*Priya Agarwal[1], Satya Prakash[1], Markus Diantoro[2], Firdaus Mohamad Hamzah[3], Gaurav Saini[4]**

[1]Department of Civil Engineering, Sharda University, Greater Noida, Uttar Pradesh, India, [2]Center for Advanced Material for Renewable Energy, Universitas Negeri Malang, Indonesia, [3]Centre for Defence Foundation Studies, UniversitiPertahananNasional Malaysia, Kuala Lumpur, Malaysia, [4]Department of Civil Engineering, Netaji Subhas University of Technology, Delhi, India

Scientific paper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.62638/ZasMat1326

Zastita Materijala 66 (4)
867 - 879 (2025)

Microplastics from disposable paper cups: A growing concern in everyday life

ABSTRACT

Microplastics (MPs) released from disposables are receiving widespread attention due to direct human exposure during use. The present study investigates the quantification and size classification of MPs released from disposable plastic-coated paper cups commonly used for serving hot beverages. In order to evaluate MPs that can possibly seep into hot beverages in 15 minutes, the study examines five different types of paper cups (A–E) with varying film thicknesses (20–80 microns) and capacities (70–220 ml). Fluorescence microscopy, Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and liquid particle counter (LPC) were employed to characterize MPs. The findings indicate high-density polyethylene (HDPE) MPs, primarily 2-5 µm with negligible percentage of particles larger than 15 µm. A 100 ml disposable cup may release up to 0.7 million MPs, affected by liquid pH and temperature. The results from the recyclability analysis shows up D as more resistant to moisture and biodegradability due to thicker paper boards than the HDPE film lining. Routine users may ingest 657-876 million MPs annually which could potentially affect human health and the environment. The results of the study are expected to provide insight into the health impacts and will contribute to the knowledge pool of microplastic removal technologies.

***Keywords**: Spectroscopy; HDPE; LPC; size variation; health effects; human ingestion.*

1. INTRODUCTION

Global production of plastic now exceeds 413.8 million metric tons in 2023 [1]. So far, 44% of plastic is utilized for packaging material, thus generating significant amounts of plastic waste [2]. Plastic packaging materials and containers such as bottles, caps, cups, foils, trays, sealant films, bags, pouches, cutlery, etc. are used all over the world for the storage and consumption of various types of foods, (hot and/or cold) beverages (including formula milk for babies), and mineral/carbonated water [3]. Such materials and containers are generally made from thermoplastic resins, specifically polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS). These plastics are preferred since they can be subjected to mechanical recycling [2].

*Corresponding author: Gaurav Saini
E-mail: gauravsaini@gmail.com
Paper received: 24.12.2024.
Paper accepted: 25.01.2025.

Even though using plastic has many benefits, the associated environmental pollution is a growing concern the world over [4]. Plastic particles under 5 mm diameter are defined as microplastics (MPs) [5-7]. Many studies have found such particles in a variety of domains including the marine and freshwater systems, air, soil, and ultimately food also as well as the bodies of living beings including humans[4, 7].The current report on the global market of paper cups issued by International Market Analysis Research and Consulting Services Private Limited (IMARC) Group in 2022 stated that the usage of paper cups has reached 263.8 billion units annually [8]. These disposable cups are primarily used for serving hot beverages to individuals. Generally, these are coated with polyethylene so that there is no soaking or leakage of liquids thereby increasing the durability of paper cups. Disposable paper cups are used everywhere in malls, cafeterias, restaurants, educational institutions, offices, homes, roadside tea/coffee stalls, etc. People opt for them as they are lightweight, easy to carry, cost-effective, reliable, and save time cleaning as they are discarded after a single use.

Table 1. List of sources of MP intake and the various analytical methods used for their characterization

Sources	Size Range (μm)	Concentration	Analytical Methods	Polymer types	Location	References
PE-coated paper cups PP cups PS cups	5-50	675-5984, 781-4951 838-5215 particles/L	Raman spectroscopy, SEM, AFM	Polyethylene (PE), Polypropylene (PP), Polystyrene (PS)	China	[9]
Take-out food containers	43-500	3-29 items/container	Discovery microscope, ATR-FTIR SEM	PP, PS, PE, Polyethylene terephthalate (PET), polyester, rayon, acrylic, nylon	China	[10]
Tea Bags	1-150 < 1	11.6 billion MPs and 3.1 billion NPs (nano plastics) for single cup	FTIR, SEM	Fibers	Canada	[11]
Bottled mineral water	1.5-10	4889 ± 5432 particles/L (reusable) 2649 ± 2857 particles/L (single use) 6292 ± 10521 particles/L (glass)	Micro-Raman spectroscopy	PET, PE, and PP	Germany	[12]
Paper Cups	25.9-764.8	102 + 21.1 × 10^6 sub-micron-sized particles/ml	FTIR, SEM	PE	India	[13]
Returnable plastic bottles Single-use plastic bottles Beverage cartons Glass bottled waters	50–500	118 ± 88 particles/l 14 ± 14 particles/l 11± 8 particles/L 50 ± 52 particles/l	Micro-Raman spectroscopy	PET, PP, PE, and Polyamide (PA)	Germany	[16]
Plastic feeding and water bottles	20-500	53- 393 Particles/ml (per 100 opening/closing cycles)	laser direct infrared (LDIR)	Polycarbonate (PC), PP, polyphenylene sulfone resins (PPSU)	China	[17]
Bottled mineral water	11-530	317± 257 MP/L	FTIR Imaging	PVC, PA, PEST, PS, and PE	Germany	[18]
Polystyrene-made food containers (PMFCs)	50	86 items/container	SEM	PE, PP, PS, Polyester, PC, Polyurethane (PU)	Taiyuan, China	[19]
Take-out food containers	201–500	3–43 items/container	FTIR, SEM	PP, PE, Polyester	China	[20]
Take away food containers	250-5000	29-552 items/container	focal plane array (FPA)-FTIR	PA, PU and PS	China	[21]
Disposable plastic containers	≤ 500	639 items kg^{-1}	-	PE, PET, PP, and PS	China	[22]
Tea Bags	620-840	94% of bag released MPs	Raman imaging	PET, PE, NY6 (Nylon 6), and PP	China	[23]
single use (disposable) plastic water bottles	>4.7	553 ± 202 microplastics/L/cycle of opening and closing of the cap	Trinocular optical microscope,	PE	USA	[24]
Take-out food	≤ 500 μm	639 items kg^{-1}	-	PE, PET, PP, and PS	China	[25]
Bottled water	>100	10.4 MPs per liter	FTIR	PP, nylon	New York (US)	[26]
single-use plastic-bottled water glass-bottled water	≥50	140 ± 19 p/L 52 ± 4 p/L	ATR-FT-IR	PT, PE, PP, and PA	Thailand	[27]
Bottled water	500-1000	2.89 ± 0.48 items/L	ATR-FTIR	PP, PET	India	[28]

Food delivery is a convenient service and has seen its utility increase multi-fold in the last few years, esp. during the COVID-19 pandemic. Unfortunately, it uses several disposable items for packaging, holding beverages, and as cutlery. A large number of people are routine tea or coffee drinkers and prefer having the beverage of their choice multiple times a day; mostly in disposable cups. Depending on their habits, different volumes of hot beverages are consumed during the day.

It is commonly known that MPs can be found in many items due to contact materials that leach the MPs from the inner surfaces. Table 1 includes a broad range of studies on microplastic contamination in various sources, presenting data on size range, concentration, analytical methods, polymer type, and geographical locations.The micron-sized particles are released from the plastic feeding and water bottles, mineral/carbonated water bottles, glass water bottles, single-use, and reusable PET bottles, plastic food containers, and disposable plastic and paper cups. The sizes of these particles were reported to be in the 5-500 µm range [9-13]. Analytical techniques have been widely used to characterize MPs in various shapes, sizes, and polymer types. The MPs analysis is divided into two parts: physical characterization of MPs (color, size) using microscopy and chemical characterization (composition, structure) using spectroscopy to confirm its composition [14]. In previous studies, a variety of techniques were employedincluding fluorescence microscopy, SEM, FTIR, laser direct infrared (LDIR), atomic force microscopy (AFM), and Raman spectroscopy [15-18].

PET (84%) and PP (7%), key materials used in the production of both bottles as well as caps, were found to form the majority fraction of particles in the water produced from returnable plastic bottles [16]. Processed meat contains PS contamination ranging from 4-18.7 particles/kg of packaged meat originating from the PS meal tray [15]. Also, in takeout food containers that are commonly used for storing and transporting different types of foods in daily life, the MP concentration was estimated as 3-29 items/container [10], 29-552 items/container [21] and 3-43 items/container [20].

MPs can enter the body of a human being through several pathways: dermal, inhalation, and ingestion [30,31]. The annual MP exposure to human beings was estimated as 81,000 (male child), 121,000 (adult male), 74,000 (female child), and 98,000 (adult female), respectively through ingestion and inhalation pathways (in combination) [32].

MPs can be present in food as a result of environmental contamination, and throughtherelease of MPs from packaging materials and storage containers, such as tea bags, containers, cups, bottles, etc. resulting in direct MP exposure in humans [12]. Several studies have investigated that MPs are present in a wide variety of foods and beverages [33], including honey, sugar [34], and milk [35], among others. MPs in fruits and vegetables [36] due to the potential uptake of MPs by plants from the wastewater laden with MPsreleased into the soil [37].

The MPs in PM2.5 in the environment are harmful to human health and can lead to mortality and associated economic losses [38]It has been reported that exposure to MPs can result in adverse medical conditions such as oxidative stress, neurotoxicity,causedamage and inflammation to the intestine, entering the bloodstream, disseminating to other tissues, and persisting for prolonged periods [39]. It has also been reported that particles that are ingested into the human body can undergo cellular uptake and subcellular translocation or localization inside the digestive tract [40]. Due to their small size, and chemical constitution, MPs potentially can cause both physical as well as chemical hazards to human beings. MPs in the environment are commonly perceived as complex because of their variety in size, shape, and density. There are significant repercussions of these MPs on human health. Additionally, the sizes of MPs can significantly influence their health effects and removal processes.

This study is a detailed investigation into the size variations of the MPs that are released from "commonly used" paper cups into hot beverages such as water, tea, coffee, etc. The study aims to quantify and characterize the MPs released through hot beverage consumption in disposable paper cups and to classify such particles according to their sizes. Five types of disposable paper cups, having different volumes, were used to assess the MPs that could potentially be leached into hot liquids in 15 minutes. The leached particles were characterized by using several characterization techniquesFluorescenceMicroscopy (presence of MPs), FTIR (to identify the type of polymer), SEM (surface morphology), and LPC (liquid particle count, to count the particles).The aim was to investigate the effect of pH and temperature on the release of MPs.

This study not only gave the idea of particle count that was consumedthrough hot beverages into the paper cup but also the sizes of the particles.This highlights the extent of MP contamination by disposable paper cups and underscores the need for alternatives.The study was expected to yield information of immense interest for the size-dependent health impacts and measures needed for the MP's removal from waste streams.

2. MATERIALS AND METHODS

2.1. Collection of Disposablepaper cups

Out of 15 different types of plastic-coated disposable paper cups, 5 cups produced by different manufacturerswere purchased from the local market in Gautam Buddha Nagar, Uttar Pradesh, India (Fig. 1). These cups are made up of cellulose, the main component of paper-based disposable products with plastic coating in the interior lining for improved durability and water resistance. These were selected based on their sale and average consumers' preferred volumes. These cups are used in cafeterias, restaurants, offices, residences, etc. Table 2 provides technical specifications for sample cups labeled as A, B, C, D, and E havingcapacities of 70ml, 100ml, 120ml, 170ml, and 220ml, respectively.Cup A, with the size of 2 ounces, has a thickness of (160+70) ±15μm where 160 μm is the thickness of the paper board and 70 μm of the film layer, with a permissible variation of ±15 μm. Certainly, Cup B has the thinnest paper board (130 μm) with the thickest film layer (80 μm).Moving up, cups C, D, and E increase in capacity with sizes ranging from 4 to 7 ounces and thickness from (190+50) ±15 to (280+20) ±15 μm. Cups with thicker materials may provide better insulation and durability, making them appropriate for use in hot beverages.

Figure 1. Different types of cups used in the study are denoted as A, B, C, D, and E.

Table 2. Physical properties of cups used in this study

Cup type	Size (Oz)	Capacity (ml)	Top Diameter (cm)	Bottom Diameter (cm)	Height (cm)	GSM	Thickness (Paper board + film) (μm)
A	2	70	5	3.8	5	150	(160+70) ±15
B	3	100	5.5	3.8	7.2	120	(130+80) ±15
C	4	120	6.5	5.2	6	165	(190+50) ±15
D	5	150	6.5	4.4	8.9	180	(230+30) ±15
E	7	220	7	5.2	9.1	220	(280+20) ±15

2.2. MPs sample preparation from disposable cups

The methodology implemented for this study includes the release of MPs, characterization, and factors to be considered for parametric analysis.

The disposable cups were first thoroughly rinsed with ultrapure water at room temperature. To extract the MPs from disposable cups, 100mlultrapurewater (at a temperature of 85–90°C,pH~7)was directly pouredintoeachcup [41]. These cups were properly covered to prevent contamination from aerial deposition. They were allowed to sit undisturbed for 15 minutes (Fig.2a). The MP particles leached out from the inner lining of the cup into the solution. This temperature was used as it is the same as tea and coffee when poured into the cup.This duration was used to simulate the average duration a typical hot beverage stays in the cup for an average user, between the time it is poured and consumed.

a) b)

Figure 2. (a) Hot water was poured and left undisturbed for 15 minutes in each cup for MP leaching. (b) The cup was cut and dipped in hot water for the separation of plastic film from the inside of the cup

Control samples were prepared by pouring 100mlultrapure water at room temperature into each cup type for 15 minutes to track aerial deposition. The experiment was conducted at pH 5, 7, and 9 and temperatures of 30, 60, and 90^{o} C to study the effect of pH and temperature on the number of MPs released. The water samples were analyzed for the presence of MPs leached from the cups into the hot water.

To extract the hydrophobic film from the disposable cups, another batch of fresh cups was cut using steel scissors anddipped in lukewarm (temperature of 30 – 40° C) ultrapure water such that the hydrophobic plastic film was completely separatedfromthepaperlayer of the cup using forceps (Fig. 2b). The separated hydrophobic films of each cup type were further examined to determine the polymer type of the inner lining (Fig.3).

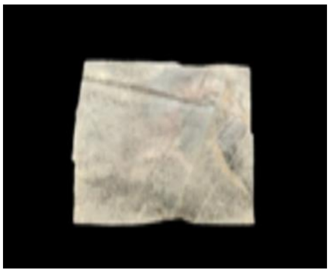

Figure3. Separated plastic film from the plastic cup

Triplicate samples were prepared for both MPs and hydrophobic film extraction for each of the five different types of cups. A series of steps were taken, whenever possible, to further decrease the risk of contamination. All the glassware and tweezers used in the experiment were first washed with ultrapure water and then dried in the oven. The microscope slides and coverslips, used for fluorescence microscopy, were cleaned by soaking in 70% ethanol and drying before use to reduce the external interference factors of MPs. Cotton lab coats and gloves were worn during the tests to avoid contamination by plastic fibers. The following laboratory measures were taken to increase the certainty level of the experimental results that the MPs counted were actually from the samples.

2.3. Characterization and analysis of released MPs

First, the prepared samples were examined for the presence of MPs. This was done by using a regular compound laboratory microscope at 400X. Next, the chemical composition and surface morphology of the MPs were determined. Further, the quantity of MPs present in the cups was assessed by using liquid particle counting.

2.3.1. FluorescenceImaging

2.3.1. FluorescenceImaging

The fluorescence images of MPs were taken by Nikon Eclipse Ti-E fluorescence microscope and were used to identify and quantify the MPs in the liquid [42]. Nile Red (NR), a hydrophobic, metachromatic, and photochemically stable dye, commonly used for staining the surface of micro-plastic particles that fluoresce when irradiated with orange-red light (excitation wavelength: 534-558 nm, emission wavelength: >590 nm) [43]. In samplepreparation,20µLofwatersamplewasdrop-cast ontotheslideandstainedwith NR dye. The prepared glass slide was allowed to dry and then the stained samples were viewed under a fluorescence microscope at magnifications ranging from 100X to 400X.

2.3.2. FourierTransformInfrared(FTIR) Spectroscopy

The chemical composition of plastic-coated disposable paper cups was determined by FTIR (Agilent Cary 630) with <2 cm^{-1} spectral resolution.

The hydrophobic film separated from the different cups was analyzed toi identify the grade of plastic used in the teriorlining.A small part of the sample is placed on the plate and the crystal at the top is brought in contact with the sample surface such that the plastic particles are exposed to infrared radiation and a spectrum is formed forvibration of chemical bonds between different atoms. The triplicates of each cup type on different spots were recorded, and the spectra were compared withasetofreferencedata (polymer library) toidentifythepeaks of the type of polymer present [44]. In other words, FTIR allows for the identification of the type of plastic/s present in the samples under study.

2.3.3. Scanning Electron Microscope (SEM)

The surface morphology of the particles was obtained using a scanning electron microscope (FEI Quanta 200). SEM was preferred for the liquid samples to analyze the size distribution andshape of the MPs in them. For sample preparation, 200 µL of liquid wasdrop-castontoacoverslipandallowed to dry. The triplicate samples were viewed at different magnifications ranging from 1000X to 25,000X to obtain the characteristics of MPs at different sizes.

2.3.4. Liquid Particle Counter (LPC)

Liquid Particle Counter (PAMAS, equipment ID. EQ 181) was chosen for accurate quantification of the number of micro-plastic particles that leached out from the inner lining of the disposable cups. The equipment determines the number of particles (micro-plastics, in the present study) present in liquid samples. The equipment used for the current study had a size limitation of 2-50 microns. This counting process is automated and run by a computer program, which counts the particles. Triplicates of each sample were analyzed to give the average number of particles per ml present in the sample.

3. RESULTS AND DISCUSSION

3.1. Detection of MPs

Fig.4 shows some of the images of released MPs using a fluorescence microscope at different magnifications. It was observed that on average, 6±2 MPs were present in 20 μL of the sample. Further regular laboratory microscope was used to detect particles in the ultrapure water sample that were kept in the cups at room temperature. Furthermore, no particles were observed for the control samples, at 400X magnification.

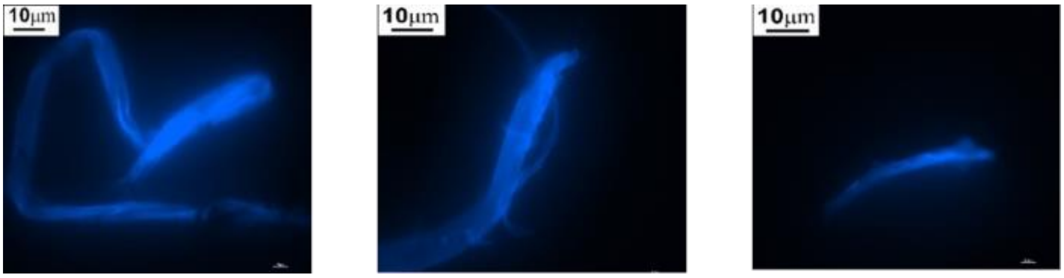

Figure 4. Fluorescence microscope images of the microplastic particles at 100X-400X magnification

3.2. Identification of MP polymer type

Fig.5 shows FTIR analyses of the microplastics extracted from all the samples studied here. The obtained spectrum of samples A- E was then compared with the Bio-Rad library database and the comparison of the samples' spectra with the HDPE reference spectrum also satisfies the condition of the match between at least four absorption bands [44]. The bandsat wave number 2919cm^{-1} and 2850cm^{-1} can be attributed to the CH stretch of all the hydrocarbon constituents present in the polymers [45].

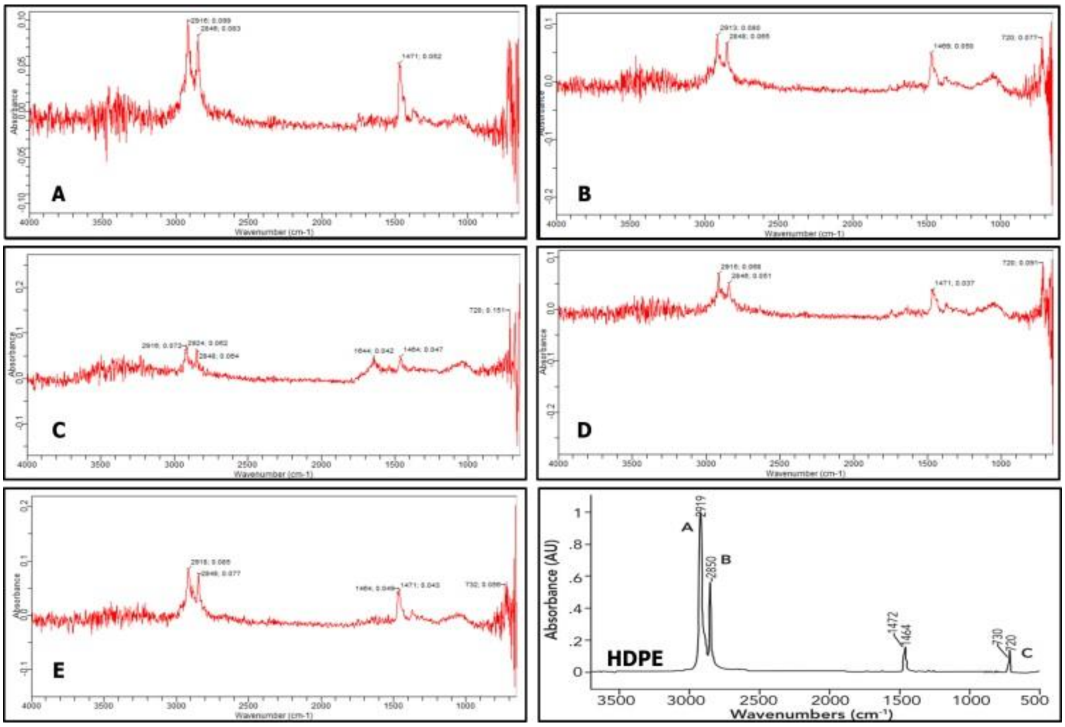

Figure 5.ComparisonofFTIRspectra of plastic films extracted from the inside surface of disposablecupssamplesA-EwithHDPE

Thepeaks positioned CH_2 bend, and the peaks located at wave numbers at wave numbers 1472 and 1462cm^{-1} correspond to 730 and 720 cm^{-1}represent CH_2 rock [44]. Therefore, it is concluded that these peaks in samples closely match HDPE. Thus, FTIR results of the different samples show that the plastic films extracted from the samples were HDPE-grade plastics and that any MPs leached through exposure to hot water/beverage are made of HDPE.

3.3. Micro-image of MPs in disposable cups

Samples of different disposable cups were view edunder SEM at 1000 to 25,000X magnifications.

The micron-sized particles were leached out into the hot water from the disposable paper cups, and tested in this study (Fig.6). These MPs were observed to either have a definite shape (such as, spherical or rod-like) or were irregularly shaped. Further, the MPs of smaller sizes formed small, agglomerated clusters and were scattered across the entire field of vision. Particles of various sizes were seen across the field of vision for different samples, signifying a range of particle sizes.

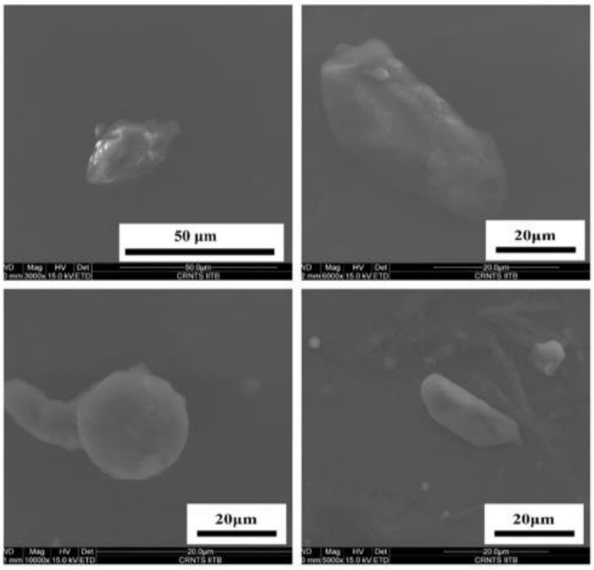

Figure 6. SEM images represent different particle sizes and shapes

3.4. MPreleasedfrom disposable cups

The quantification of MPs in different types of cups was carried out using a Liquid Particle Counter.

It can be depicted from Fig.7that thousands of particles were released into the liquid when hot water was stored in the disposable cups for a short duration. The quantity of MPsleached out by cup type B which has a thickness of the HDPEfilm of 80 microns was 5988 MPs in 1ml of water whilecup type E having a thickness of 20 micronswas 653 MPs/ml.As a result,the number of MPs released by each cup depends on the thickness of the HDPE film interior lining; cup type B releases the most number of MPs due to its thicker HDPE film.

The Liquid Particle Counter can measure sizes ranging from 2-50 µm. In the presented Table 3, a detailed breakdown of the average number of MPs per milliliter of sample is categorized into 9 size ranges; ≥2-<5 µm, ≥5-<7.5 µm, ≥7.5-<10 µm, ≥10-<15 µm, ≥15-<20 µm, ≥20-<25 µm, ≥25-<30 µm, ≥30-<50 µm and =50 µm.

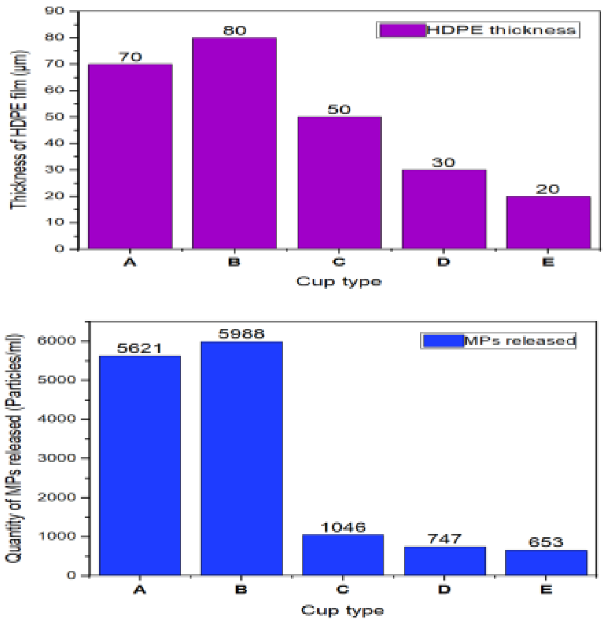

Figure 7. Microplastics released by each disposable cup with HDPE film thickness

Table 3. Average MPs Count of Sample Cup types A, B, C, D, and E using LPC

Average number of Particles per ml of sample										
Sample Name	≥2-<5	≥5-<7.5	≥7.5-<10	≥10-<15	≥15-<20	≥20-<25	≥25-<30	≥30-<50	50	Total
A	4565	511	345	142	19	26	3	9	1	5621
B	5337	471	135	36	5	4	0	0	0	5988
C	811	160	39	17	4	8	1	5	1	1046
D	528	135	58	17	3	4	1	1	0	747
E	483	77	43	24	6	12	1	6	1	653

Sample cup type B leached out 5337 MPs/mlof size (≥2-<5 μm) while Sample CupE released 483MPs/ml of the same size range. Other sample cup types: C, D, and E released 811 MPs/ml, 528 MPs/ml, and 483 MPs/ml respectivelyofdominant size 2-5 μm. The size distribution reveals a decreasing trend as the size range increases, with fewer particles in a larger size range. The largest MP size, found by LPC is 50 μm, and very few particles of this size were observed in each sample (Table 3).

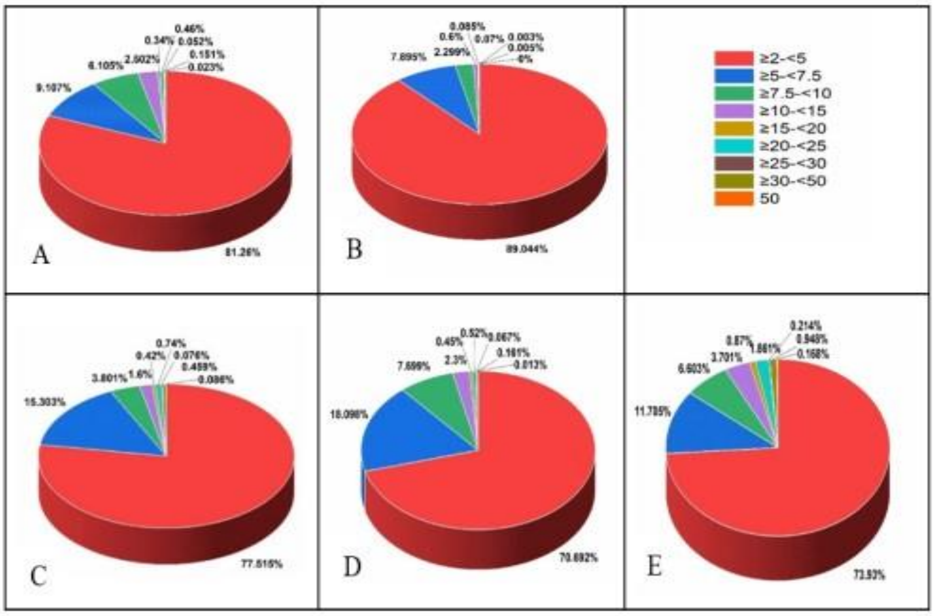

Figure 8. Size distribution of MPs released by disposable cups.

Most of the MPs detected by LPC belonged to the size range of 2-15 μm for the different samples. The majority of these particles in sample cup A-E were in the size range of ≥2-<5 μm as shown in Fig.8. In sample cup type B, 89.1% of the particles had a size less than 5 μm and this represented the highest concentration of particles in this size range. Sample D had the smallest concentration of particles, as compared to the other samples, in the particle size range of ≥2-5 μm; still, this value was 70.69%. The percentage of MPs observed in all the samples for size ≥5-<7.5 was 7.89%-18.09%. As shown in Fig. 8, there were extremely few particles with a size higher than 15μm.

3.5.Effect of factorsonthe level of MPs releasedpH

To investigate the effect of pH on the MPs released from disposable cups, experiments were performed at room temperature.

Fig.9 shows the number of MPs released from the disposable cups at varying pH 5, 7, and 9. The level of MPs released from disposable cups is found to be dependent on the pH of the liquid contained in the cups. The highest number of MPs released is 7256 particles/ml measured for cup type B at pH 5.The MPs released by cup types D and E are comparatively littleat varying pH levels.

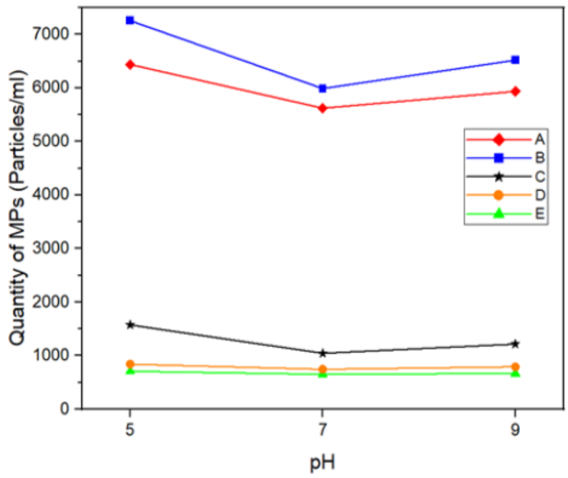

Figure 9. MPs are released from disposable cups at pH 5, 7, and 9.

Temperature

To examine the effect of temperature on MPs released from disposable cups, experiments were performed by heating ultrapure water at 30, 60, and 90^{O} C and filling the cups.

More MPs were released at 90^{O}Ccompared to 30^{O} C for each disposable cup (Fig. 10). In this study, there was no substantial increase of MPs from 30 to 60 ^{O} C. Therefore, it attributed to the inadequacy of the water temperature to degrade plastics of the interior lining of cups and leach out MPs.The highest quantity of MPs is released by cup type B, 5988 particles/ml at 90^{O} C.

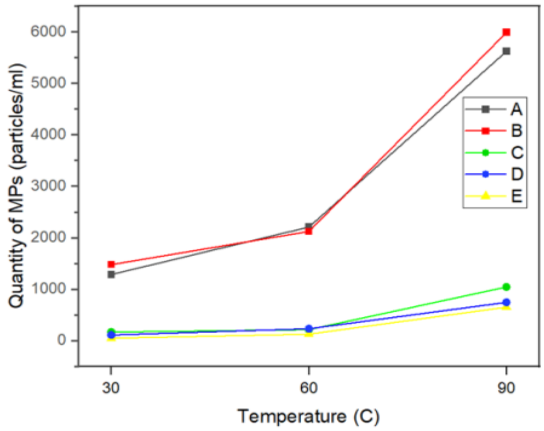

Figure 10. MPs released from disposable cups at 30, 60, and 90^{O} C

Exposure time

To study the effect of time on MPs released when hot ultrapure water was poured into the cups and resided for 5 min and 30min (Fig. 11). Zhou et al. [46] used PP, PET, and PE cups which released 1808-3723 particles/L and 3028-4293 particles/L after 5 min and 30 min of exposure respectively of size range 0.025-5mm. Therefore, it may be suggested that if people take longer time to drink in disposable cups, they ingest more MPs.

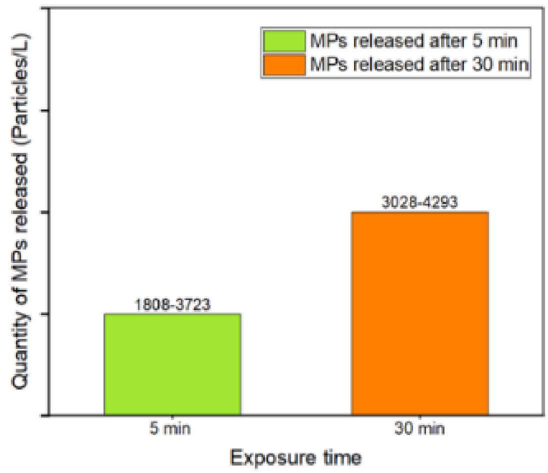

Figure 11. MPs were released from disposable cups after 5 min and 30 min of exposure time [46]

Recyclability

The recyclability analysis of disposable cups in Fig. 12a involves a wet and dry cycle to evaluate the environmental impact. For this, water at 90° C is poured into each cup for 5 min and the cups are then allowed to dry thoroughlyfor 2 hours to make them used again. This cycle is repeated multiple times to assess the performance of cups.In Fig.12b, cup type D has the greatest number of cycles identified as 4, butcup B only has 1. It evaluates the cup's resistance to moisture, biodegradability, and the potential chemical reactions that can occur when the liquid comes in contact with the inner lining of the cup under practical conditions.

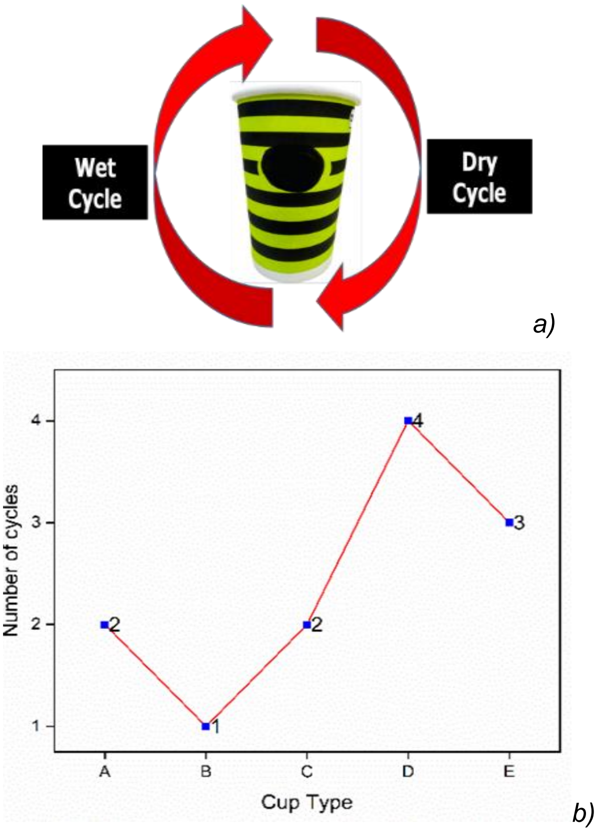

Figure 12. a) Wet and dry analysis of cups b) Number of cycles recorded for each type of cup

In a similar study, paper cups exposed to hot water for 15 minutes released 102 + 21.1 x 10^6 MPs/mL in the size range of 150 nm- 4.77 µm [13]. This range represented both the nanoplastics as well as microplastics. In another study investigating a common, daily-use consumer item, a plastic tea bag, it was found that about 2.3 million microplastics (size range: 1-150 µm) and 14.7 billion nanoplastics (size <1µm) were leached out of a single teabag [11]. In another study, low MP concentrations in disposable plastic items such as plastic packaging, cups, transparent storage containers, and expandable boxes were reported to release MPs with concentrations of 1.07 ± 0.507, 1.44 ± 0.147, 2.24 ± 0.719, and 1.57 ± 0.599 plastic particles (including both micron and submicron sizes) per mL in hot water [47].

In the current work, the concentration of the MPs released from the disposable cups of different types; Sample A-E were noted as 5.6 x 10^6 MPs/L, 5.9 x 10^6 MPs/L, 1x 10^6 MPs/L, 0.74 x 10^6 MPs/L and0.65 x 10^6 MPs/L respectively with the size limit of 2-50 μm. However, in other studies on disposable cups, relatively fewer MPs were discovered(Fig. 13). A recent study used PE, PP, and PS cups and found 2718±125, 2720±108, and 2629±121 leached particles/L respectively [48].

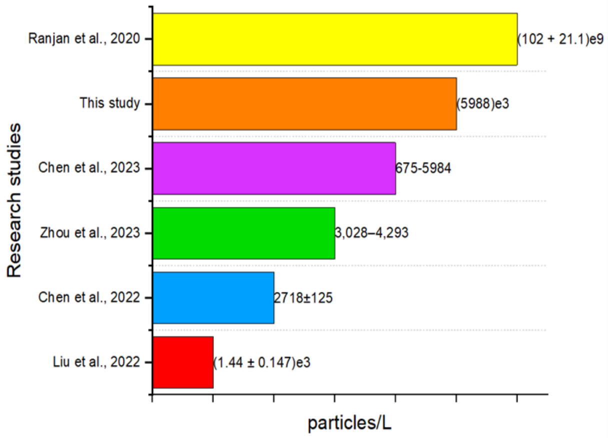

Figure 13. Quantity of MPs released from disposable cups in different research studies

A single beverage of 100ml consists of approximately 0.6 million MPs as seen in this work. The number of particles (in millions) consumed by a person daily can be calculated by 0.6 x N where N is the average number of disposable paper cups consumed by an individual per day for hot beverage consumption (assuming 100 ml intake per cup). On average, 3-4 cups are preferred by a casual tea/coffee drinker which leads to the ingestion of approximately 1.8-2.4 million MPs in a single day. In a year, hundreds of millions of MPs can potentially reach a human body through the consumption of hot beverages in such disposable paper cups. It is estimated that people may unconsciously ingest 219 million particles in a year due to the use of a single cup daily and around 657-876 million MPs annually due to the use of 3-4 cups in a day.That is a huge number to be consumed by a person in a hot beverage.

On consumption, these plastic particles can potentially accumulate in the tissues of various organisms including humans [49]. The size variation may have implications on the associated health effects. Particles of a particular size may find it easier to absorb into the body. It was reported that small-sizeparticles(<0.1–10 μm) can pass through the blood-brain barrier and placenta, and particles of 2.5 μm and above can reach systemic circulation via endocytosis and phagocytosis [50]. MPs (size <2 μm) are present in human blood anddifferent organs. MPs of size <2.5 μm can cross the respiratory barrier and remain in the human lungs causing respiratory and cardiovascular toxicities [51]. In the current study, it has been found that the maximum number of particles that are released are in the 2-5 μm size range, making it a bigger cause of concern. According to previous research studies, the MPs (size: 0.1-1-μm) in the gastrointestinal tract could be conveyed to mucosal lymphoid tissues via endocytosis by M cells [52], and larger MPs (size ≤ 130 μm) could be mechanically kneaded through loose junctions in the single-cell epithelial layer as well as into the circulatory system [53, 54]. MPs of 150 μm size can be absorbed by biota tissue, organs, and even cells, resulting in negative health effects [55]. Human blood, lungs, saliva, hair, sputum, face skin, hand skin, stool, and placenta samples have all indicated the presence of MPs [50]. In the current study, the MPs released from the disposable paper cups lie in similar size ranges and hence have the potential of being taken up by human beings and causing significant adverse health risks.

4. CONCLUSIONS

This study is the first detailed investigation into the size variations of the MPs released from daily-use item like paper cupsusingLPC for more accurate and quantitative estimation of MPs, although it could not quantify sub-micron-sized MPs.The knowledge of the MP's sizes can also be effectively used for their comprehensive removal from water and wastewater. The recyclability factor of disposable cups will help in making sustainable decisions and promote the production of cups.On investigating the physical characteristics of disposable cups, it was determined cup B has a thicker film layer on the interior lining. TheHDPE MPs were quantified and classified into the size range of 2-50 μm using LPC.Experiments were conducted to explore the effect of pH and temperature on the level of MPs released from disposable paper cups. It is crucial to highlight that the MPs were released more at pH 5 thus depending on the composition of liquid contained in the cup and at high temperatures and it depends. As a result, as many as 5988 particles per ml of sample can be generated when hot beverages are present in such cups. The adverse health effects of MPs are influenced significantly by their sizes and so are the removal techniques. The results of this study are not only of relevance to scientists, engineers, and medical professionals but to common people as well, who are unknowingly being exposed to such contamination by the use of such cups. Consumers must be aware of the harmful effects being caused to the environment of using these cups. It requires changes in cup preference (use of ceramic clay or glass cups/flasks) and updates in the manufacturing of disposable cups like the use of sustainable material (bamboo) that will compost. Manufacturers must be encouraged to use sustainable raw materials for manufacturing common-use items. This can result in a reduction of MPs reaching the human body and the environment.These results are expected to enhance consumer awareness about the potential exposure to MPs through routine acts as well as knowledge of size-dependent health effects and the development of appropriate comprehensive removal techniques.

Acknowledgments

This work is partially funded by Universitas Negeri Malang under Ministry of Education, Culture, Research and Technology of Indonesia

Competing Interest

The authors declare no competing interests.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data availability

The data and supplementary material are available on request

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IZVOD

MIKROPLASTIKA IZ PAPIRNIH ČAŠA ZA JEDNOKRATNU UPOTREBU: SVE VEĆA ZABRINUTOST U SVAKODNEVNOM ŽIVOTU

Mikroplastika (MP) koja se oslobađa iz jednokratnih proizvoda dobija široku pažnju zbog direktnog izlaganja ljudi tokom upotrebe. Ova studija istražuje kvantifikaciju i klasifikaciju veličine MP-a koji se oslobađaju iz papirnih čaša obloženih plastikom za jednokratnu upotrebu koje se obično koriste za posluživanje toplih napitaka. Da bi se procenili MP koji mogu da prodru u tople napitke za 15 minuta, studija ispituje pet različitih tipova papirnih čaša (A–E) sa različitim debljinama filma (20–80 mikrona) i kapacitetima (70–220 ml). Fluorescentna mikroskopija, infracrvena spektroskopija Furijeove transformacije (FTIR), skenirajuća elektronska mikroskopija (SEM) i brojač tečnih čestica (LPC) korišćeni su za karakterizaciju MP. Nalazi ukazuju na polietilen visoke gustine (HDPE) MPs, prvenstveno 2-5 mm sa zanemarljivim procentom čestica većih od 15 mm. Čaša za jednokratnu upotrebu od 100 ml može osloboditi do 0,7 miliona MPs, pod uticajem pH tečnosti i temperature. Rezultati analize mogućnosti recikliranja pokazuju da je čaša D otpornija na vlagu i biorazgradljivost zbog debljih papirnih ploča od HDPE folije. Rutinski korisnici mogu uneti 657-876 miliona MP godišnje što bi potencijalno moglo da utiče na zdravlje ljudi i životnu sredinu. Očekuje se da će rezultati studije pružiti uvid u uticaje na zdravlje i doprineti prikupljanju znanja o tehnologijama za uklanjanje mikroplastike.

Ključne reči: *spektroskopija; HDPE; LPC; varijacija veličine; efekti na zdravlje; ljudsko gutanje.*

Naučni rad
Radprimljen: 24.12.2024.
Rad prihvaćen: 25.01.2025.

Priya Agarwal: https://orcid.org/0000-0003-4252-8172
Satya Prakash: https://orcid.org/0000-0001-6633-7480
Markus Diantoro: https://orcid.org/0000-0001-6666-3702
Firdaus Mohamad Hamzah: https://orcid.org/0000-0002-6750-6183
Gaurav Saini: https://orcid.org/0000-0002-3975-346X