



Various advanced wastewater treatment methods to remove microplastics and prevent transmission of SARS-CoV-2 to airborne microplastics

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Abstract

Microplastics (MPs) and SARS-CoV-2 interact due to their widespread presence in our environment and affect the virus' behaviour indoors and outdoors. Therefore, it is necessary to study the interaction between MPs and SARS-CoV-2. The environmental damage caused by MPs is increasing globally. Emerging pollutants may adversely affect organisms, especially sewage, posing a threat to human health, animal health, and the ecological system. A significant concern with MPs in the air is that they are a vital component of MPs in the other environmental compartments, such as water and soil, which may affect human health through ingesting or inhaling. This work introduces the fundamental knowledge of various methods in advanced water treatment, including membrane bioreactors, advanced oxidation processes, adsorption, etc., are highly effective in removing MPs; they can still serve as an entrance route due to their constantly being discharged into aquatic environments. Following that, an analysis of each process for MPs' removal and mitigation or prevention of SARS-CoV-2 contamination is discussed. Next, an airborne microplastic has been reported in urban areas, raising health concerns since aerosols are considered a possible route of SARS-CoV-2 disease transmission and bind to airborne MP surfaces. The MPs can be removed from wastewater through conventional treatment processes with physical processes such as screening, grit chambers, and pre-sedimentation.

Keywords Advanced wastewater treatment · Advanced oxidation processes · Adsorption · Membrane bioreactors · Microplastics · SARS-CoV-2

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Introduction

Ecosystems can be affected by microplastics (MPs) particles ranging in size between 0.1 μm and 5 mm (Fig. 1) (Kutralam-Muniasamy et al. 2020). It is possible to manufacture MPs directly (in small sizes), called primary microplastics, such as virgin resin pellets, microbeads in personal care products, industrial scrubbers in abrasive cleaning agents, and plastic powders used for moulds (Khalid et al. 2020). However, it is becoming increasingly clear that MPs pose a threat to aquatic life and humans (Van Cauwenberghe et al. 2014) as well as to

the environment (Viveknand et al. 2021). The secondary microplastic particles are produced when larger plastic particles fragment (Naik et al. 2020). The fragmentation of large plastics occurs due to textiles, paint, tyres, or plastics being released into the environment.

The MPs can absorb persistent organic pollutants (such as polychlorinated biphenyls) (Wang et al. 2021a, b, c) as well as heavy metals (Mao et al. 2020). A million times more persistent organic pollutants can adhere to plastics than to ambient air, which can further be desorbed by organisms, causing them to accumulate at higher trophic levels (Bakir et al. 2014) (Fig. 2). Various additives are added to the plastics during manufacturing, including

Fig. 1 Size and structure of MPs in the sewage

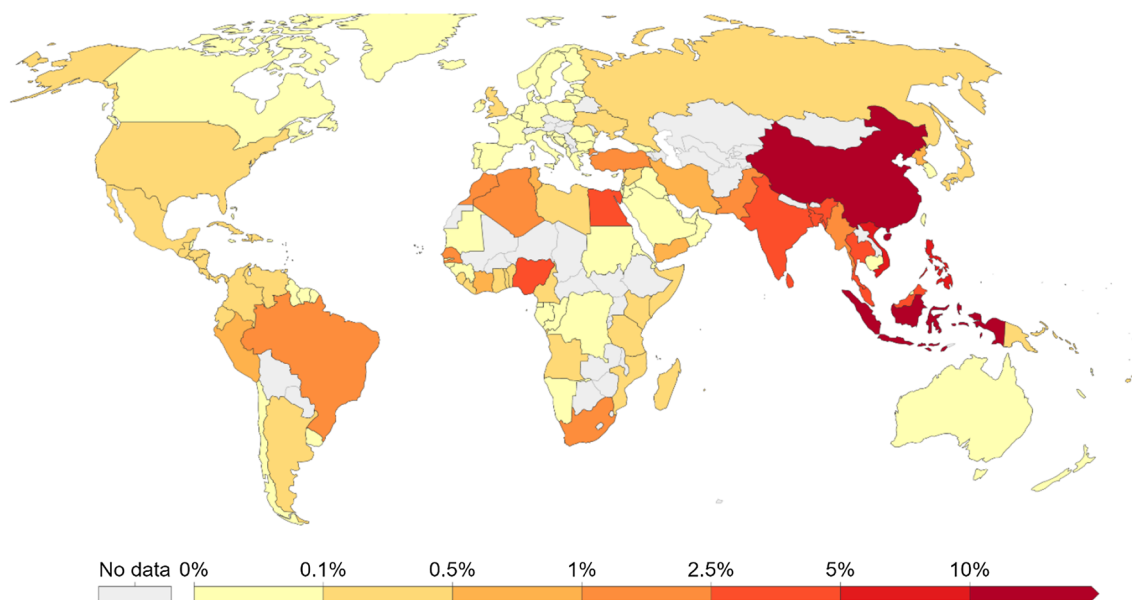
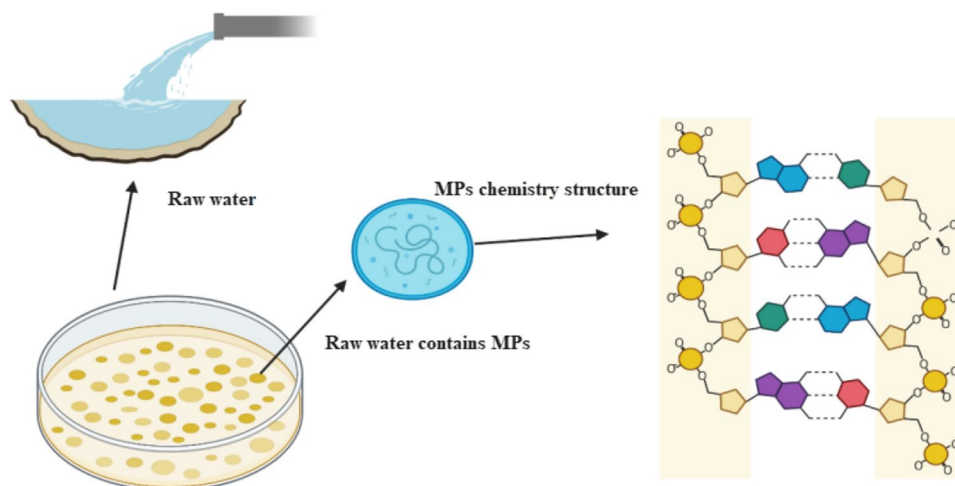


Fig. 2 Mismanagement of plastic waste globally in 2021. *Source:* Our World in Data based on BP Statistical Review of World Energy & Ember (2021)

techniques (pyrolysis-GC-MS, thermal extraction-GC-MS, and liquid chromatography (LC)) (Elert et al. 2017), as well as non-destructive spectroscopic techniques (Nuelle et al. 2014), such as Fourier transform infrared spectroscopy (FTIR) (Löder et al. 2015) and Raman spectroscopy (Dümichen et al. 2017). The most popular technique was a spectroscopic (FTIR and Raman) analysis of MPs in environmental samples (Hidalgo-Ruz et al. 2012). With these techniques, a spectroscopic is identifying MPs (ca. < 1 mm) as tiny as μm is challenging. Here is an analysis of these methods, including advantages and limitations (Table 1) (Rocha-Santos et al. 2015).

Plastics (Table 2), such as polyethylene, polypropylene, and polystyrene, are integral to the production of face masks and gloves. Their waste is a known source of environmental pollution has led to widespread concern that SARS-CoV-2 may be transmitted via personal protective (Zahmatkesh et al. 2022b) equipment (PPE) (Abbasi et al. 2020). Managing the wastewater systems efficiently at a local and regional level will help prevent the spread of SARS-CoV-2 at all levels by preventing sewage pollution from plastic waste containing SARS-CoV-2 (Kitajima et al. 2020). Infectious disease transmission and prevalence of COVID-19 pandemics (Zahmatkesh et al. 2022a). Due to various environmental factors (climate change, water transfer, air, and food) (Zahmatkesh and Sillanpää 2022) and disinfection of surfaces and hands (Eslami et al. 2020). The amount of MPs produced depends on the physical properties of the plastic material, including its stiffness, thickness, anisotropy, density, etc. (Ivleva 2021). On the other hand, MPs smaller than $10 \mu\text{m}$ can be suspended and transported through the air (Sobhani et al. 2020).

Several studies have shown that SARS-CoV-2 can survive in aerosol droplets for 3 h (Zahmatkesh et al. 2022c) and on plastic surfaces for 72 h at a room temperature of 20°C and relative humidity of 40% (Aboubakr et al. 2021). In addition, several studies have shown that viral levels in environmental matrices are declining. However, the SARS-CoV-2 can still threaten public health if used gloves and face masks are not adequately collected and disposed of under various environmental circumstances (Lo Giudice 2020). If SARS-CoV-2 contaminated PPE (Kasloff et al. 2021) waste is not appropriately managed (Ong et al. 2020), hundreds of MPs can be emitted by plastics. Thus, MPs may transmit the SARS-CoV-2 virus ($< 10 \mu\text{m}$) emitted from PPE waste up to 10 miles by wind or ventilation systems, especially sewage systems, from indoor to outdoor environments or from urban to remote areas (Silva et al. 2020). If PPE is disposed of improperly, MPs are released into the sewage (Silva et al. 2020), providing an additional transmission vector for SARS-CoV-2 (De-la-Torre et al. 2021).

Since the 1980s, wastewater treatment has enhanced effluents' final quality (Talvitie et al. 2017). Based on the

Table 1 The chemical characterisation can be used to improve MP identification

Identified microplastics by number and type	High-quality spectrum		Time required for measurement		Challenge
	Raman	FTIR	Raman	FTIR	
FTIR imaging is less sensitive to microplastics; thus, microscopic particles (less than $1 \mu\text{m}$) v are appropriate for Raman	Microscopic particles ($< 10 \mu\text{m}$) that are impossible to detect; a smaller fraction of microplastics ($< 20 \mu\text{m}$) is underestimated	The purity of the sample is critical	Prolonged measurement time	Rapid measurement	Different particles are focused
C=C compounds, as well as aliphatic and aromatic compounds, are easily detected	A wide range of aliphatic compounds as well as polyesters has been detected	There is a strong relationship between measurement parameters and accuracy	Microplastics can be detected less often, resulting in reductions in measurement time, accompanied by a loss of spectra quality	Research can be conducted even in large sample areas	A dataset created that is too large for downstream analysis; only a subset is usable
Polyesters (except PET) pose a challenge for accurate identification	The fluorescence is partially visible	Particle size and thickness are important considerations			
		If particles exceed $50\text{--}100 \mu\text{m}$ in size, they are absorbed entirely			



Table 2 Due to the extensive use of masks and PPE kits during the COVID-19 epidemic

Polymers detected in WWTPs		Different shapes of MPs detected in the WWTPs							References
Polymers	Density (g/cm ³)	Size of MPs (µm)	Fibre (%)	Granule (%)	Pellet (%)	Film (%)	Foam (%)	Fragment (%)	
Polyethylene	0.89–0.98	125	58	–	0	4	4	35	Duis and Coors (2016)
Polypropylene	0.83–0.92	125	8	–	4	15	4	70	Duis and Coors (2016)
Polystyrene	1.04–1.1	125	58	–	1	8	2	30	Gies et al. (2018)
Polyethylene terephthalate	0.96–1.45	125	39	–	2	5	1	53	Lares et al. (2018)
Polyester	1.24–2.3	125	15	–	2	6	–	77	Long et al. (2019)
Polyamide	1.02–1.16	125	68	–	5	2	5	21	Mason et al. (2016)
Polyoxymethylene	1.41	125	13	–	6	13	3	65	Müller et al. (2018)
Polyvinyl chloride	1.16–1.58	65	18.5	–	3	9.9	1.3	67.3	Murphy et al. (2016)
Synthetic rubber	0.85–0.9	64	65.6	0.45	5.4	0.2	0.22	28.1	Lares et al. (2018)
Polyaryl ether	1.14	43	17.7	49.8	2.5	–	–	30	Gies et al. (2018)
Polyurethane	1.2	50	85.92	–	–	14.08	–	–	Murphy et al. (2016)
Polyvinyl fluoride	1.7								Yang et al. (2019)

concentrations of MPs in influent and effluent, the removal efficiency of the WWTP was calculated (Iyare et al. 2020). Except for the study that determined that it is possible to remove up to 88% of MPs from wastewater using conventional treatment techniques (preliminary and primary treatment), tertiary treatment removes up to 97% (Sun et al. 2019). Furthermore, the pre-treatment impacted MPs size distribution, as it removed MPs of larger sizes (Talvitie et al. 2017). Although conventional WWTPs can significantly reduce MPs, the high volumes of effluent discharged make them a significant MPs source (Sun et al. 2019). Between 35–59% of the MPs were removed before a primary treatment (preliminary treatment) (Bilgin et al. 2020) and 50–98% after primary treatment (Wu et al. 2021). The MPs in wastewater are further reduced to 0.2–14% (Talvitie et al. 2017) by secondary treatment (usually biological treatment and clarification). In this condition, sludge flocs or bacterial extracellular polymers (Zhang et al. 2020) in the aeration tank help accumulate debris from the plastic removal process (Petroody et al. 2021). A secondary treatment using chemicals such as ferric sulphate or other flocculants could also be effective in removing MPs since these chemicals could cause suspended particulates to aggregate and form flocs (Zhang et al. 2020). The MPs are likely to be removed significantly more efficiently with tertiary treatment. Following the tertiary treatment, the MPs in the wastewater declined further to 0.2–2% relative to the influent. Membrane-related technologies have been shown to be the most effective at removing MPs (Wu et al. 2021).

Detection of MPs in WWTPs effluent and influent can reasonably be expected. There have only been a few studies on MPs in WWTPs influent, and studies have reported particle concentrations ranging from 1 to 10,044 particles/L (Estahbanati et al. 2016). MP concentrations that ranged from 0 to 447 particles/L have been measured from WWTPs effluents. The MPs concentration varies significantly between these WWTPs, possibly due to the different sampling methods, pretreatments, and analysis methods used in each study. The MPs concentrations may increase if a more refined mesh size is applied (Stanton et al. 2020). The analysis of quantitative data without chemical characterisation may lead to errors (Mason et al. 2016), particularly when distinguishing natural fibres from synthetic ones. Thus, some studies included fibre count in their analysis. The standardising or harmonising sampling and analysing methods of MPs are urgently needed to compare MPs concentrations across studies.

The polymers have been detected in influent and effluent from WWTPs (Cheung et al. 2017). A variety of polymers were found to be dominant in influent and effluent of WWTPs, including polyester (PES, 28–90%), polyethylene (PE, 4–41%), polyethylene terephthalate (PET, 33–25%), and polyamide (PA, 33%–35%) (Ziajahromi et al. 2017). Synthetic clothes are made out of PES, PET, and PA, while personal care products, such as body scrubs and soaps, and food packaging, are made from PE (Cheung et al. 2017; Lares et al. 2018; Ziajahromi et al. 2017). The shape is another critical indicator used for MPs classification. MPs



have a complex shape that can affect their removal efficiency in WWTPs, affecting how they interact with other contaminants and microorganisms (Zahmatkesh et al. 2020). There are currently two typical classification schemes used to classify MPs. MPs are retained on different sieve sizes in the first method, and a second technique uses microscopic imaging.

Several studies have concluded that humans consume MPs mainly through food and drinking water, although the conclusions are extrapolated from a limited amount of research. MPs are rare in the body, but limited information regarding their size and characteristics. The direct measurement of MPs in humans and large mammals is challenging due to ethical and technical issues. Nevertheless, the faeces can serve as excellent representative samples for studying the interactions between MPs and gut flora, as they may provide direct evidence of MP inhalation. MPs have been identified in the faeces of animals in only a few studies, but not in an effective and optimised manner.

Microplastics removal efficiency in advanced wastewater treatment:

An advanced treatment could provide a significantly different treatment process to improve effluent quality before discharge. The tertiary treatment technologies could be used (Zhang et al. 2021a, b, c), including denitrifying biological aerated filters (BAFs), gravity sand filtration (GSF), disc filters, and dissolved air flotation (DAF), membrane bioreactors (MBRs), and advanced oxidation processes (AOPs). The primary and secondary treatments have already removed most of the MP from wastewaters; tertiary treatment is likely to have less impact on MP removal. In addition, the tertiary

effluent has a fewer MPs concentration of 0.2–2%, in contrast to the tertiary influent. The concentrations of MPs would depend on the samples taken from the effluent and the measurement methods (Zahmatkesh et al. 2022f).

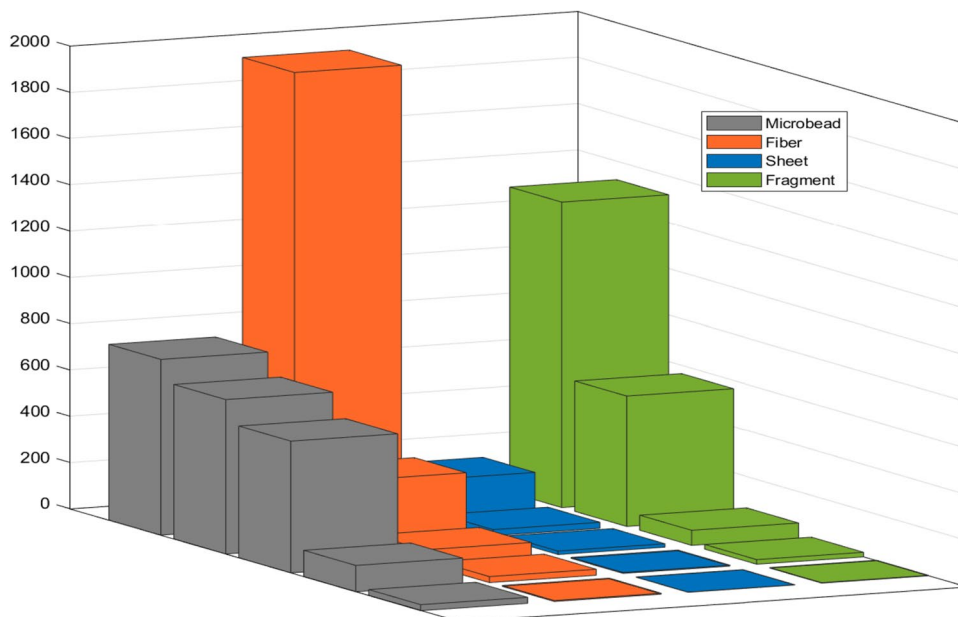
The removal efficiency of MPs can vary depending on the advanced treatment technique. In several studies, the removal efficiency of MPs using various advanced treatment techniques has been compared, and tertiary treatment that utilises membrane-related techniques proved to be the most effective method. On average, the MPs are declined by 97% with advanced treatment. The treatment process affects the removal efficiency of MPs. The most powerful technology that can remove MPs is a MBR (99.9%), followed by three main types of methods: rapid sand filter (97%), dissolved air flotation (95%) and disc filter (40–98.5%) (Ngo et al. 2019) (Figs. 4, 5).

Effect of membrane process on removing microplastics

The MPs are still a challenge for membrane technology. The studies have highlighted the potential when membrane separation and membrane bioreactor MBR technology are used alongside other treatment methods to achieve more effective MPs removal (Poerio et al. 2019). There is a strong correlation between removing plastic particles and the parameters used to identify them, such as their shape, size, and mass. Several factors can affect the membrane process performance, including material, pore size, thickness, and surface properties (Golgoli et al. 2021; Zahmatkesh et al. 2022g) (Fig. 6).

As wastewater treatment progresses, biofilms are becoming more popular with processes such as fluidised bed

Fig. 4 Removed various MPs in the primary treatment (grit chamber + primary settling), secondary treatment (bioreactor + secondary settling), and tertiary treatment (coagulation + ozone, membrane disc filter and rapid sand filtration) and effluent



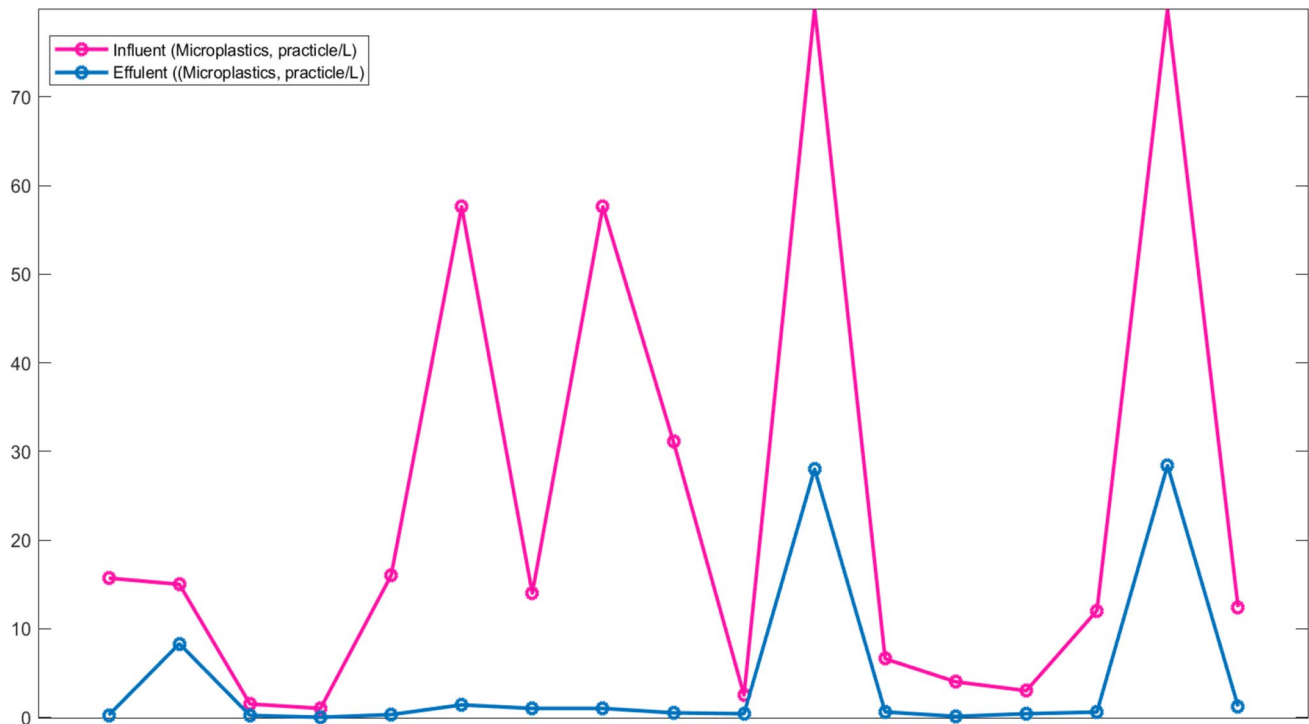


Fig. 5 Overview of previous studies for removing MPa (Dubai et al. 2013; Dris et al. 2015; Tagg et al. 2015; Mason et al. 2016; Carr et al. 2016; Mintenig et al. 2017; Michielssen et al. 2016; Talvi-

tie et al. 2017; Talvitie et al. 2017; Leslie et al. 2017; Ziajahromi et al. 2017; Lares et al. 2018)

reactors, rotating biological contactors, and MBR. Due to its high capacity to remove contaminants, MBR is the most popular among these technologies for high-strength wastewater treatment (Padervand et al. 2020). As a result of the dual biodegradation and membrane filtration mechanisms, only small molecules can pass through the membrane. The solid particles, biomass, and macromolecules are captured in the membrane and removed with the slow sludge (Zhang et al. 2020). Thus, MBRs can remove up to 99.9% of MPs. In test results conducted at Kenkaveronniemi WWTP in Finland, the technology reduced MPs concentrations from 6.9 ± 1.0 item/L down to 0.005×0.004 item/L. Talvitie et al. (2017) test found only two MPs passing through the MBR system because of clogged filters and leaks in seals. The technology was also successful for Lares et al. (2018), who observed 99.4% MP removal. MPs were removed at a consistent and significant rate by MBR. In contrast to other wastewater treatment filters, membrane bioreactor filters do not have large pores (around 0.08 m) that MPs cannot pass through. As a result, MBR effectively eliminates MPs from wastewater flow, and it is probably the most efficient wastewater treatment technology (Zahmatkesh et al. 2022h) (Table 3).

The MBR technology has identified the three main limitations: controlling biofilm thickness (Ngo et al. 2019), congestion (Joo et al. 2021), and liquid distribution (Lv et al. 2019),

determining its efficacy. According to Lares et al. (2018), 99.4% of the MPs were removed in comparison to Talvitie et al. (2017). The size of the MPs in Lares et al. (2018)'s research was significantly greater than that of the other studies, 250 m versus 20 m, with the MPs being removed at a rate lower than 99.4%. The membrane primarily captures MPs of larger size. As a result of the constrained factors, MBR technology is ineffective after a period of operation.

Effect of ultrafiltration on removing microplastics

Removing MPs during the coagulation and ultrafiltration processes (UF) represents a significant challenge because these technologies are used to produce drinking water (Ma et al. 2019). In recent years, only a few papers have reported the removal of MPs through coagulation and UF processes. The ultrafiltration and coagulation techniques are used along with Fe-based coagulants, and (Ma et al. 2019) reviewed the type and behaviour of PE removed from drinking water. PE, one of the plastic pollutants detected in the water, has a density similar to water ($0.92\text{--}0.97$ g/cm³), making its removal by water treatment challenging. Following coagulation, there was a low removal efficiency (below 15%) of PE particles, indicating that the only coagulation process is insufficient to remove MPs. However, when coagulation was enhanced with polyacrylamide (PAM), PE removal efficiency was

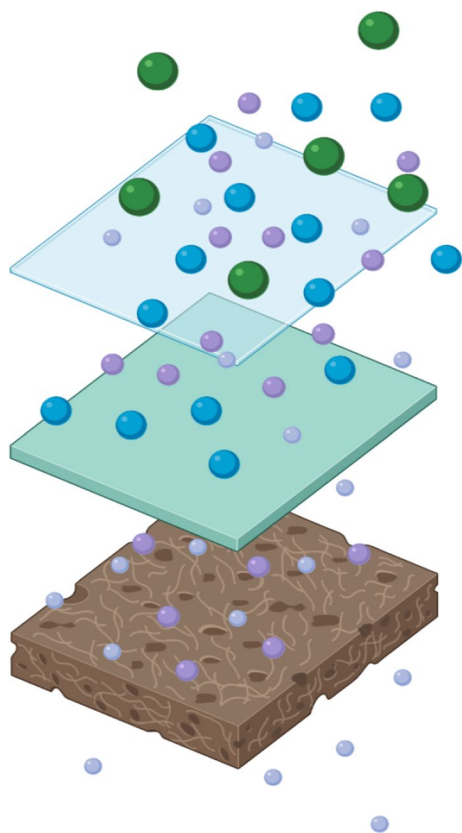


Fig. 6 Water filtration membrane

significantly increased from 13 to 91% for small-particle size ($d < 0.5 \mu\text{m}$) (Li et al. 2021).

As part of the UF performance, coagulation with PE led to a progressively reduced layer of membrane fouling. Due to large PE particles being present in the floc cake layer by increasing the dosage of coagulant, the porosity of the layer increased. Using only flocs resulted in less severe membrane fouling, and the PE particles with larger sizes influenced membrane fouling positively. Following the coagulation with 0.2 mmol/L PAM and 2 mmol/L $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, the membrane flux dropped by 10% only in the presence of large-particle PE ($2 < d < 5 \mu\text{m}$) (Enfrin et al. 2020). There is no guarantee that these results will be valid since many factors can influence them. For example, membrane process and plastic characteristics (chemical composition, size, and shape) may influence the results.

Effect of reverse osmosis on removing microplastics

According to Ziajahromi et al. (2017), reverse osmosis (RO) effectively removed MPs. In order to characterise and quantify MPs, samples were taken from a wastewater treatment facility that uses several treatment methods such as sand and sedimentation, biological treatment, flocculation, de-chlorination / disinfection, ultrafiltration, and RO. The observations of the samples after RO reveal the presence of microplastic fibres. A FTIR is beneficial in detecting and identifying irregular-shaped MPs in attenuated total reflectance techniques (ATR) as modified polyester resin (alkyd resin), commonly used in paints. According to the authors,

Table 3 Using various technologies to remove MPs

Various treatment methods for removing MP	Smallest size of MP (μm)	MP Influent concentration (mg/L)	MP Effluent concentration (mg/L)	MP removal (%)	Techniques for detection	References
A 2O	50	–	–	54.4	FTIR	Yang et al. (2019)
A 2O	47	47.4	34.1	28.1	Raman	Liu et al. (2019)
Activated sludge	25	1.4	0.5	66.7	FTIR	Ziajahromi et al. (2017)
Trickling filters	64	2.6	0.5	80.8	FTIR	Gies et al. (2018)
Primary/RO	25	2.2	0.2	90.4	FTIR/Visual	Ziajahromi et al. (2017)
Primary/dissolved air flotation	20	2	0.1	95	FTIR	Talvitie et al. (2017)
Primary/MBR	20	6.9	0	99.9	FTIR/Raman	Talvitie et al. (2017)
Primary/MBR	250	57.6	0.4	99.4	FTIR/Raman	Lares et al. (2019)
Primary/MBR	0.7	68	51	–	Visual	Leslie et al. (2017)
Primary/MBR	20	91	0.5	99.4	Visual	Michielssen et al. (2016)
Primary/MBR	250	57.6	0.4	99.3	FTIR/Visual/ Raman	Lares et al. (2018)
Primary, secondary, tertiary (GF, BAF)	125	–	0.009	–	Visual	Mason et al. (2016)
Primary, secondary, tertiary (gravity filter)	40	–	0	–	FTIR/Visual	Carr et al. (2016)



this microplastic detection is due to membrane defects or a small opening in the pipework, thus showing the need to devise methods to remove MPs ad-hoc (Im et al. 2021). In conjunction with membrane bioreactor technology, MPs can be removed most effectively with RO (Skuse et al. 2021).

Nanotechnology has revolutionised RO processes, and biomimetic RO membranes have improved RO efficiency. However, this technology has captured only 90.45% of the plastic debris that extends beyond 25 cm. Compared to MBR, the result is lower, 99.9%, with more minor MPs (20 µm). Although the WWTPs have four treatment stages, including primary, secondary (Poerio et al. 2019), tertiary treatments and RO, 10 M of plastic debris are released into the natural aquatic environment each day.

Effect of chlorination and UV-oxidation on removing microplastics

The chlorination and UV-oxidation are the most widely used advanced oxidation processes in WWTPs. Chlorine as a disinfectant is widespread in WWTPs (Kelkar et al. 2019). Despite this, MPs were not entirely resistant to chlorine attacks. More MPs were formed during chlorination because MPs cracked during the process (Ruan et al. 2019). This may have been caused by chlorination breaking the bonds and creating new ones during the reaction (Lv et al. 2019). According to the new chemical structure of high-density polyethylene (HDPE) in chlorine disinfection (Eichhorn et al. 2001), it consisted of C–C–C asymmetrical chains, C–C–C symmetrical chains, CH₂ twists, and CH₂ bends, observing a compression force on Raman peaks after intense chlorination (Wang et al. 2018). In addition, an entirely new chlorine-carbon bond was formed (Cl–CH₂–C–H). Increasing toxicity and hydrophobicity of carbon-chlorine bonds could lead to MPs adsorbing and accumulating potential hazards quickly.

The chlorine occurs during polystyrene's aliphatic and aromatic degradation (Zebger et al. 2003). Moreover, the aliphatic C–H backbone shifted towards a higher wavenumber (from 2901 to 2940 cm⁻¹). The shift signified that the backbone bond was compressed towards higher energy. The solid nature of MPs oxidised by chlorination also changed their physical and chemical characteristics (El-Shahawi et al. 2010). A polypropylene was not susceptible to chlorination. Although high dosages and long exposure times were used, no changes in chemical bonds were observed. The coexistence of other pollutants, microorganisms, and biofilms may affect the MPs structures due to competitive reactions and chlorine quenching.

MPs, due to UV-oxidation, changed in topography and chemical properties. The MPs were primarily homogenous and compact in the original. In the process of UV-oxidation, MPs become rather rough. Polyethylene, polypropylene, and

polystyrene suffered everyday degradations due to slight oxidation, cracks, and flakes. Having a crack or flake in MPs caused them to break easily, which led to smaller and even nanoscale plastics (Cooper et al. 2010). Fractures can extend into cracks, considered stress concentrators, and fracture loci. The brittle surface areas or layers cause the embrittlement of flakes of microplastic. The UV-oxidation MPs are less well known for their intermediates and toxicity. The MPs degradation should be studied in detail in regard to UV irradiation time and environment differences. Salinity and organic matter dissolved in wastewater also affect the degradation of MPs in WWTPs (Zahmatkesh et al. 2022i).

Effect of ozonation and activated carbon on removing microplastics

Advanced water treatment technologies such as ozonation and granular activated carbon (GAC) filtration are used primarily to reduce contaminants (Wang et al. 2020a, b, c). The effects of ozonation integrated with GAC filtration on MPs removal have been investigated. They found that MPs concentrations in effluent were slightly increased; however, 56.8–60.9% of the MPs were removed using the GAC filtration process (Zahmatkesh et al. 2022j). MPs may also be broken up into smaller sizes during the ozonation process, which will benefit subsequent GAC filtering since this method is particularly effective at removing small particles. The top three polymer types removed by GAC filtration were PE, PP, and PAM.

Microplastics in the airborne

Sources of MPs in the air are widely dispersed, which determines exposure to them in the environment. With the assumption that MPs are evenly distributed per cubic metre on the surface and are vertically distributed up to 10 km above the ground, an effective radiative forcing of 0.044 × 0.399 mW/m² has been calculated for present-day AMPs. Several factors lead to primary MPs, primarily synthetic textiles, erosion of synthetic rubber tyres, and city dust (Revell et al. 2021). The wind transfer is credited with creating 7% of all ocean contamination (Chen et al. 2020). There may also be sources of AMPs, such as plastic fragments released from clothing and house furnishings, materials in buildings, waste incineration, landfills, industrial emissions, particle resuspension, particles from traffic, synthetic particles used in horticultural soils (e.g., polystyrene peat), sewage sludge used as fertiliser, and tumble dryer exhaust (Prata 2018; Wang et al. 2021a, b, c). Fashion and season play a significant role in influencing the amount and quality of MPs particles in airborne clothing. In addition, artificial textiles may contribute to environmental pollution in indoor



and outdoor settings (O'Brien et al. 2020). Several factors affect their fate and dispersal in indoor and outdoor environments. MPs may also be subject to the same factors affecting particle transport in the atmosphere as particulate matter (Horton et al. 2018), including wind, temperature, and pollution concentration (Bullard et al. 2021).

Despite the lack of studies on environmental exposure, AMPs cause illnesses in industrial workers (Fig. 7). MPs can cause occupational illnesses in certain positions even when they are expected to be exposed to low environmental concentrations (Prata 2018). The following industries can produce airborne MPs: (a) synthetic textiles, (b) flocks, and (c) vinyl chloride and polyvinyl chloride (PVC) (Amato-Lourenço et al. 2020).

Plastic particles or leachates from plastic particles have been linked with occupational diseases (Xu et al. 2020).

Depending on an individual's metabolism and susceptibility, response to inhaled particles may be manifested in different ways, including immediate bronchial reactions (asthma-like), diffuse interstitial fibrosis (Campanale et al. 2020) and granulomas with fibre inclusions (extrinsic allergic alveolitis, chronic pneumonia), inflammatory and fibrotic changes in bronchial and peribronchial tissues (chronic bronchitis), and pneumonia (Silva et al. 2021). The synthetic textile, flock, vinyl chloride, and PVC industries are often occupational diseases. This is because the plastic particles irritate the skin and cause these diseases, and they are usually undifferentiated. For example, two workers have been died when chronic inhalation of polyacrylate nanoparticles caused respiratory failure from inadequate ventilation in an air spray unit.

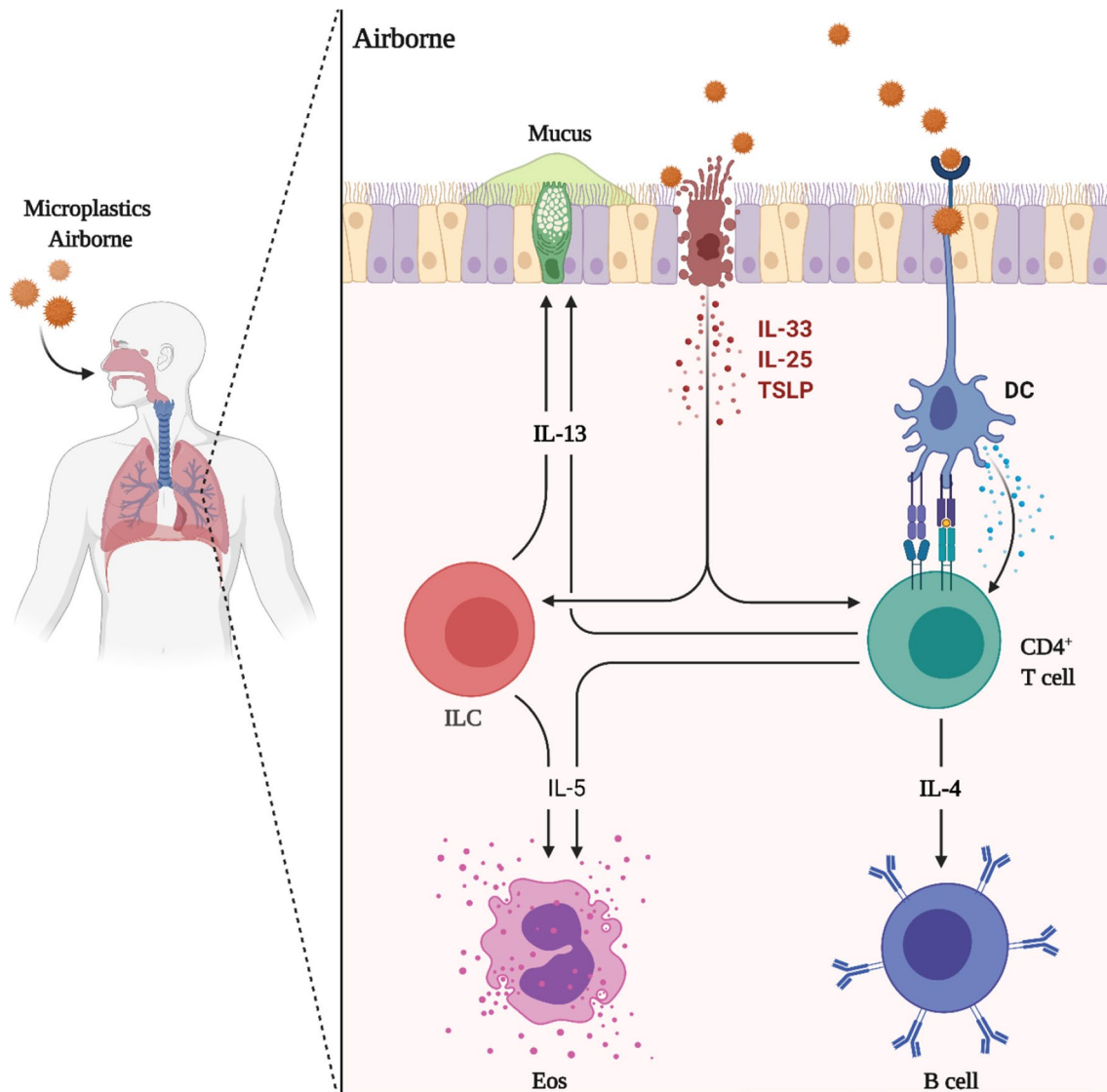


Fig. 7 Effect of AMPs on the human body system



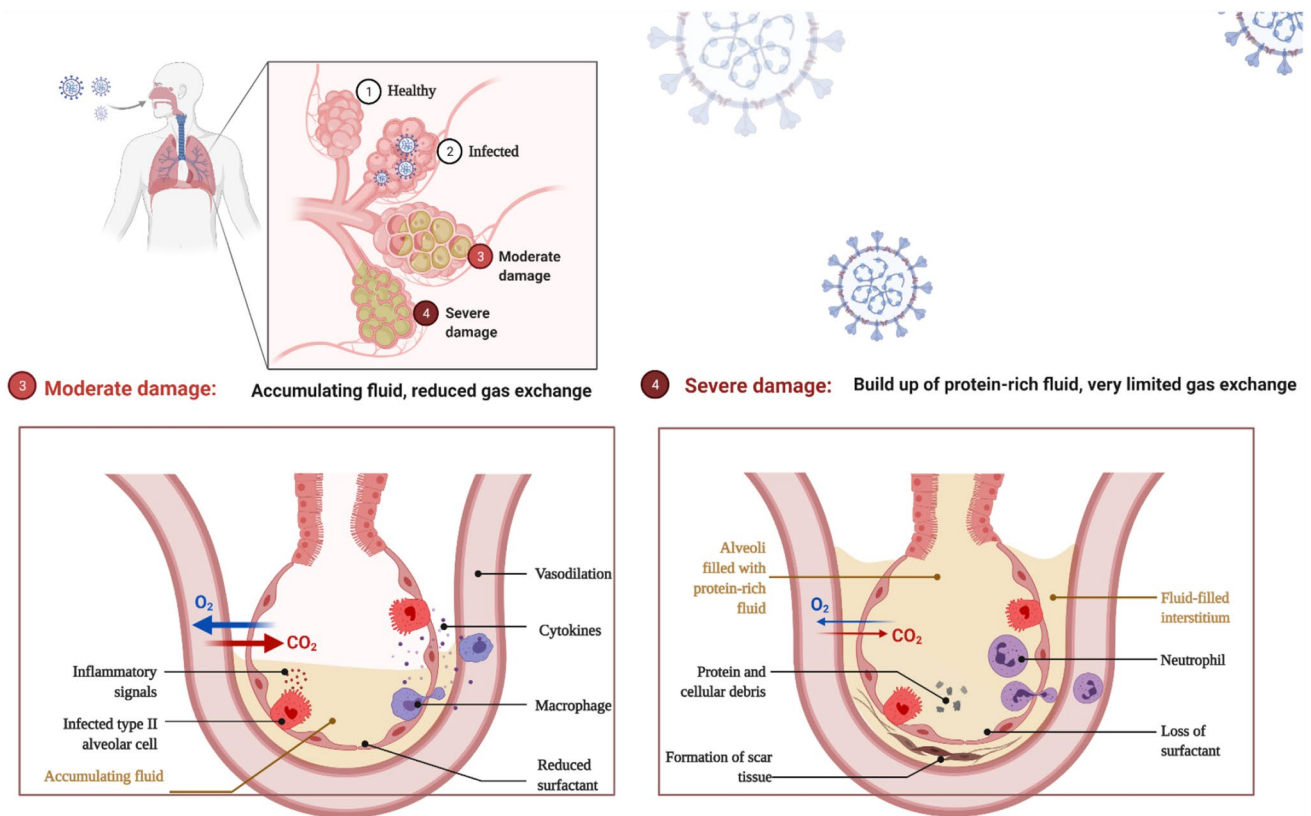


Fig. 8 Effect of SARS-CoV-2 on respiration

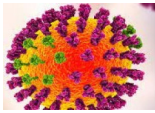
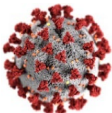

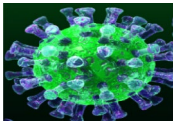
Airborne microplastic and SARS-CoV-2 in the area surrounding

SARS-CoV-2, a new human coronavirus that causes severe respiratory tract infections, has recently emerged as a significant concern for global health (Fig. 8). Transmission of SARS-CoV-2 is believed to occur primarily through direct contact between people and surfaces, and it is crucial for viral transmission that a virus can survive in the environment. The viruses survived on plastic surfaces for up to five days at room temperature and 3 h in aerosols (Prather

et al. 2020). Due to MPs' ability to be carried in the air, SARS-CoV-2 can incubate in formed viral biofilms on their surfaces (Zahmatkesh et al. 2022d). Since MPs are carried airborne over long distances (over 100 km), this allows for a more extended range of travel for the virus than is currently expected (Wang et al. 2020a, b, c) (Table 4).

The SARS-CoV-2 virus is easily contracted by touching contaminated surfaces and hands; thus, it has been strongly urged to wash hands with soap or sanitiser to prevent the virus from being spread and wear masks to avoid excreting droplets/fluids (Fig. 9). An airborne MPs contaminated with

Table 4 Epidemiological comparison of respiratory viral infection

Disease	Flu	SARS-CoV-2	SARS-CoV	MERS
Disease-causing pathogen				
R ₀ (basic reproductive number)	1.3	2–2.5 (COVID-19 data as of March 2020)	3	0.3–0.8
CFR (case fatality rate)	0.05–0.1%	3.4% (COVID-19 data as of March 2020)	9.6–11%	34.4%
Incubation time	1–4 days	4–14 days (COVID-19 data as of March 2020)	2–7 days	6 days
Hospitalisation rate	2%	19% (COVID-19 data as of March 2020)	Most cases	Most cases
Community attack rate	10–20%	30–40% (COVID-19 data as of March 2020)	10–60%	4–13%
Annual infected (global)	1 billion	N/A (ongoing)	8098 (in 2003)	420

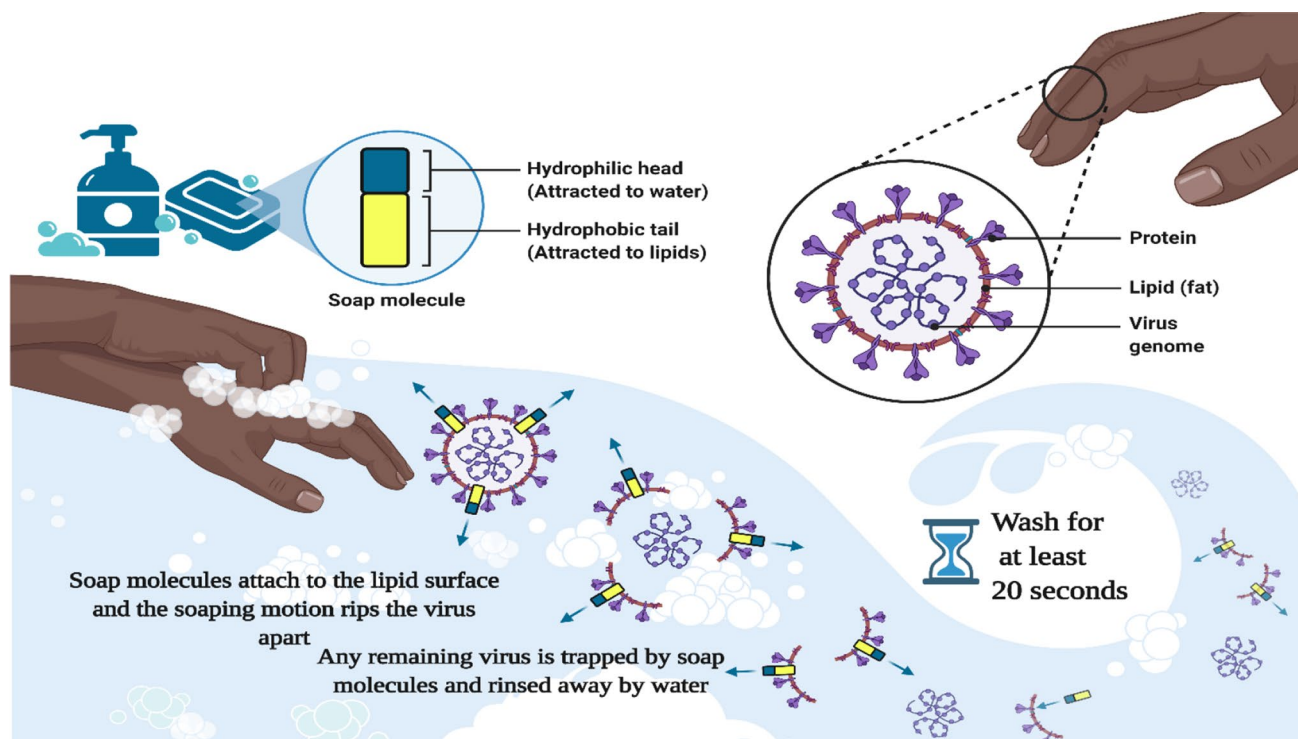


Fig. 9 The process of killing SARS-CoV-2 with soap

the virus is another way to contract it. According to studies, SARS-CoV-2 can survive on plastic surfaces (also in aerosol) for five days at room temperature (Aboubakr et al. 2021). In contrast, it does not survive on copper for four days (Fig. 10), stainless steel for two to three days, wood or glass for four days, or cardboard for 24 h (Marquès et al. 2021). The SARS-CoV-2 and MPs were found in faeces, and it is believed that the aerosolisation of viruses in contaminated faeces has led to the spread of this outbreak.

Since MPs, as well known, can transport to new areas and contaminate them by re-concentrating, they are associated with significant ecological risks. The research has recently shed light on their sources, pathways, reservoirs, and their distribution and deposition in the environment. SARS-CoV-2 can survive and spread in aerosol forms; it has primarily been detected downstream up to 13 feet from the source, although there have been isolated infections found up to 8 feet upstream. MPs appear at all levels of the atmosphere, as demonstrated by airborne MPs. Due to its size (around 120 nm) (Zahmatkesh et al. 2022e), SARS-CoV-2 can adhere to MPs' surfaces and transport them via biofilms. MPs have enormous surface-to-volume ratios, making them an excellent sorbent for contaminants. However, Microbial communities and viruses are closely associated with particulate matter in urban environments. SARS-CoV-2 may be able to bind MPs through a mechanism of adsorption. The MP fibres and the high air temperature and humidity

were associated with SARS-CoV-2 RNA shown in Figs. 11 and 12. MP's may carry viruses in the air and increase their survival, thus helping them enter the human body.

Despite ongoing research, airborne particulate matter-associated microbiomes, particularly viruses, remain largely unexplored in urban environments. The SARS-CoV-2 may be able to bind MPs through adsorption. Given that fibres have a large surface area, they are valuable carriers. Also, proof substances prevent rapid evaporation, thereby extending virus survival. It would appear that SARS-CoV-2 can survive and internalise MPs with the help of the protective protein coating they acquire during environmental exposure, referred to as eco-corona (Zahmatkesh et al. 2022d).

Detection of microplastics in human faces

There are growing concerns about MPs' impact on the environment, and they have already entered the food chain. Furthermore, plastic packaging for food and water, such as polyethylene and polystyrene, is also a source of MPs. MPs can enter the body in other ways in humans, including digestion, absorption, and metabolism through the digestive system, breathing through the lungs, and ingestion through the mouth. Human lung tissue has been found to contain MPs. MPs can also be ingested through food; as well as; MPs are known to carry heavy metals and organic pollutants into the environment and



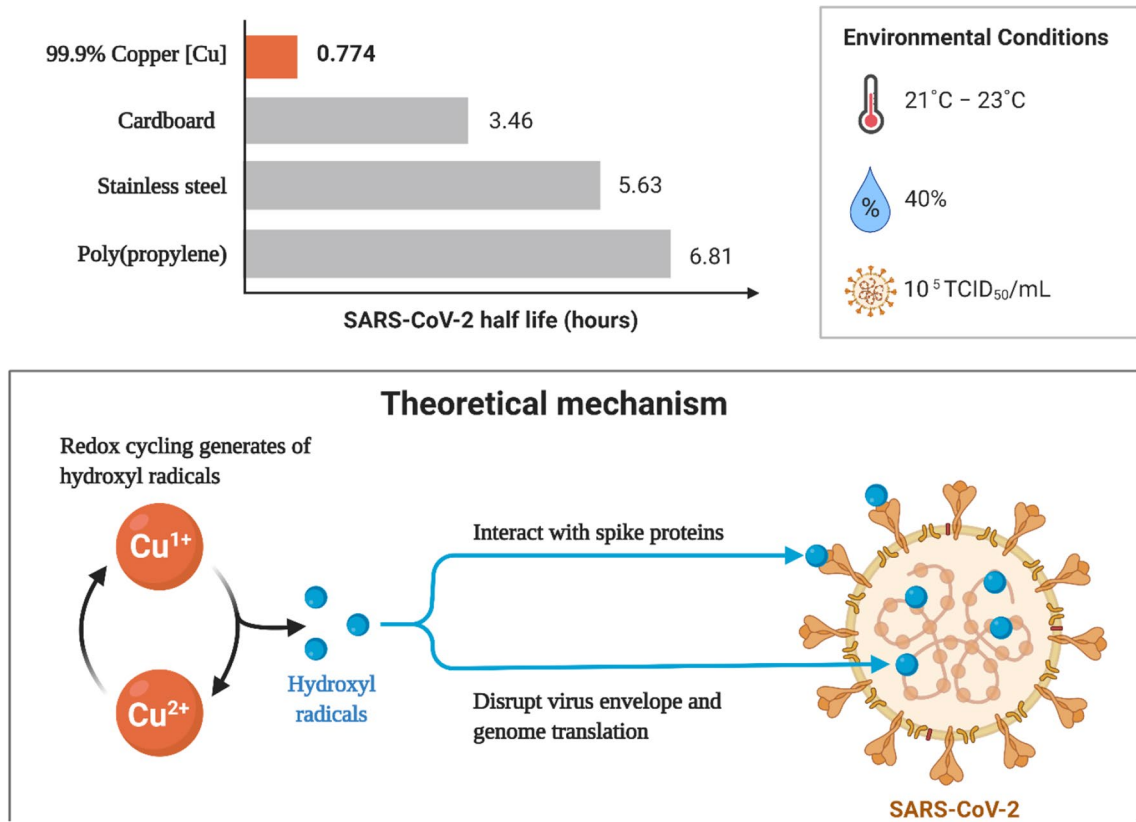


Fig. 10 SARS-CoV-2 less viable on a copper surface

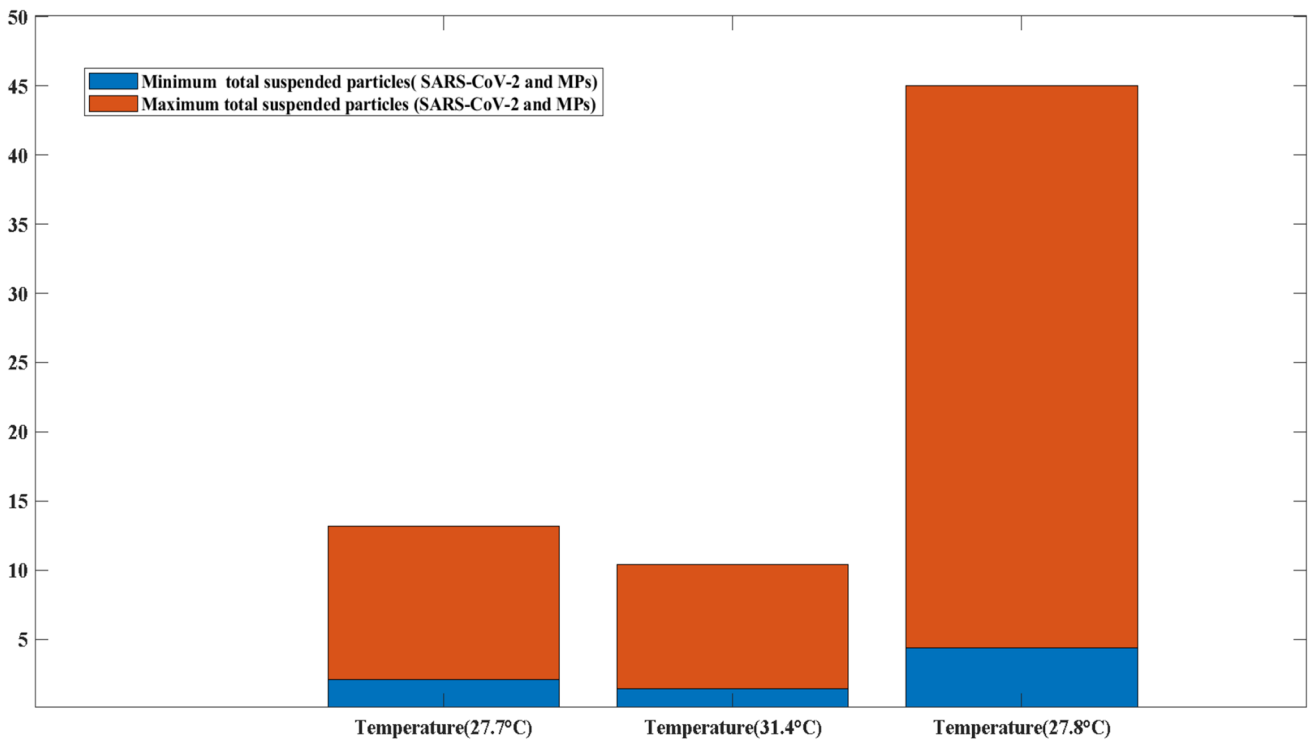


Fig. 11 The impact of temperature on MPs and SARS-CoV-2

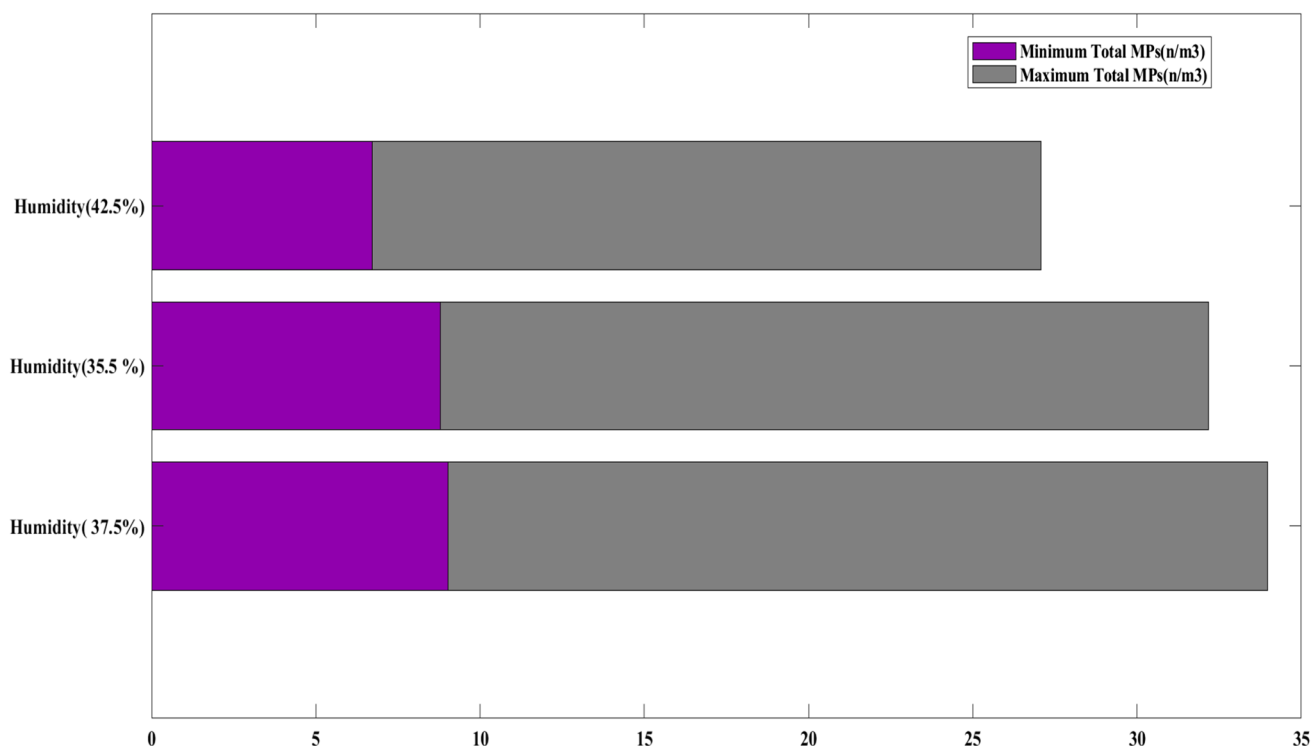


Fig. 12 MPs and SARS-CoV-2 in relation to humidity

organisms after they are ingested. Despite the growing evidence that biota absorbs MPs, laboratory experiments have begun showing that MPs are also being ingested in faeces and solid waste. Numerous organisms naturally eliminate MPs from the inside of the human body through the excretion of digestible and indigestible materials in faeces. Mussels can even eliminate MPs as pseudofeces. Several studies have examined excreta from low and high trophic organisms to understand better the presence of MPs in faeces under ambient conditions. They have provided essential data regarding the composition and dimensions of microplastics found in faeces. Schwabl et al. (2019) demonstrated that human stool contains nine different polymer types of MPs. Thus, plastics are assimilated differently depending on the plastic colour, shape, and size. Recent studies have detected colour, size, shape, and polymer characteristics of microplastics ending up in the environment through faeces, and thus these characteristics could help identify what type of MPs ends up in the environment.

Conclusion

Human health is threatened by microplastics' penetration into food chains, which pose a serious threat to aquatic and terrestrial ecosystems. WWTPs provide an entry point for MPs into natural aquatic systems, preventing them from spreading throughout the environment. In advanced

wastewater treatment, removing MPs can be achieved with a potential approach compared to other techniques, particularly membrane bioreactors, which have a high capacity for removing MPs.

When personal protective equipment is improperly disposed of, MPs and SARS-CoV-2 may be released into the atmosphere. By transmitting the illness, these MPs contribute to its spread. SARS-CoV-2 can be transmitted through the air if MPs are improperly disposed of or contaminated. SARS-CoV-2-contaminated plastic waste, such as gloves and face masks used in medical care, should be managed appropriately to prevent further SARS-CoV-2 infections. It is important that incentives are provided to encourage technological advancement in order to reduce environmental pollution from plastic waste.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Consent to participate Not applicable.

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