Smart Technologies for the Control of Emerging Contaminants in Ambient Air

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Abstract. Air quality protection and control is an issue of growing interest. The aspects related to the spread of the coronavirus have accentuated this attention. Furthermore, among the emerging contaminants (EC's) in ambient air, the microplastics (1 – 5 μm) are a great concern arising from anthropogenic activities. These pollutants may bring detrimental effects on human health. To control the EC's, the first activity is the characterization. To date, limited studies highlight and describe technologies able to identify and measure the presence in the air of these types of emerging pollutants (EP's). Furthermore, the presented studies show a methodology gap in their experiments.
The research presents and discusses the state-of-the-art adopted technologies to characterize MPs in ambient air and pointing out strengths and weaknesses. Knowledge gap, uncertainties and recommendations are highlighted. The paper provides useful information in enhanced monitoring to support policymakers in emerging microplastics pollutants and related issues, as well as potential smart technology to be implemented.

Keywords: microplastics, air quality management, emerging pollutants, smart instrumentation

1. Introduction

Emerging pollutants (EPs) are recognized as a synthetic or naturally-occurring chemical or biological compounds that are not yet monitored and regulated in the environment (UNESCO, 2021). At present, there is a growing awareness of Es in atmosphere (Zarra et al., 2019), especially microplastics (MPs) of which is made-up of synthetic solid particles with size 5 mm - 100 nm, derived from fragmented larger plastics (Mbachu et al., 2020). In fact, the rate of plastic production per year is 3%, and reached 322-348 million metric tons in 2016-7017. 10% of this volume ended up to waste, while only 3% had been recycled (Enyoh et al., 2020; Gasperi et al., 2018). MPs differ from other EPs by having a longer degradation rate (i.e., hundreds to thousands of years) (Zhang et al., 2021). Moreover, these pollutants can be found in ambient air both indoor and outdoor, and the recent SARS-CoV-2 outbreak (COVID-19) has increased MPs due to the facemask disposal (Enyoh et al., 2020). MPs can enter human body through ingestion, inhalation and skin contact (Campanale et al., 2020). Its consequences can be physical toxicity, inflammation, immune reactions, etc. (Campanale et al., 2020; Enyoh et al., 2020). Therefore, this type of EP can be a serious problem, and their control is necessary. Key action in control is the characterization, to implement the most appropriate and targeted mitigation measures (Giuliani et al., 2012; Zarra et al., 2014).

The paper aims to present and critically evaluate and compare the existing methods in the characterization of MPs in the ambient air, providing informative outlooks as well as some potential avenues. Data about the principal emissions sources, details on the different typologies of MP detectable in the air and the general concentrations presents in the environment are pointed out. Information's about the existing control methodologies and methods are highlighted.

2. MPs in ambient air: source and typologies

As an emerging pollutant, MPs are produced from primary source such as the direct production for consumer and industrial application, while secondary source refers to the fragmentation of larger plastic particles through chemical and/or mechanical process in the environment (Zhong and Li, 2020). The three (3) most common types of MPs are fibers, beads, and fragments of irregular shape (Zhang et al., 2021). Moreover, they were made from a different organic structure such as polyethylene (PE), polystyrene (PS), polyurethane (PU), polyvinyl chloride (PVC), etc. (Bianco et al., 2020; Zhang et al., 2021). The dispersion and transport of MPs in the air are mainly influenced by the particle size and climatic factors such as atmospheric pressure, wind direction, temperature, snowfall and rainfall (Zhang et al., 2021; Zhong and Li, 2020).

3. MPs characterization methods

Characterizing MPs is one of the most significant steps in addressing this pollution. The characterization consists of determining the structure and size-range. The lack of standardized methods approved and for all typologies is a shortcoming and a challenge at this moment to obtain a complete characteristic assessment of MPs.

Table 1. Current MPs characterization methods with strengths and weaknesses

Method	Instrument/s	Strengths	Weaknesses	References
Visual	Microscope/ stereoscope	Fast and simple	Erroneous identification for MPs >1 mm	(Gaston et al., 2020)
Spectroscopy	Fourier Transform Raman Spectroscopy	Identification of ≥2 μm MPs and structure (≤20 μm)	Large and complex data generation. Difficult detection for opaque plastic particles.	(Levermore et al., 2020; Tofa et al., 2019)
Thermal Analysis	Pyrolysis Gas Chromatography	Mass fraction, amount and size of MPs identification	Long time analysis and not appropriate for large quantity samples	(Laurentie et al., 2018)

Table 1 summarized the three main recognized methods currently applied and their principal strengths and weaknesses. The reported methods are limited only to simple, but not to complex MPs. Furthermore, the presence of different factors in the environment, such as moisture (or humidity), are a hindrance to obtaining an accurate characterization, for which multi-parameter methods are suggested to improve a complete MP characterization.

4. MPs control technologies

To date, limited technologies directly treat MPs in air. O'Brien et al. (2020) for instance report the application of an inbuilt filtration system to capture MPs emissions from the mechanical dryer of synthetic textile laundry. The system seems effective for indoor environment with large MPs size (~ 200 μm), while for MPs of 50 μm the type of filter material must be further studied.

capture large MP particles, however, there is no assurance on the complete removal because small-sized MPs (>10 μm) can still escape into the environment. In this case, further treatment is still required for the complete removal of MPs. Also, in the study of Wang et al. (2020) and Rajala et al. (2020), hazardous reagents were employed, which adds toxicity and requires proper handling & disposal. On the other hand, Tofa et al. (2019) applied photocatalytic degradation to MPs. The system seems to be environmental-friendly, however, it lacks selectivity especially to high-density MPs. While, Sundbæk et al. (2018) investigated MP's (20 μm) sorption to macroalga (seaweed), *Fucus vesiculosus*, highlighting that the macroalga were selective based on MPs surface charge and that the MPs cannot be recycled when it adheres to the surface. Table 2 summarize the reported treatment technologies and their principal strengths and weaknesses.

Table 2. Summary of the strength and weakness of the different MPs control technologies

Technology	MP Size	Removal Efficiency	Strengths	Weaknesses	References
Advanced Biofilter	100 μm	79 – 89%	Can retain >100 μm MPs due to multiple layer design (gravel, filtrate and stone wool)	Longer acclimatization period (i.e., 2.5 months)	(Liu et al., 2020)
Photo-Aging with Organic Acids and Fe (III)	2 – 150 μm	---	Fast response degradation with the presence of low molecular weight organic acids	Reliant to the particle size and generate hazardous waste	(Wang et al., 2020)
Photocatalytic degradation	50 μm	---	Relying to sunlight as energy source	Difficult to scale up and large space is required	(Tofa et al., 2019)
Coagulation/ Flocculation	<10 μm	99.40%	Easy MP removal with chemical addition and ordinary mixing	Generation of hazardous sludge required further treatment and disposal	(Rajala et al., 2020)
Adsorption to algae, moss, etc.	20 μm	94.50%	High affinity to absorb MPs particles	Selective to a particular type of MP (i.e., PE, HDPE, etc.)	(Sundbæk et al., 2018)

The most practical approach to treat MPs is to solubilize them into the aqueous phase. Liu et al. (2020) installed biofilter as an advanced polishing step in WWTP while Rajala et al. (2020) applied coagulation/flocculation to remove MP substances, and Wang et al. (2020) studied photo-aging of MPs (2 – 150 μm) with organic acids (OAs) and Fe (III). Both three systems successfully

5. Future Perspectives

To ensure a complete control of MPs, a continuous characterization and consequently optimization of the treatment process, is suggested and shall be performed on a regular basis. In this view the implementation of a smart, real-time monitoring system, based on the Artificial Intelligence (AI) technique, can be represent the new challenge. Recent studies from Bianco et al. (2020) highlight the application of 3D/digital holographic signatures with machine learning (deep-learned) for MPs detection. Further advances are however needed in terms of sensors and neural network algorithm optimization.

6. Conclusion

MPs are considered emerging contaminants in ambient air and responsible of persistent effects in the human body due to their long decomposition. The paper presents and discusses the recent development in the field of MPs management in the air. Characterizing MPs include determining the size-range and structure; however, the present methods do not allow to detect complex MPs. On the other hand, physical and biological methods are the main current MPs treatment approaches, however, they only serve as pre-treatment because MPs with size >100 μm can still escape in the atmosphere. Continuous monitoring of MPs represents the new challenge. In this view smart technologies based on artificial intelligence approach are innovative systems to improve the reliability of current systems by showing rapid and accurate detection.

7. References

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