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RESEARCH ARTICLE

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Quantification, characteristics, and distribution of microplastics released from waste burning furnaces and their associated health impacts

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Abstract

Although investigation of microplastics (MPs) present in air environment has been intensively carried out, quantification, characteristics, and distribution of MPs released from the waste burning furnace (WBF) has been missing in literature. The aim of this study was to characterize the presence of MPs released from WBFs and analyze their associated health impacts. The examined locations were at two WBFs (nominated as TPS1 and TPS2) in Sidoarjo, Indonesia. MPs were collected using a 9 cm diameter glass beaker for a period of 8 h at two different sampling points, which are 3 and 15 m from each WBF. Several characteristics of MPs in terms of the number of particles, size, shape, color, and polymer type were comprehensively characterized. This study found that the obtained MPs were of fiber type and in the range of 46–77 and 41–59 particles at TPS1 and TPS2, respectively. In general, the polymer types of MPs were, respectively, cellophane and polytetrafluoroethylene at TPS1 and TPS2. Moreover, it was estimated that about 1.9–2.3 MPs can enter the human body via inhalation. This study offers a pilot examination of MPs released from WBF and findings from this study are crucial to provide new knowledge as a basis to carefully regulate the use of WBF particularly that are located closely to local community.

KEYWORDS
emerging pollutants, environmental health, microplastic

1 | INTRODUCTION

Plastic pollution has fast become the chief global health hazard attributed to its massive production and subsequent flawed disposal scheme that bring about negative impacts not only on the environment but also on general human wellbeing. To date, this problem is most evident in developing countries particularly in Asia and Africa regions. Indonesia alone generates around 6.8 million tons of plastic waste per year and this is projected to be worse in the future by an annual increase of 5%. By proportion, 70% of the generated plastic waste is considered mismanaged in the forms of open burning (48%), irresponsible dumping on land, or poorly handled dumpsites (13%), and leakage into waterways and oceans (9%). Among these, open burning particularly via waste burning furnaces (WBF) at temporary waste collection sites or around the residential community is still widely practiced while remaining more intensive in rural areas. This contributes immensely to the unwanted existence of plastics in the environment, which could subsequently transform into microplastics (MPs) via complex mechanisms such as fragmentation or degradation (Liu et al., 2019).

The presence of MPs in the environment such as in soil, water, and air has been broadly reported. For instance, the abundance of MPs on the Mumbai coast was found to be 165–547 items/L in water samples while the abundance in sediment ranged from 4900 to 14.500 items/kg dry weight (Gurjar et al., 2022). A study conducted in the Baram River, Malaysia logged an occurrence of MPs ranging from

9.3 ± 1.2728 to 18 ± 1.4142 items/L (Choong et al., 2021). The appearance of MPs in the air compound was also observed by Cai et al. (2017), who found 175–313 particles/m^2/day of fiber and non-fibrous particles of MPs falling from the atmosphere. It is also interesting to note that airborne MPs have greater mobility than those in sediment or water (Yao et al., 2022). Although studies on the presence of MPs in water and soil have become more intensive compared to studies in the air environment, their presence in the air can be more threatening because of greater accessibility to enter the human body via inhalation.

Several investigations have detected MPs in human bodies due to daily exposures (Zhang et al., 2020) and their accumulation in the body tissues can affect the public health such as inflammation, oxidative stress, and physical stress (van Raamsdonk et al., 2020). In one study, 12 MP particles sized between 5 and 10 μm were noticed in a pregnant woman, from which five particles were found on the fetal body, four on the maternal side, and three on the chorioamnionitis membrane (Ragusa et al., 2021). Additionally, 33 polymeric particles and four fibers were identified in human lung tissues obtained after autopsies (Amato-Lourenço et al., 2021). MPs were also found in eight human stool samples, sizing from 50 to 500 μm and averaging 20 MPs particles per 10 g of human stool (Schwabl et al., 2019). From the human health viewpoint, MPs or nanoplastics could cross cell membranes and trigger respiratory inflammation diseases or lung cancers (Kelly & Fussell, 2020). Moreover, since MPs could act as a carrier of polycyclic aromatic hydrocarbons (PAHs), it is also possible for increasing cancer risk (Akhbarizadeh et al., 2021).

It is worth stressing that although studies investigating MPs present in the atmosphere have been carried out in numerous locations worldwide, an investigation on the quantification, characteristics, and distribution of MPs released from WBF has never been performed. Therefore, this study aims to characterize the presence of MPs released from WBFs and analyze their associated health impacts. Having observed the potential health hazards on humans resulting from the MPs exposure to the WBF activities, this kind of study is imperative to examine the threat from the aspects of its resource, intensity, and dispersal as compelled by the effort to safeguard environmental and human well-being. Such knowledge offers insights into MPs derived from the WBF events so that remedial acts can be planned, regulated, and executed on time to minimize its adversary impacts.

2 | MATERIALS AND METHODS

2.1 | Materials

The materials used in this study were hydrogen peroxide (H_2O_2) or strong acid solutions employed to break down organic matters such as dust and dirt. Distilled water was also utilized in this study to rinse the equipment in the laboratory before use. Monel screen mesh T165 with a pore size of 40 μm was used to filter the sample alongside aluminum foil to close the sampling equipment.

2.2 | Sampling location

Study locations in this study are shown in Exhibit 1. This study was conducted outdoor in two temporary waste collection sites (TPS) with the WBF in Krian Village, Sidoarjo Regency, East Java, Indonesia, during February and March 2022. Both locations were selected because they are close to housing area, which is very crucial since MPs have the potential to enter human body system by inhalation. Another selection criterion was because it is accessible and reliable to put sampling equipment. The first location is TPS Tambak (TPS1) located at 7°24′3.50"S 112°34′59.81"E. This TPS manages wastes from the community in Tambak District with a daily collection rate of not more than 500 houses. Besides taking the community waste, this TPS also receives waste from hospitals and industries around Krian Village. Another examined location is TPS2 Kemasan (TPS2) located at 7°24′31.03"S 112°35′20.56"E, managing wastes in Jeruk Legi District with a daily collection capacity of not more than 300 houses. For data validity, three replications were carried out. A trial-and-error test was performed in the first week of February, while the first, second, and third replicate samplings were conducted in the second and third weeks of February, and March the first week, respectively. This was then followed by sample counting and identification in the laboratory.

2.3 | Sampling method

The instrument used to collect the sample was a 1 L glass beaker with a diameter of 9 cm. In addition, this study used a wooden tripod with a height of 150 cm for 8 h of passive sampling, the technique of which followed that of Jenner et al. (2021). The glass beaker was placed at a height of 150 cm, that is, the level at which the workers in TPS inhale the air with the arrangement as schematized in Exhibit 2. After sampling, the glass beaker was closed using aluminum foil and brought to the ECOTON laboratory located not far from the sampling locations for the next examination.

2.4 | MPs identification

At the laboratory, the sample was rinsed three times using the H_2O_2 solution and then left at room temperature until all bubbling disappeared to remove organic compounds in the glass beaker. The use of H_2O_2 as the solvent because it can be used for eliminating biogenic organic matter (Nuelle et al., 2014). After that, the sample was filtered with Monel screen mesh T165 and rinsed in another beaker with distilled water. This step was repeated three times to ensure that no particles were retained in the beaker.

After being filtered, particles left on the Monel screen were ready for the MPs identification. The microscope used was Trinocular Digital Ways Dw-tc-y Black Edition with K-D056 Kaisi rotation LED lamp for microscope and 51 MP camera connected to Samsung Smart TV 32″. Under the microscope, the sample was counted while its shape, size, and color were carefully observed. After that, 10 randomly selected particles were put one by one into the Whatman GF/C no.1 filter and

EXHIBIT 1 Study locations. [Color figure can be viewed at wileyonlinelibrary.com]

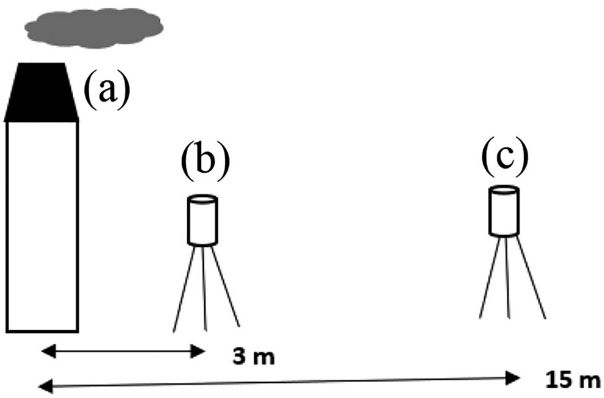

EXHIBIT 2 Sampling instrument arrangement for (a) waste burning furnace and (b-c) sampler.

neatly folded, and then sent for FTIR analysis. In this study, FTIR was carried out by using Thermo Scientific Nicolet iS10. The selection of FTIR was because it is a simple technique for identification of polymer type via vibrational spectrum analysis, which is unique for every polymer type (Tagg et al., 2015).

3 | RESULTS AND DISCUSSION

3.1 | Number of MPs

Exhibit 3 summarizes MPs and their characteristics observed in this study. At location 1 of TPS1, there were on average 15 and 26 MPs particles at point 1 and point 2, respectively. In addition, 14 and 20 particles were averagely found at point 1 and point 2, respectively, at location 2 of TPS2. It is interesting to note that the number of MPs was higher at the farthest distance sampling point and this is consistent for all data. It is essential to first understand the transport behaviors of MPs in the air. Brahney et al. (2021) reported that the length of stay of plastic aerosol in the atmosphere can be varied from 1 to 156 h depending on the particle size. Another study also confirmed that the transport behaviors of MPs in the air environment highly depend on the weight of the fiber or granule particle.

EXHIBIT 3 MPs and their characteristics detected in this study.

Sampling point	Number	Shape	Color	Size (mm)
TPS1 point 1	46	Fiber	Black, blue, yellow, red	0.4–4
TPS1 point 2	77	Fiber	Black, blue, yellow, red	0.1–2
TPS2 point 1	41	Fiber	Black, blue, yellow, red	0.6–3
TPS2 point 2	59	Fiber	Black, blue, yellow, red	0.1–1

A higher number of MPs found at the farthest sampling point is potentially due to the weight of the fiber. Lighter-weight MPs fibers can stay in the atmosphere longer than those heavier. This allows possible traveling to longer distances and even faster in the direction of the wind. In previous studies, the number of MPs found in outdoor air varied from 2 to 355 particles/day as observed in Paris by Dris et al. (2016), to 510–925 particles/day found in Central London by Wright et al. (2020). In addition, Ambrosini et al. (2019) in Italy detected 36

EXHIBIT 4 Summarized findings from present and previous studies

Sampling point	Number/period	Size (mm)	Shape	Polymer	References
Sidoarjo, Indonesia, outdoor air	87/8 h	0.1–4	Fiber	Cellophane, polytetrafluoroethylene	Present study
Central Italian Alps, outdoor air	44/24 h	>0.75 long	Fiber, fragment, film	Polyamide, polyethylene, and polypropylene	(Ambrosini et al., 2019)
Paris, outdoor air	2–355/24 h	0.2–0.6	Fiber	Polyethylene-terephthalate, polyamide	(Dris et al., 2016)
Surabaya, outdoor air	9–85/13 h	0.1–5	Fiber, fragment, film	Cellophane, polyethylene terephthalate	(Asrin & Dipareza, 2019)

MPs particles in the Central Italian Alps while in Hamburg, Germany, Klein and Fischer (2019) found 275 MPs particles in the metropolitan area.

3.2 | Size of MPs

Sizes of MP particles found in this study are shown in Exhibit 3. At point 1, which is 3 m from WBF, MPs sizes measure around 0.4–4 mm, meanwhile, at point 2, which is 15 m from WBF, the sizes are 0.1–2 mm. It is witnessed that the bigger MPs are found at point 1, which is closer to the WBF. Meanwhile, the smaller MPs are more commonly detected at further distances from the WBF. This size difference was proven by Palmer and Herat (2021) that reported MPs with smaller particle sizes and lower density have a greater potential to migrate alongside the wind and water, such that they can fly further in the direction of the flow.

Comparison with other previous works is listed in Exhibit 4. The sizes of MPs found in the previous study in outdoor air varied from 0.1 to 10 mm. For instance, in the study conducted in Bushehr, Iran (Akhbarizadeh et al., 2021), MP sizes are not larger than 2.5 mm, while in Asselyah, Iran, the sizes are 0.1–1 mm (Abbasi et al., 2019). In contrast, Peñalver et al. (2021) noticed MPs in La Aljorra, Spain, range from 1.25 to 2 mm. The fiber dust found in the textile and paper industry can be inhaled by workers. The durability of the fiber is highly dependent on its diameter so particle sizes of more than 3 μm are considered too large to be inhaled into the bronchi and bronchioles. Therefore, the high-risk MP sizes for the body, especially for the respiratory tract, are below 3 μm.

3.3 | Shape of MPs

Exhibit 5 shows the fibers found in this study. At both locations, TPS1 and TPS2, all MP shapes are of fiber type. Several studies ratified that fiber fragments are one of the dominant types of MPs in environmental samples (Cai et al., 2021). Fragmented larger lines may create a lot of fibers/lines as suggested by previous works (Acharya et al., 2021). Fibers are the secondary MPs formed from textile degradations such as polyester, nylon, and spandex yarns. Fiber is shaped like a strand of thread, light in color, and thin. When exposed to ultraviolet (UV), MP fibers will turn blue. The sizes of these fiber-shaped MPs are around 50 μm (Tanaka & Takada, 2016). The studies of MPs in the air conducted by Dris et al. (2016) and Li et al. (2020) found MPs only in the form of fiber in Paris and China, respectively. The total fibers detected were 2–355 and 14.1×10^{-3} f/mL at each study location. Fiber is mostly found in the air because of its light and thin shape so that it is easily carried by the wind.

3.4 | Color of MPs

Black was the most dominant color of the MPs found from both locations, that is, 58 and 44 particles, respectively, in TPS1 and TPS2. In TPS1, the second is blue with 30 particles detected while in TPS2 is red with 25 MPs particles. The color of MPs found in the previous study was homogeneously colored (Klein & Fischer). In Iran, Akhbarizadeh et al. (2021) witnessed MPs in black, transparent, red, orange, and grey. Meanwhile, blue, black, yellow, and red were the colors of MPs found in Australia by Soltani et al. (2021) Also, in India, the colors of MPs were yellow, green, red, and transparent (Patchaiyappan et al., 2021).

To make the yellow color, materials such as anthraquinone are used, which can be fast produced, have color strength, and are transparent. Anthraquinones are commonly utilized in polymers such as PP, PS, LDPE, HDPE, PMMA, PC, PBT, and PET. In addition to yellow, red MPs are discovered. The commonly used red pigment is Anthraquinone, which is medium to high in color strength and transparency. This red pigment is usually used in PS, PP, LDPE, and HDPE polymers. Interesting and largely used categories of dyes include triphenylmethane, azo, anthraquinone, perylene, and indigoid, which are also the main focus of the study by Fleischmann et al. (2015) since these compounds cover a wide spectrum of applications.

3.5 | Polymer type

In general, the polymer type of MPs at TPS1 was cellophane, while at TPS2, the polymer type was polytetrafluoroethylene. Exhibit 6 shows the FTIR result of MPs. In TPS1 at a distance of 3 m from WBF, a small peak in wavenumber 3266 cm^{-1} was identified as O-H stretching in the sample. This particle is recognized as the cellophane polymer. In this sample also, a peak in wavenumber 1382 cm^{-1} is visible and

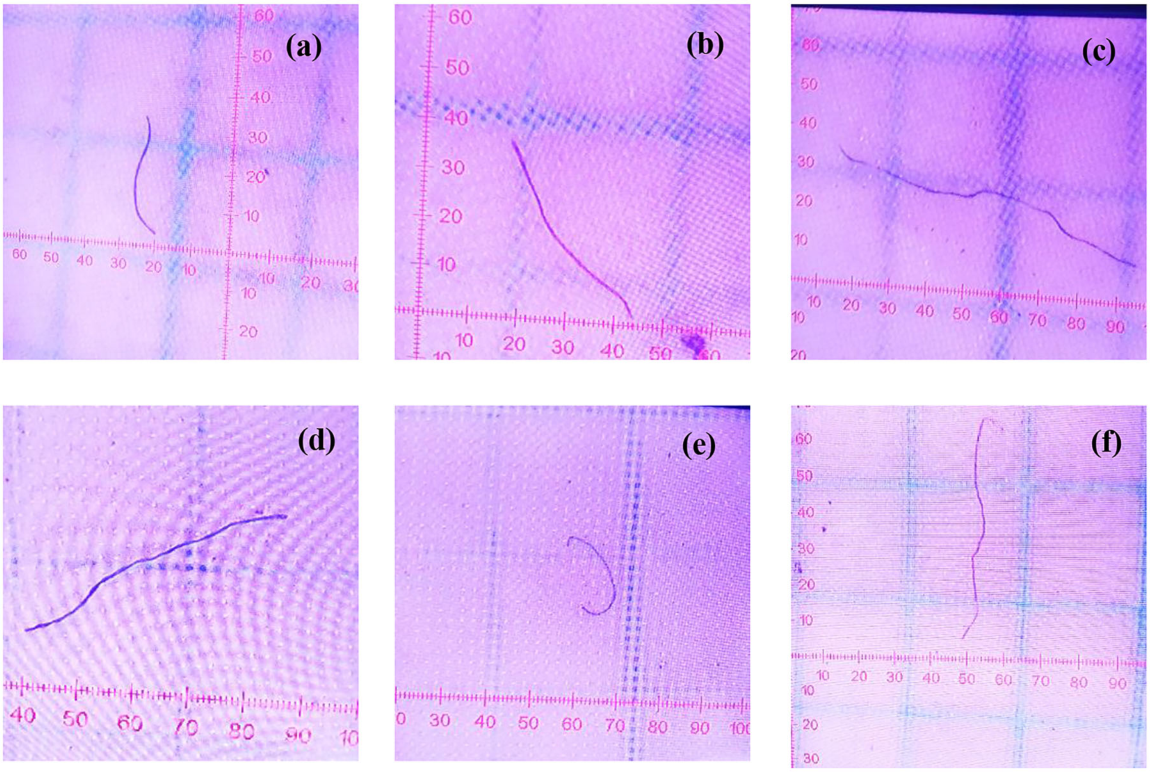

EXHIBIT 5 Fibers found in the present study (a) black in TPS1 P2, (b) red in TPS1 P2, (c) blue in TPS2 P2, (d) black in TPS1 P1, (e) blue in TPS1 P1, and (f) red found in TPS2 P1. [Color figure can be viewed at wileyonlinelibrary.com]

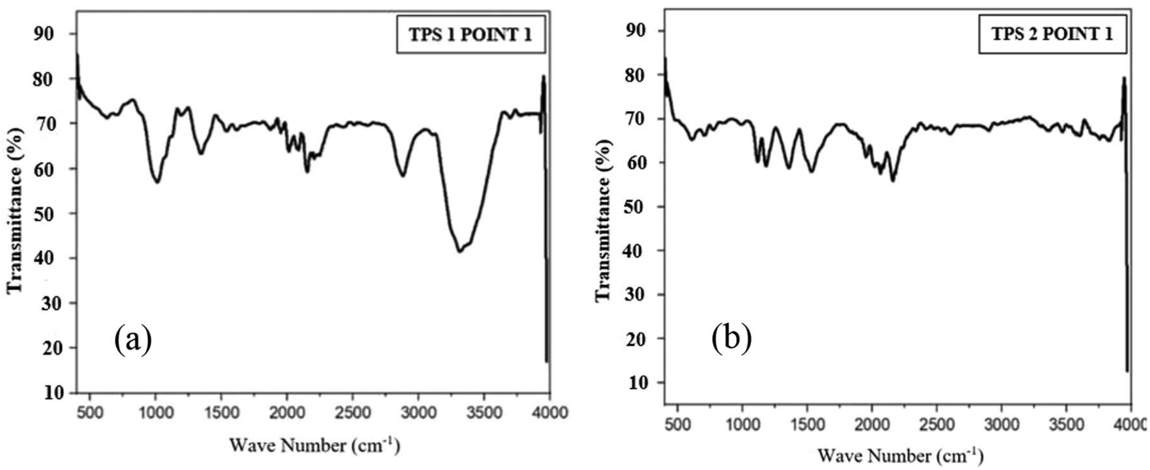

EXHIBIT 6 FTIR spectra of polymers found in (a) TPS1 (cellophane) and (b) TPS2 (polytetrafluoroethylene).

identified as C-H stretching. Lastly, there is a peak in wavenumber 1016 cm^{-1} that is identified as C-X stretching. In a previous study by Gorassini et al. (2016), FTIR band assignments of cellophane were associated with a peak at wavenumber 3336 cm^{-1} as O-H stretching and at 2893 cm^{-1} as C-H stretching. Besides that, cellophane was also described with the peak at wavenumber 1367 cm^{-1} as O-H bending, and at wavenumber 1022 cm^{-1} as C-O stretching (Kotelnikova & Mikhailidi, 2011).

In TPS2 point 1 at a distance of 3 m from WBF, a deep peak in wavenumber 1150 cm^{-1} is identified as C-O stretching. This particle is known as polytetrafluoroethylene or PFTE. Also seen is a peak in wavenumber 1205 cm^{-1}, which is associated with the P-O stretching, and lastly, there is a peak in wavenumber 1388 cm^{-1} identified as C-H. The peak of polytetrafluoroethylene is seen at wavenumber 1300 to 1000 cm^{-1}, which was mainly seen at a wavenumber of more than 1230 and 1155 cm^{-1} (Piwowarczyk et al., 2019).

The polymer found in TPS1 is cellophane. Cellophane is a moisture-resistant plastic wrap that is useful for all sorts of things. Cellulosic film applications include tapes and labels and particularly in medical application, it is widely used for dialysis membranes. They are usually found also in supermarkets as vegetable and fruit wrappers. Similar to bubble wraps, cellophane is a very popular and useful material for use in the community. All the types of polymer found are linked to various impacts on human health, especially types of polymer found in MPs in this study, that is, cellophane. As a plastic polymer that is commonly found in water, air, and even soil, cellophane bags contain large doses of dioxins that are harmful to health, including causing cancer and hormone disorders (McKeen, 2017).

The polymer found in TPS2 is polytetrafluoroethylene or PTFE, which has been used commercially since the 1940s. Polytetrafluoroethylene is generally known as a non-stick coating surface for pans and other cookware, fabrics, fabric protectors, food wrappers, and carpets that have been treated to resist stains. Polytetrafluoroethylene is safe to use, but heating it above 300°C can be dangerous to health. At temperatures of more than 300°C, polytetrafluoroethylene will begin to break down and emit polymer fumes, which can then be inhaled by humans and thus cause increased health risks. Temporary symptoms that may be experienced due to exposure to Teflon are flu and polymer fume fever conditions, where the body feels pain, chest discomfort, headache, fever, and chills.

3.6 | Possible impacts on health

The fibers accumulated in the respiratory tract can be rapidly lost by transportation in the bloodstream throughout the body is currently the main particle dispersal hypothesis. However, there is very little literature on the health effects of MPs in the form of fiber stored in the respiratory tract in humans or animals. Lung cancer, Mesothelioma or pleural cancer, and pulmonary fibrosis are the main health effects of fiber-forming MPs in the respiratory tract. The most specific health effects of inorganic fibers in the body are mesothelioma and pleural plaques. Mechanically, this effect may be due to fiber composition, surface properties, and shape. Therefore, this section is structured according to the health effects caused by inorganic fibers such as fiber-shaped MPs.

To examine the impacts of MPs on humans, the measurement of the particles that may enter the body through inhalation is next carried out according to the scenario described by Abbasi et al. (2019). The number of MPs potentially digested by the human body is measured using the average of MPs detected at the sampling location. The calculation in this study is done by finding the average particle observed at each location and dividing it by the sampling equipment diameter. The particle number per cm was then used as the potential MPs that can enter human nostril via inhalation.

At TPS1, the average number of MPs found was 20 particles. If the number is divided by the sampling equipment diameter, which is 9 cm, it results in 2.3 particles/cm. Considering human inhalation diameter by 1 cm per nose hole, it is possible that 2.3 particles can enter the human body system by inhalation. Meanwhile, in TPS2, the average number of MPs found was 16 particles, which can enter the human body. These calculations were proven by Pauly et al. (1998), who found MPs in the shape of fiber in human lungs after autopsy. The study observed that fibers can be observed in almost all the specimens (87%) in New York City. In another location, São Paulo, Brazil, 37 MP particles were found in 13 of the 20 samples of human lung tissue inspected after an autopsy, the 37 particles in the form of fibers and polymers discovered were polyethylene and polypropylene (Amato-Lourenço et al., 2021). From the findings of Jenner et al. (2022) in detecting MPs in living human lung tissue, 39 MP particles were found in 11 of 13 lung tissue samples. The MPs discovered were in the form of fiber and fragments, while the types of polymers identified were PP, PET, and resin.

The whole process of burning waste harms both the environment and human health. Burning plastic waste has the potential to release harmful chemicals into the atmosphere. For example, the smoke from burning plastic waste releases halogenated additives and polyvinyl chloride. Burning plastics in the environment also produces uranic, dioxins, and polychlorinated biphenyls (PCBs) (Gilpin et al., 2003). Methane and CO_2 are released into the air when plastic wastes are piled up until they decompose. During the burning of plastics, CO_2 is also released into the atmosphere.

4 | CONCLUSIONS

Quantities and characteristics such as shape, size, color, and polymer type of MPs at TPS with WBF in Sidoarjo, Indonesia, were determined. The smaller MPs were detected at point 2 at a farther distance of 15 m from WBF. At point 1 (about 3 m from WBF), MPs sizes were around 0.4–4 mm whereas at point 2, MPs sizes were 0.1–2 mm. Similar size changes could be spotted at TPS2 as well. Most of the MPs colors found were black in both sampling locations. The types of polymer of MPs in TPS1 and TPS2 were, respectively, cellophane and polytetrafluoroethylene. Moreover, it has been estimated that about 1.9–2.3 MPs have the potential to enter the human body via inhalation. For Sidoarjo Regency Government, it is better if the practice of burning waste is completely terminated because daily activities there result in air pollution whereas garbage burning triggers climate change. Furthermore, it is recommended that the local government can educate the community to reduce their waste while introducing alternative resources that can be used repeatedly in ensuring both the environmental and human health longevities.

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CONFLICT OF INTEREST STATEMENT

The authors reported no declarations of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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