC/-MS revealed that polyamide particles were consistently present, while polypropylene particles were only identified at the end of the shift due to limitations of the specific techniques. The particle sizes were predominantly smaller than 1.0 μ m, with irregularly shaped particles being the most common. The study's findings suggest that polyamide's higher density and hygroscopic nature could make it more prone to remaining suspended in the air compared to polypropylene.

• In conclusion, this study highlights the importance of monitoring and controlling airborne particle concentrations in workplaces involving synthetic yarn processing, as the potential for



respiratory exposure and environmental impact exists. The results also underline the need for further research into the effects of particle size distribution and material properties on air quality.

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