



UNIVERSITI PUTRA MALAYSIA

***OCCURRENCE AND DISTRIBUTION OF MICROPLASTICS IN
BOILED WATER FROM DIFFERENT ELECTRIC KETTLES & WATER
FILTER MACHINES AVAILABLE FROM MALAYSIA***

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WATER FROM DIFFERENT ELECTRIC KETTLES & WATER FILTER
MACHINES AVAILABLE FROM MALAYSIA**



**BY
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**Thesis submitted in fulfilment of the requirement for the degree of Bachelor of
Science in Environmental and Occupational Health with Honours from the
Faculty of Medicine and Health Sciences, Universiti Putra Malaysia**

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ABSTRACT

OCCURRENCE AND DISTRIBUTION OF MICROPLASTICS IN BOILED WATER FROM DIFFERENT ELECTRIC KETTLES & WATER FILTER MACHINES AVAILABLE FROM MALAYSIA

HUSNA BINTI YUSNIZAM

Introduction: In Malaysian households, people normally own electric kettles and water filter machines to boil water before drinking. However, the occurrence of microplastics in boiled water that might be sourced from these appliances has become a serious concern since the boiled water from electric kettles and water filter machines are used as drinking water as well. **Objectives:** This study aims to provide an understanding of microplastics in boiled water from different electric kettles and water filter machines as well as its suitability as drinking water. **Methodology:** Water samples were collected from nine electric kettles and five water filter machines and extracted using membrane filtration. Microscope was used to identify microplastics' colour, size, shape, and polymer types. FTIR spectroscopy was used to identify the polymer types of the microplastics. One-way ANOVA statistical analysis was used to compare microplastics occurrence in different groups of electric kettles and water filter machines. **Results and Discussion:** Microplastics' size in electric kettles and water filter machines were ranged between 55.036 μm to 1795.833 μm and 55.036 μm to 1795.833 μm respectively. Samples from plastic electric kettles (850.743 μm) and water filter machine K (751.564 μm) had the longest microplastics particles might be due to boiled water exposed more to plastic surfaces. Transparent microplastics dominated electric kettles (plastic electric kettles: 71.25%) and water filter machines (Water filter machine J: 76.67%) samples. The fragment was the major shape in electric kettles (glass electric kettles: 61.54%) and water filter machines (Water filter machine N: 76.56%) samples. The type of polymer found in the samples was polyethylene terephthalate (PETE), polycarbonate (PC), and polyvinyl chloride (PVC). One-way ANOVA statistical analysis showed no significant difference in the size of microplastics particles in boiled water from different types of electric kettles and water filter machines' brands. This indicates that types of electric kettles and water filter machines' brands were considered not to influence the size of microplastics instead it might be influenced by the materials of the plastics themselves. **Conclusion:** Abundance of microplastics particles were detected in different electric kettles and water filter machines available in Malaysia which made the boiled water from these appliances considered not suitable to be used as drinking water

Keywords: Microplastics, Electric Kettles, Water Filter Machines

ABSTRAK

KEHADIRAN DAN TABURAN MIKROPLASTIK DALAM AIR REBUSAN DARIPADA CEREK ELEKTRIK DAN MESIN PENAPIS AIR YANG BERBEZA YANG TERDAPAT DI MALAYSIA

HUSNA BINTI YUSNIZAM

Pengenalan: Kebiasaannya, rakyat Malaysia memiliki cerek elektrik dan mesin penapis air di rumah mereka untuk memasak air sebelum meminum air tersebut. Namun, kehadiran mikroplastik di dalam air yang telah dimasak di mana kehadiran mikroplastik tersebut mungkin berpunca daripada cerek elektrik dan mesin penapis air telah menjadi isu yang membimbangkan. Hal ini kerana air yang dimasak dengan menggunakan cerek elektrik dan mesin penapis air juga digunakan sebagai air minuman. **Objektif:** Kajian ini bertujuan untuk memberi kefahaman tentang mikroplastik di dalam air yang dimasak dengan menggunakan cerek elektrik dan mesin penapis air yang berbeza serta kesesuaiannya untuk dijadikan sebagai air minuman. **Metodologi:** Sampel-sampel air telah dikumpul daripada sembilan cerek elektrik dan lima mesin penapis air dan telah diekstrak dengan menggunakan penapisan membran. Mikroskop telah digunakan untuk mengenal pasti warna, saiz, bentuk dan jenis polimer mikroplastik. Spektroskopi FTIR telah digunakan untuk mengenal pasti jenis polimer mikroplastik. Analisis statistik “One-way ANOVA” telah digunakan untuk membandingkan kehadiran mikroplastik dalam kumpulan cerek elektrik dan mesin penapis air yang berbeza. **Keputusan dan Perbincangan:** Saiz mikroplastik di dalam cerek elektrik dan mesin penapis air masing-masing berjulat antara 55.036 μm hingga 1795.833 μm dan 55.036 μm hingga 1795.833 μm . Sampel daripada cerek elektrik plastik (850.743 μm) dan mesin penapis air K (751.564 μm) mempunyai partikel mikroplastik terpanjang adalah mungkin disebabkan oleh air yang dimasak terdedah lebih kepada permukaan plastik. Mikroplastik lutsinar telah mendominasi sampel cerek elektrik (cerek elektrik plastik: 71.25%) dan mesin penapis air (Mesin penapis air J: 76.67%). Bentuk serpihan adalah bentuk major yang dijumpai di dalam sampel-sampel daripada cerek elektrik (cerek elektrik kaca: 61.54%) dan mesin penapis air (Mesin penapis air N: 76.56%). Jenis polimer yang dijumpai di dalam sampel-sampel ialah polietilena tereftalat (PETE), polikarbonat (PC) dan polivinil klorida (PVC). Analisis statistik “One-way ANOVA” menunjukkan tiada perbezaan yang ketara dalam saiz partikel mikroplastik di dalam air yang dimasak daripada pelbagai jenis cerek elektrik dan jenama mesin penapis air. Hal ini, menunjukkan bahawa jenis cerek elektrik dan jenama mesin penapis air dianggap tidak mempengaruhi saiz mikroplastik sebaliknya mungkin dipengaruhi oleh bahan plastik itu sendiri. **Kesimpulan:** Banyak partikel mikroplastik telah dikesan di dalam cerek elektrik dan mesin penapis air yang berbeza dan yang terdapat di Malaysia menyebabkan air yang dimasak daripada peralatan-peralatan tersebut dianggap tidak sesuai untuk digunakan sebagai air minuman.

Kata kunci: Mikroplastik, Cerek elektrik, Mesin Penapis Air

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LIST OF ABBREVIATIONS

PC	Polycarbonate
PETE	Polyethylene terephthalate
PVC	Polyvinyl chloride
LDPE	Low-density polyethylene
PP	Polypropylene
PS	Polystyrene
POU	Point of Use
ABS	Acrylonitrile-butadiene-styrene
PE	Polyethylene
POM	Polyoxymethylene
FTIR	Fourier Transform Infrared Spectroscopy
UV	Ultraviolet
PMMA	Polymethyl methacrylate

CHAPTER 1

INTRODUCTION

1.1 Study Background

In Malaysian households, people normally own electric kettles and water filter machines to boil water before drinking. The ownership of electric kettles and water filter machines in Malaysian households up to the year 2000 is 1,896,746 and 54,088 respectively (Saidur, Masjuki, & Jamaluddin, 2007). The number of ownerships in 2015 for both kettles and water filter machines was also estimated to be increased to 2, 381, 816, and 77, 370 respectively. Besides, on average, Malaysian use about 0.48 hours per day for electric kettles while 11.9 hours per day for water filter machines to boil water (Saidur, Masjuki, Jamaluddin, et al., 2007).

There are many types of electric kettles and water filter machines available in Malaysia. Mostly, the types of electric kettles that can be found in Malaysian households are usually made of plastics, stainless steel, and glass. While for water filter machines, many brands have become popular choices in Malaysia such as Coway (Malaysia) Sdn. Bhd., CUCKOO International (MAL) Sdn. Bhd., Aqua Kent RO Malaysia. NEP Holdings (Malaysia) Berhad, 3M Malaysia Sdn. Bhd., AMWAY (Malaysia) Sdn. Bhd., Panasonic Malaysia Sdn. Bhd., PureGen Technologies Sdn. Bhd., Nikom Global

Marketing (M) Sdn. Bhd., and Bio Pure (Elken Global Sdn. Bhd.) (TechSci Research, 2021).

However, there are several issues regarding the use of electric kettles and water filter machines that have been previously studied. Electric kettles have been known to help people boil water conveniently but they still pose several issues to humans in many ways. There was a study found that using electric kettles with nickel-plated or chromium-plated heating elements may release nickel into the boiled water (Berg et al., 2000). Besides, electric kettles are also been considered as one of the electrical appliances in households that is significantly affecting electricity consumption (Bedir et al., 2013, as cited in Sena et al., 2021). Other than that, Al-Anzi et al. (2021) found that the reboiling process of water in electric kettles has been affected the water quality and the degree of the effect was influenced by the type of electric kettles.

Using water filter machines may also pose several issues to humans. Water filter machines might have problems in terms of microbiological quality if they have poor maintenance and improper hygienic conditions (Moosa et al., 2015). Besides, a water filter machine is one of the appliances that consume a large amount of electricity in a household since it needs to be kept on all day long (Kondou et al., 2011, as cited in Gadelkareem et al., 2019).

1.2 Problem Statement

In Malaysia, the use of electric kettles and water filter machines to boil water is widespread, but most of the studies were focused more on the energy consumption of electric kettles and water filter machines. Therefore, the plastic electric kettle might be the potential source of the microplastics occurrence in the boiled water. Commonly, plastic electric kettles are made of low-density polyethylene (LDPE), polypropylene (PP), or polystyrene (PS). All these plastics have been claimed as heat-resistant plastics since they have a high melting point. However, different types of plastics may have different resistance towards degradation which are depending on the chemical composition of the polymer. The prolonged use of electric kettles and water filter machines made of plastic might also cause the thermal degradation of the polymer. According to (Raji et al., 2018), this phenomenon is called thermal ageing of polymer which refers to molecular deterioration as the result of overheating due to the presence of tertiary hydrogen atoms in the polymer chain. Other than that, Park et al. (2019) stated that the Point of Use (POU) water dispenser machines use many types of components containing polymeric materials such as acrylonitrile-butadiene-styrene (ABS), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyoxymethylene (POM), silicone, and ethylene-propylene rubber. This shows that water filter machines usually contain many plastic surfaces which might lead to a higher potential of microplastics emission into the water when the water gets heated or boiled inside the machine. Therefore, the issue concerning plastic thermal degradation arises when most of the boiled water especially in the household nowadays is boiled using electric kettles and water filter machines which might lead to the presence of microplastics in the boiled water.

So far, the focus of microplastics studies in Malaysia has been more on the aquatic environment (Khalik et al., 2018; Saipolbahri et al., 2020; Sarijan et al., 2018; Yang Hwi et al., 2020; Zaki et al., 2021). Specifically, the evidence of microplastics contamination in drinking water due to boiling water in electric kettles or water filter machines is still less explored. To the extent, the suitability of boiled water from electric kettles and water filter machines as drinking water have been less explored in Malaysia.

1.3 Study Justification

This study would be able to provide information on whether boiling water using electric kettles made of plastic, stainless steel and glass, and water filter machines will have the tendency for degradation of their plastic surfaces which may introduce microplastics in boiled water. This study will also provide information on the characteristics of microplastics that might be emitted by the plastic surfaces of electric kettles and water filter machines such as colour, size, shape, and polymer types.

Moreover, this study will be able to fill in the gap of knowledge between microplastics studies in Malaysia. It could provide information on microplastics in boiled water from electric kettles and water filter machines available in Malaysia since many microplastics studies in Malaysia have been more focused on inland water. Besides, this study will also be able to provide information on whether the boiled water from electric kettles and water filter machines are suitable to be consumed as drinking water.

1.4 Research Questions

1. Is there any occurrence of particles in boiled water using electric kettles and water filter machines?
2. What are the characteristics of particles properties (colour, shape, and polymer types) in boiled water?
3. Is the particles occurrence in plastic electric kettles higher compared to other groups of kettles and water filter machines?
4. Is the boiled water from electric kettles and water filter machines suitable to be as drinking water?

1.5 Research Objectives

1.5.1 General objective

This study aims to provide an understanding of microplastics in boiled water from different electric kettles and water filter machines as well as its suitability as drinking water.

1.5.2 Specific objectives

1. To determine the occurrence of microplastics in boiled water using electric kettles and water filter machines.
2. To characterize microplastics properties (colour, shape, and polymer types) in the boiled water from electric kettles and water filter machines.
3. To compare microplastics in boiled water from different groups of electric kettles and water filter machines.
4. To assess the suitability of boiled water as drinking water.

1.6 Research Hypotheses

The hypotheses tested were shown below in the null form:

1. There will be an occurrence of microplastics in boiled water using electric kettles and water filter machines.
2. There will be higher microplastics occurrence in plastic electric kettles compared to other groups of kettles and water filter machines.

1.7 Definition

1.7.1 Conceptual Definition

i) Microplastics

Any synthetic solid particle or polymeric matrix, with regular or irregular shape and with size ranging from 1 μm to 5mm, of either primary or secondary manufacturing origin, which are insoluble in water (Frias & Nash, 2019).

ii) Electric Kettles

An electric kettle is an electrical appliance, that has a self-contained heating unit, for heating water, and automatically switches off when the water reaches the boiling point or at a preset temperature below 100 °C (Murray et al., 2016).

iii) Water Filter Machines

Water filter machines, commonly known as water dispenser is a machine that provides a comprehensive way to fulfil the demand for drinking water and has a filtration function that can remove impurities and process the water to be ready to consume (Yonathan et al., 2019).

1.7.2 Operational Definition

i) Microplastics

Microplastics were observed by determining their properties found in the boiled water of selected electric kettles and water filter machines in terms of their colour, size, shape, and polymer types. These properties were determined by using the membrane filtration method, Olympus CHK Compound Microscope for identifying size, shape, and colour, and Fourier Transform Infrared Spectroscopy (FTIR) for identifying the composition of the polymer.

ii) Electric Kettles

Three different types of electric kettles that are made of plastic, stainless steel and glass are obtained which are commonly found and available in Malaysia.

iii) Water filter machines

The identified five brands of water filter machines that are available in Malaysia. All the selected types of water filter machines are direct-piping water dispensers, use filtration methods and have both hot and cold-water dispensers.

1.8 Conceptual Framework

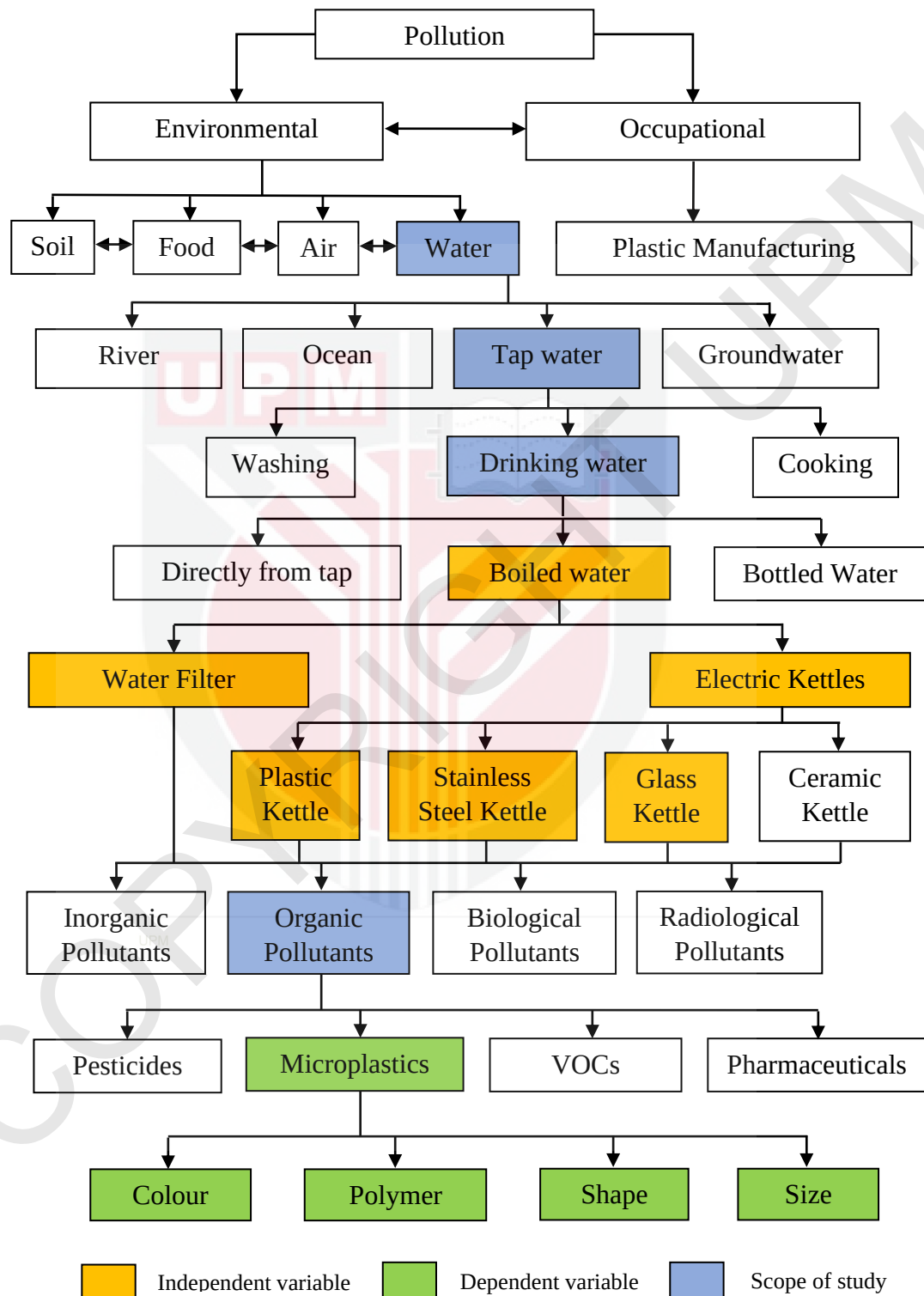


Figure 1.1: Conceptual Framework

CHAPTER 2

LITERATURE REVIEW

2.1 Boiling Process of Electric Kettles and Water Filter Machines

Electric kettles are the most convenient household appliances for people to boil water. The boiling process in the electric kettles is also a very simple process that only takes a short time to boil. However, the duration for an electric kettle to boil the water are still depending on the volume of water which can be considered the boil duration is practically linear with the volume of water-filled (Murray et al., 2016).

According to (Shah et al., 2019), electric kettles usually consist of two electrical parts which were a heating element and an on-off switch (**Figure 2.1 – 2.3**). The heating element was usually placed in a metal tube, directly into the water chamber in order to achieve a faster boiling process (Hassan et al., 2008). Shah et al. (2019) also stated that the heating element will be heated up when electric current flows into it and, through the conduction process it will heat the water-filled inside the electric kettle at full power to raise the temperature until 100°C. In other words, the heat conduction will occur when the energy transfer from more energetic to fewer particles of a substance due to interactions

between particles and later, a controller jet of steam from the boiling water will be used to cut the power supply via a fast-acting bimetallic strip (Hassan et al., 2008).



Figure 2.1: Open type heating elements - Heating Coil (Source: Techinfus.com)



Figure 2.2: Closed type heating elements - Heating plate (Source: Techinfus.com)



Figure 2.3: Electric kettles' switch (Source: Ifixit.com)

For water filter machines, these appliances had slightly the same method to boil water as electric kettles which the water will be heated by heating elements as well. However, water filter machines usually had two types of tanks which are hot and cold water (**Figure 2.4**). Sometimes it could be up to three types of tanks depending on the types and models of the water filter machines. For instance, Taiwan Tech had water filter machine models that consist of three types of tanks which are hot-water tank, warm-water tank and cold-water tank (Cheng et al., 2019). According to the general process of hot water in water filter machines stated by The Water Delivery Company (2017), as the water from the main pipe enters the machine, it will pass through two activated carbon filters first. Then, the hot water will be heated around 95°C by the heating element without further filtration and exit out of the tap.

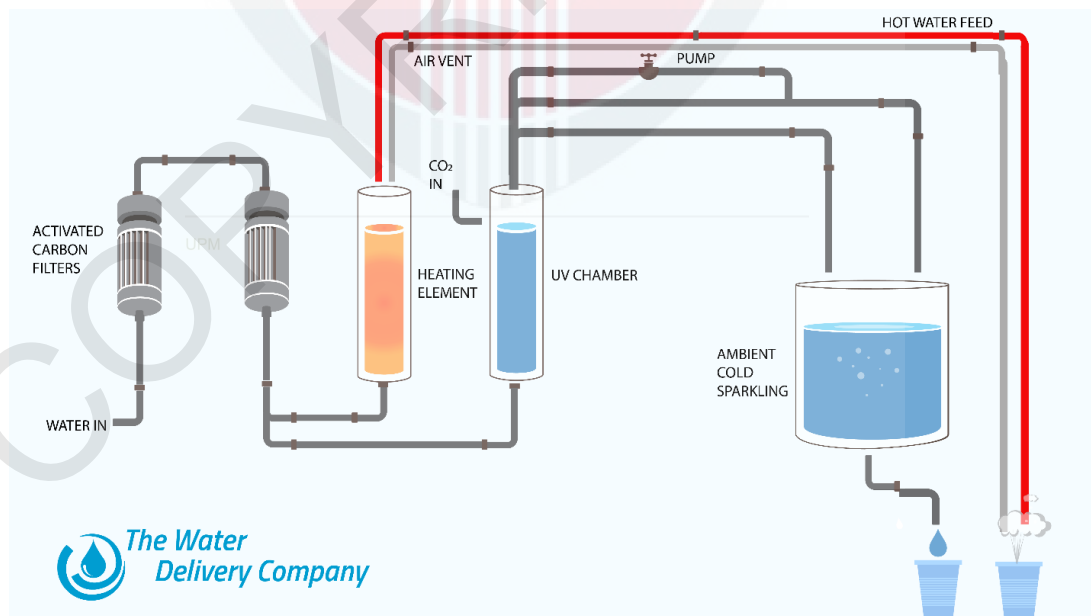


Figure 2.4: Water filter machines general components (Source: The Water Delivery Company)

2.2 Negative Effects of Boiling Process

Boiling water in electric kettles and water filter machines may produce some negative effects on the surface material of those appliances since the high temperature of the water might cause some leaches from them. For the plastic electric kettle, thermal degradation might occur as the plastic surfaces being damage due to the high temperature of the boiling process. Sturm et al. (2019) mentioned that there was a higher generation rate of particles after boiling water in the plastic electric kettle compared to the glass electric kettle. According to Ray & Cooney (2018), thermal degradation of polymer usually involves a series of chemical reactions through chain scission of the macromolecules. However, the reaction mechanism of thermal degradation still depends on several factors like macromolecular structure, environmental conditions, and additives (Ray & Cooney, 2018). Therefore, the degradation of plastic surfaces of plastic electric kettles when boiling water might also be influenced by the structure of the plastics, environmental conditions, and additives.

Stainless steel electric kettle on the other hand also has negative effects from the boiling process even though it is assumed not to cause any plastic leaches. Based on a previous study, stainless steel electric kettle has been commonly associated with nickel leaches (Berg et al., 2000). They mentioned that the heating element in the electric kettle might be the one responsible for the nickel leaches into the boiled water. In the other study, it stated that cooking with stainless steel kitchenware can also be the source of nickel leaches into the water (Kamerud et al., 2013). However, the test has not been conducted

using tap water, instead, they use tomato sauce. Even so, they conclude that the brand of tomato sauce was not the main influencer of nickel released but the grade of stainless steel, cooking time, and previous usage or seasoning of the stainless steel would be the factors. Therefore, from the result of previous studies, there could be a tendency as well for stainless steel electric kettles to release some nickel into the boiled water during the boiling process.

On the contrary, glass electric kettles have been recommended as a safer replacement to stainless steel and plastic electric kettles (Jillian Exton, 2019). It is because electric kettles that are made of glass especially borosilicate glass has been claimed to be safe for human use for boiling water since it is non-toxic. According to HealthxCenter (2020), borosilicate is made of silica and boron dioxide and it is well known for being chemical and thermal resistant. Moreover, borosilicate glass did not consist of any harmful toxins like phthalates or Bisphenol A (BPA) which contain in plastics (HealthxCenter, 2020).

However, there were many stainless steel and glass electric kettles nowadays that contain some plastic parts and surfaces. According to Gallego-Schmid et al. (2018), stainless steel electric kettles still consists of about 419 g of polypropylene which was based on their measurement. For instance, some stainless steel and glass electric kettles that are available in the market still have a lid made of plastics (**Figure 2.5 – 2.6**). Jillian Exton (2019), mentioned that the hot steam of the boiling process from the kettle might

also condense onto the plastic lid and will drip into the water. Sometimes, the water in the electric kettle could also touch the lid on the inside during the boiling process, especially when the water was filled over the maximum level where the boiling water could be spilt out from the lid. Therefore, the same phenomenon as mentioned by Ray & Cooney (2018) could occur afterwards where it could lead to the degradation of the plastics surfaces due to the high temperature of the boiling water and cause microplastics occurrence in the boiled water.



Figure 2.5: Plastic lid of glass electric kettle (Source: Trusted Reviews)



Figure 2.6: Plastic lid of stainless steel electric kettle (Source: Bajaj Electricals Ltd. 2021)

As for water filter machines, most of the previous studies only focused on the research about electrical consumption of water filter machines and there was no study on its boiling process negative effect on their surfaces up to this point. However, most of the water filter machines have a hot water tank inside them to boil and store the hot water. This hot water tank is usually made of stainless steel (**Figure 2.7**). Therefore, the negative

effect was expected to be the same as stainless steel electric kettles. Other than that, water filter machines typically consist of many tubes made of plastics such as polypropylene, polyethylene and polyvinyl chloride (Park et al., 2019). Thus, this situation could be considered the same as electric plastic kettles since the hot water with the high temperature might cause thermal degradation to the plastics surfaces of those tubes as well.

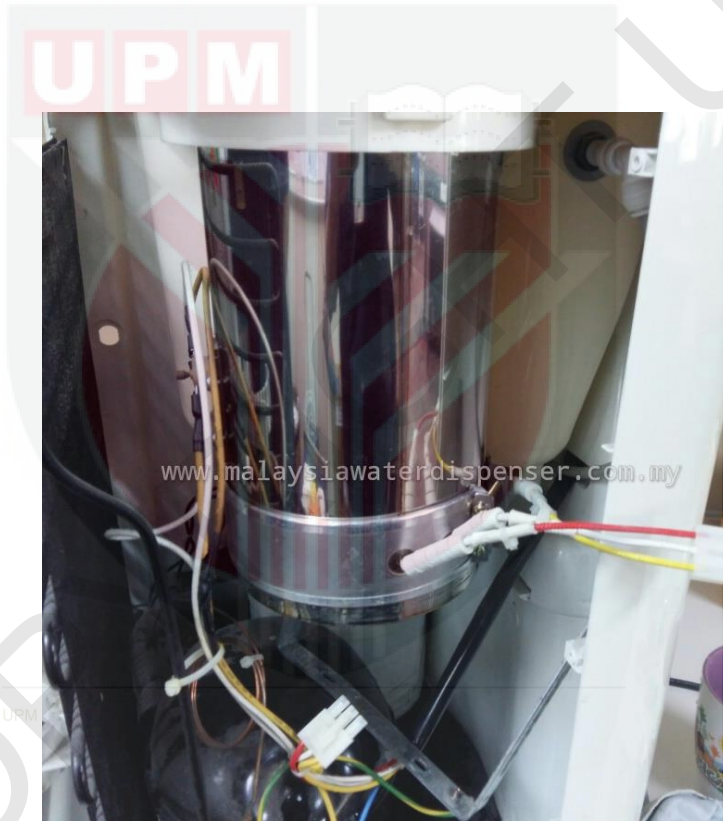


Figure 2.7: Hot water tank in water filter machine (Source: 1-Stop Malaysia Water Filters & Water Dispenser Photography Blog)

2.3 Past Studies on Boiled Water

Table 2.1 shows aspects of boiled water that has been studied in terms of their quality, the concentration of metals, effects of the boiling process and physical characteristics. A study by Zhai et al. (2020) was about the quality, safety and potability of repeatedly boiled water (RBW) and prolonged-boiled water (PBW). Some parameters of the boiled water that were being investigated by them were pH, total dissolved solids, heavy metals, volatile phenols, total alpha and beta, and radioactivity. The results show that RBW and PBW were still safe and potable as long the water meets the sanitary standards of drinking water before heating. Besides, Eze and Ekpemandu (2012) made research on microbiological parameters and chemical analysis on boiled water to determine the qualities of boiled water for food processing. The results show that the pH, conductivity, alkalinity and total dissolved solids complied with the standard of the United State Environmental Protection Agency while the total viable count and total coli form count was not acceptable to the Nigerian Industrial Standard for the microbial requirement at 70°C and 77°C. Previous research by Wu et al. (2018) and El Kutry and El-Sahar (2020) were also on the concentration of trace metals in the boiled water such as lead, cadmium, Argentum, nickel, and zinc. Wu et al. (2018) found that the concentrations of studied metals in the raw drinking water were similar to those in the boiled water but the trace metals in boiled water were generally higher than in raw water. While El Kutry & El-Sahar (2020) found that lead concentration in distilled water boiled in glazed clay pots was significantly higher than the negative controls while tap water boiled in glazed clay pots has lead concentrations significantly higher than the positive control. Instead, lead

concentrations in distilled water boiled in the unglazed clay pots showed no significant differences compared to the negative controls.

Al-Anzi et al. (2021) and Tagami and Uchida (2011) on the other hand made researches on boiled water in terms of its effects on physicochemical properties. The study by Al-Anzi et al. (2021) was about investigating the effect of reboiling potable water seven times on potable water quality. The results showed that the reboiling process has affected the water quality, where the extent of the effect could be influenced by the type of kettles. Meanwhile, Tagami & Uchida (2011) determined the effectiveness of the boiling process to remove iodine-131 from tap water in Japan. Their investigation was to confirm whether iodine-131 in the tap water that occur due Fukushima Daiichi Nuclear Power Plant accident can be removed by boiling method or not. However, they found that the boiled water still contained iodine-131 after the boiling process. Besides, Zendehboodi (2018) investigated the ability of water boiled in aluminium cookware to induce DNA damage in proliferating cells of an onion root tip in order to determine aluminium leaching from the cookware. Hence, this study has approved the potentially detrimental effects of water boiled in aluminum cookware on the cytological parameters of *A. cepa* root tip cells where the evidence on aluminum leaching from cookware has been increased.

Other than that, Garcia-Suarez et al. (2019) made a research on the life cycle assessment of boiled water to determine the environmental impacts in-home boiling of water. In their study, the environmental impact assessment of the boiled water in terms of

climate change, freshwater eutrophication potential, fossil depletion, and terrestrial acidification potential have been investigated. The results showed that the boiled water system had low climate change and fossil depletion impacts compared to the bottled water, but still higher than the RO device. Besides, freshwater eutrophication potential was the lowest for the boiled water and mainly related to the production and the distribution of Liquefied Petroleum Gas (LPG), specifically electricity used in the process. Meanwhile, Ribeiro et al. (2011) studied the physical characteristics of the boiled water which was its bubbles. They explored the dynamics of many interacting bubbles in boiling water by using a laser scattering experiment where the purpose of their study was actually to fill in the hiatus of the previous study. Hence, the results showed that the return interval distribution of the laser signal does not follow an exponential distribution; contrariwise, a heavy-tailed distribution has been found.

Table 2.1: Past studies on boiled water

No.	Author	Aspects	Main Findings
1.	Zhai et al. (2020)	Quality, safety and potability of repeatedly boiled water (RBW) and prolonged-boiled water (PBW)	Repeatedly boiled water (RBW) and prolonged-boiled water (PBW) were still safe and potable as long the water meets the sanitary standards of drinking water prior to heating
2.	Wu et al. (2018)	The concentration of trace metals; Ag, As, Ba, Be, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sb, Sn, Sr, Tl, U, V, Zn in boiled drinking water	The concentrations of studied metals in the raw drinking water were similar to those in the boiled water but the trace metals in boiled water were generally higher than in raw water.
3.	Al-Anzi et al. (2021)	The effect of reboiling potable water seven times on potable water quality	- The anions showed a gradually increasing trend throughout the seven times reboiling process with the highest Cl^- concentration of 47.3 ppm and SO_4^{2-} of 21.3 ppm for the same kettle (H). - The concentrations for the selected cations increased gradually for all kettles until the fourth boiling stage where all of the cations experienced a leap. Then the concentrations of the cations slightly decreased after the fifth reboiling stage and continued to increase for the last two stages until they reached their maximum concentrations level (absolute maximum) - The level of pH from the raw sample after the first boiling stage increased and then fluctuated until boiling stage 5 and decreased reaching a value of pH below the initial raw tap water for all kettles except kettle I (Dexon). - There was no significant variation of Pb, Ni, and Cu concentration in the boiled water that can be detected from the raw sample.

4.	El Kutry & El-Sahar (2020)	Lead concentration in the water was boiled in two kinds of clay pots (glazed and unglazed)	The lead concentration in distilled water boiled in glazed clay pots was significantly higher than the negative controls while tap water boiled in glazed clay pots has lead concentrations significantly higher than the positive control. Instead, lead concentrations in distilled water boiled in the unglazed clay pots showed no significant differences compared to the negative controls.
5.	Ribeiro et al. (2011)	The dynamics of many interacting bubbles in boiling water by using a laser scattering experiment	The return interval distribution of the laser signal does not follow an exponential distribution; contrariwise, a heavy-tailed distribution has been found.
6.	Tagami & Uchida (2011)	The effectiveness of the boiling process to remove iodine-131 from tap water	The tap water boiling tests in this study showed no iodine-131 loss from the tap water with either short-term boiling (1–10 min) or prolonged boiling (up to 30 min) resulting in up to 3-fold volume reductions
7.	Garcia-Suarez et al. (2019)	Environmental impacts of in-home boiling of water	The boiled water system had low climate change and fossil depletion impacts compared to the bottled water but was still higher than the RO device. The freshwater eutrophication potential was also the lowest for the boiled water and mainly related to the production and the distribution of Liquified Petroleum Gas (LPG), specifically electricity used in the process.
8.	Zendehboodi (2018)	The ability of water boiled in aluminium vessels to induce DNA damage or cell cycle disturbance in proliferating cells of the onion root tip.	The water boiled in aluminum cookwares have potentially detrimental effects on the cytological parameters of <i>A. cepa</i> root tip cells where the evidence on aluminum leaching from cookware has been increased from the test.
9.	Eze & Ekpemandu (2012)	Qualities of boiled water for food processing; total viable count, total coli form count, pH, conductivity, alkalinity, and total dissolved solids	The pH, conductivity, alkalinity and total dissolved solids complied with the standard of the United State Environmental Protection Agency while the total viable count and total coli form count was not acceptable to the Nigerian Industrial Standard for the microbial requirement at 70°C and 77°C.

2.4 Human Health Risks Due to Microplastics Exposure

The issue of microplastics being ubiquitous in the environment have been detected to be one of the potential factors to various health complications. Human has been exposed to microplastics through many potential pathways such as dermal, inhalation and ingestion (Prata et al., 2020). Therefore, these pathways of microplastics into the human body may lead to potential health risks like oxidation stress, cytotoxicity, altering metabolism, immunity disruption, translocation to distant organs, neurotoxicity, reproductive toxicity and carcinogenicity (Rahman et al., 2021).

In a previous inhalation exposure study, oxidative stress and subsequent inflammation have been shown as the bests paradigm for Microplastics toxicity (Nel et al., 2006). Microplastics can cause oxidative stress by releasing oxidizing chemicals (such as metals) absorbed to their surface and reactive oxygen radicals from the host body that were produced through an inflammatory response (Kelly and Fussel, 2012; Valavanidis et al., 2013 as cited in A. Rahman et al., 2021). Then, the microplastics consisting of reactive oxygen species (ROS) might get increased in the host body due to UV light or the presence of reactive metals (Rahman et al., 2021). Thus, this can cause oxidative stress inside the host body which can lead to other health effects such as diabetes, atherosclerosis, inflammatory conditions, high blood pressure, heart disease, neurodegenerative disease and cancer (Dix, 2018). Based on a previous test by Schirinz et al. (2017), cytotoxicity in human cerebral and epithelial cells is also one of the effects of oxidative stress and inflammation due to the increased reactive oxygen species (ROS) in the host body.

Besides, microplastics are also potential in influencing metabolism by directly affecting metabolic enzymes or indirectly disrupting the energy balance. Previous research showed that exposure to microplastics can elevate the lactate dehydrogenase enzyme in fish and mice which can be led to the increase of their anaerobic metabolism (Deng et al., 2017; Wen et al., 2018). Similar to animals, humans might as well suffer from the same effects as those tested animals where the metabolic effects can occur due to the increasing and decreasing of energy expenditure, lowering nutrient intake or modulating metabolic enzymes (Rahman et al., 2021). Nevertheless, humans might be able to alter the metabolic effects because generally, humans have higher energy needs and complex metabolic activities compared to the tested animals (Rahman et al., 2021).

The immune system could also be affected by microplastics exposure where these particles can cause local or systemic immune responses that depend on their dissemination and host responses (Prata et al., 2020). However, individuals with genetic susceptibility that exposed to environmental microplastics will be easier for their immune function to be disrupted which can lead to other complications such as autoimmune diseases or immunosuppression (Prata et al., 2020). According to Farhat et al. (2011), microplastic-induced autoimmune diseases might be due to oxidative stress of cells, the release of immune modulators and the inappropriate activation of immune cells. Thus, these could induce the production of antibodies against self-antigens.

Additionally, microplastics can be translocated to other distant tissues through the circulatory system. Canesi et al. (2015) reported that the microplastics in the circulatory

system caused a systemic inflammatory response and blood cell cytotoxicity through internalization. Campanale et al. (2020) also found that microplastics in the circulatory system can cause vascular inflammation and occlusions while Wright and Kelly (2017) reported that pulmonary hypertension was also one of the effects. Moreover, Wick et al. (2010) and Grafmueller et al. (2015) demonstrated that microplastics especially polystyrene nanoparticles can be transported across the placenta barrier through diffusion and by using both intra and extracellular transporter proteins.

Exposure to microplastics also has been reported to cause neurological effects. Rahman et al. (2021) reported that exposure to particulate matter including microplastics might activate immune cells in the brain and oxidative stress which could lead to neurotoxicity. This activation might result in permanent damage to neurons due to particles translocation or the consequences of circulation proinflammatory cytokines (MohanKumar et al., 2008). Deng et al. (2017) also discovered that exposure to microplastics would increase the activity of acetylcholinesterase (AChE) in the brain and could affect the serum neurotransmitters. By using neural cell types, the study found that polystyrene with the size 40-70 nm in size were able to cause toxicity and decrease metabolic activity due to the increased presence of bioactive compounds (Deng et al., 2017).

For reproductive toxicity, D'Angelo & Meccariello (2021) suggested that microplastics that were ingested or bioaccumulated in mammalian tissues, including the testis, with outcomes on semen quality in rodents, as a consequence of inflammatory state

and oxidative stress damage. The study also stated that the size and molecular structure of microplastics could influence the effects on reproductive toxicity. Furthermore, D' Angelo & Meccariello (2021) reported that the main causes of testicular and sperm damage are oxidative stress together with the age-dependent decrease in antioxidant activity and mitochondria. Moreover, this study discovered that spermatogenesis failure, the apoptotic loss of both germ and somatic cells, oxidative DNA damage, failure in gene expressions and post-transcriptional gene regulation, or APT depletion are due to the overproduction of reactive oxygen species (ROS).

Humans exposed to microplastics are also susceptible to cancer risk. A review by Prata (2018) found that chronic inflammation and irritation due to microplastics ingestion might induce DNA damage that leads to cancer. Meanwhile, Sharma et al. (2020) also found that microplastics ability to adsorb carcinogenic polycyclic aromatic hydrocarbons (PAHs) might be the potential factor of cancer risk of ingested PAHs enriched microplastics by a human being. The study discovered that carcinogenic PAHs on microplastics have an adsorption capacity ranging from 46 to 236 $\mu\text{g g}^{-1}$ and the maximum binding was achieved within 45 minutes in water. Besides, the study calculated the cancer risk in terms of the lifetime of microplastics ingestion which result showed 1.13×10^{-5} for children and 1.28×10^{-5} for adults and these values were higher than the recommended value of 10^{-6} .

CHAPTER 3

METHODOLOGY

3.1 Research Design

An experimental study design was implemented in order to provide an understanding of microplastics in boiled water from different electric kettles and water filter machines as well as its suitability as drinking water.

3.2 Study Subject

A total of nine electric kettles and five brands of water filter machines were selected in this study. This study has selected electric kettles that were made of plastic, stainless steel and glass and water filter machines that were available and commonly found in Malaysia. All information regarding the collected electric kettles such as types of materials, capacity, types of heating elements, years/months of usage were recorded in **Table 3.1**. The criteria of identified water filter machines were direct-piping water dispensers, using filtration methods and having hot water dispensers. Then, all information regarding the determined water filter machines such as type of filters used and date of service was recorded in **Table 3.2**.

Table 3.1: Information of selected electric kettles

Electric Kettles	Capacity (L)	Types of materials	Types of heating elements	Years of usage
A 	1.2	Plastic	Heating plate	> 5
B 	1.7	Plastic	Heating coil	3

C



1.8

Plastic

Heating coil

3

D



1.8

Stainless Steel

Heating plate

0.5

E



1.8

Stainless Steel

Heating plate

3

F



2.0

Stainless Steel

Heating plate

0.6

G



1.8

Glass

Heating plate

1

H



2.2

Glass

Heating plate

0.5

I



1.7

Glass

Heating plate

0.5

Table 3.2: Information of selected water filter machines

Water Filter Machines	Type of Filter	Installed date	Last Service
J 	1. Taste and odour removal 2. Carbon filter 3. Carbon filter 4. Sediment filter	-	-
K 	1. Sediment filter 2. Pre-carbon filter 3. ORP filter (activated carbon) 4. Post-carbon filter	17 th April 2020	17 th October 2021

L



1. Plus Sediment
2. Pre-carbon filters
3. RO Membrane Filter
4. Plus Inno-Sense Filter
(Post-carbon + Fine filters)

August 2018

5th April 2021

M



1. Sediment filter
2. Pre-carbon filter
3. Post-carbon filter
4. UF Membrane filter

2011

2019

N



1. Nano Sediment filter
2. Mineral + ORP + Hydrogen
+ Ionizer + Alkaline filter
3. GAC Alkaline filter
4. Post Carbon filter

2nd September
2013

14th October 2018

3.3 Sample Collection of Electric Kettles

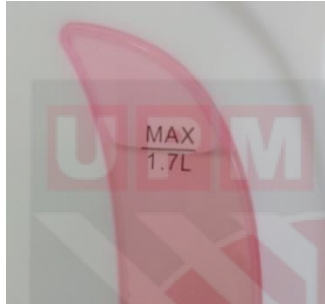
The electric kettles were rinsed repeatedly three times using tap water to ensure the electric kettles were cleaned from other pollutants. After the electric kettle was rinsed, it was filled up with tap water until its maximum fill level. Then, the electric kettle was switched on to boil the tap water. When the boiling process was automatically switched off, the tap water inside the electric kettle was let to cool down until it reached room temperature. Next, 100 mL of boiled water from the electric kettle was measured to get the first sample for analysis. This step was repeated to obtain two more sample replicates, so the total number of samples obtained for each electric kettle were three samples. 100 mL of unboiled tap water were measured as well for blank samples by using a measuring cylinder. All the steps of water sample collection from electric kettles are shown in **Figure 3.1**. Therefore, the total number of samples from electric kettles were 27 samples. All the remaining boiled water was discarded afterwards.

1



The kettle was rinsed repeatedly three (3) times using tap water to ensure the kettle is cleaned from other pollutants.

2



Then, the electric kettle will be filled with tap water to the maximum fill level.

3



The electric kettle filled with tap water was placed on the power base and switched on to boil the water for a few minutes.

4



The boiled water was let to cool until it reached room temperature (estimated 15 minutes or until it totally cools down).

5



Then, 100 mL of water from the electric kettle were measured by using measuring cylinder to get the sample for analysis.

Figure 3.1: Water samples collection steps from electric kettles

3.4 Sample Collection of Water Filter Machines

During the sampling process at the water filter machine, the hot water faucet was opened to let the water run for about one minute as the quality control step. Then, a total of 300 mL of hot water was taken immediately by using the water sampling bottle and the bottle was labelled afterwards. The total volume of water taken for each water sampling bottle was 300 mL since it was used as triplicate samples during analysis which was 100 mL for each sample. All the steps of water sample collection from water filter machines are shown in **Figure 3.2**. Hence, the total number of samples from all water filter machines was 15 samples.

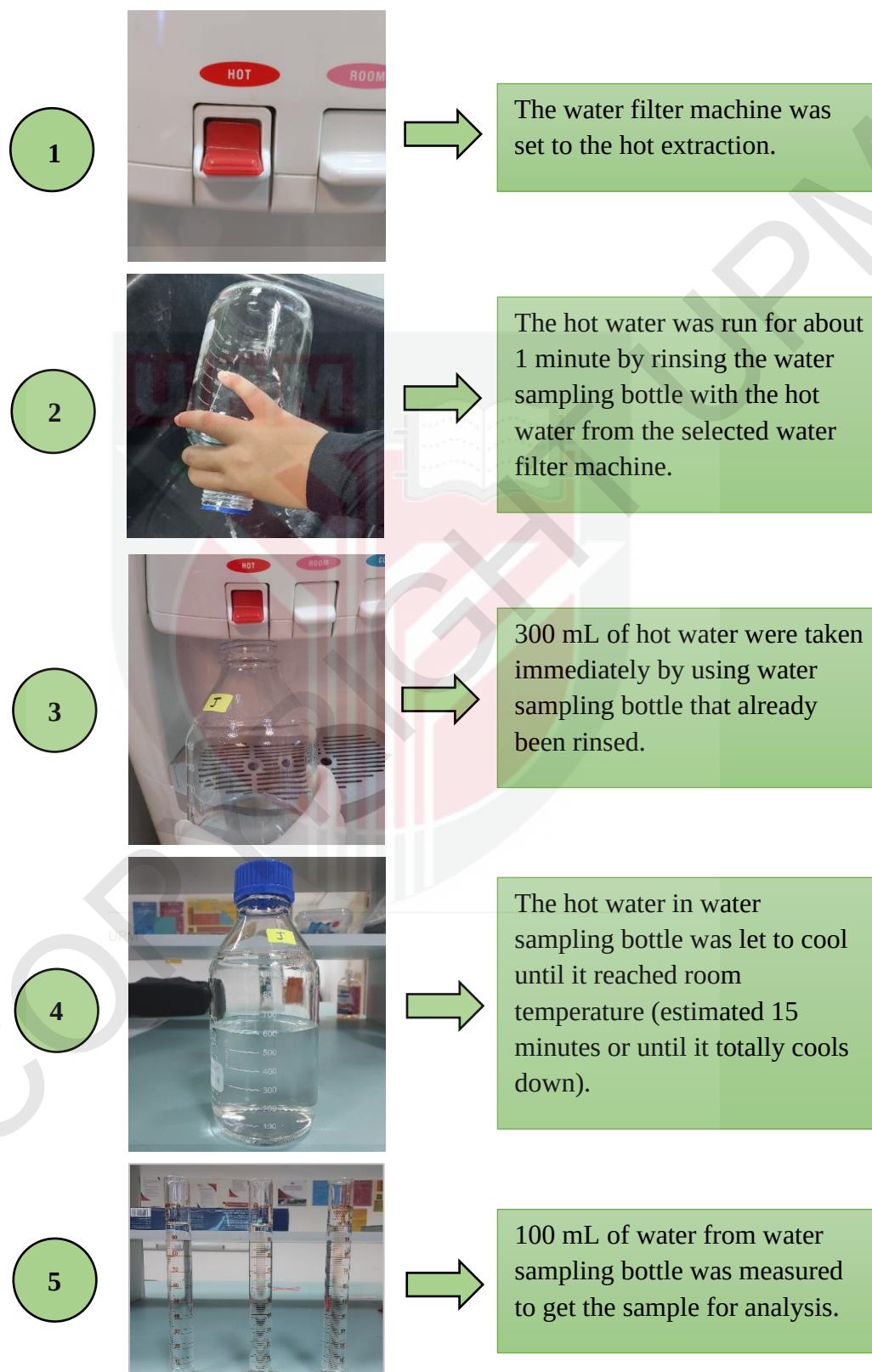


Figure 3.2: Water samples collection steps from water filter machines

3.5 Microplastics Analysis of Water Samples

All the water samples obtained from the selected electric kettles and water filter machines were filtered using the membrane filtration technique using Whatman Filter Paper 0.45 μm via vacuum filtration (Praveena et al., 2018). The use of membrane filter paper with the size of 0.45 μm was to capture smaller microplastics. During the extraction process, vacuum filtration was set up by using a pump and the membrane filter paper was put on the setup. Then, 100 mL of the water samples were measured by using a 100 mL measuring cylinder that had already been acid-washed and poured into the funnel carefully. The water sample was let to pass through the membrane filter paper for a few minutes until it was completely filtered. After that, the funnel was removed carefully and the membrane filter paper was taken out. It was then transferred into a petri dish for the air-dried process. Along the process, the membrane filter paper was carefully handled to prevent any external contamination. Then, the samples were kept in a tray covered with aluminium foil after being filtered and air-dried. The water samples from electric kettles and water filter machines were analyzed in triplicates.

3.6 Quality Assurance and Quality Control

Before the sample collection from electric kettles and water filter machines, all glassware used for the sample collection such as measuring cylinders, Petri dishes and water sampling bottles were acid washed. The acid wash was done by mixing 80mL of

nitric acid and tap water. The nitric acid was poured first into a pail and the pail was filled up with tap water until three-quarters. Then, all the glassware were soaked in the mixture for 24 hours before they were rinsed with tap water, air-dried and ready to be used. For water sampling bottles, they were air dried in the laminar flow cabinet.

3.7 Identification and Visualization of Microplastics Particles

The filter papers were air-dried proceeded with identification and visualization of microplastics particles process. For this process, the Olympus CHK Compound microscope was used to identify and visualize the microplastic occurrence on the filtered membrane filter paper. The aspects of microplastics that were observed during this process were size, shape and colour (Praveena et al., 2018). The lens magnification used was 40× which gave the total magnification of 400×. Before placing the membrane filter paper on the microscope's stage, the filter paper was divided into four quadrants; A, B, C & D. Then, each quadrant was observed at five spots. This step was to ensure all surfaces on the membrane filter paper was completely observed. If there was a confirmation of the microplastics occurrence on the membrane filter paper such as the microplastics have the same colour as the colour of their source of pollution, the spot will be circled. Besides, each spot within each quadrant was photographed. Thus, the total number of photos photographed for each filtered membrane filter paper was 20 photos.

3.8 Identification of polymer types

Samples were sent to another laboratory that has the facilities of Fourier-transform infrared spectroscopy (FTIR) method analysis. This method was performed to identify the presence of plastics polymers on the selected filter papers and the type of polymer detected in the boiled water.

3.9 Data Analysis

Table 3.3 shows the statistical analyses used for the specific objectives of this study. This study only used One-way ANOVA to analyze the research objective, comparing microplastics occurrence in different groups of electric kettles and water filter machines. This test was used to test the null hypothesis of this study which was there will be higher microplastics occurrence in plastic electric kettles compared to other groups of kettles and water filter machines. The independent variables were boiled water from selected electric kettles and water filter machines while the dependent variables were the occurrence, colour, size, shapes and types of polymers of microplastics.

Table 3.3: Statistical Analysis

No.	Specific Objectives	Statistical Analysis
1.	To determine the occurrence of microplastics in boiled water using electric kettles and water filter machines.	-
2.	To characterize microplastics properties (colour, shape, and polymer types) in boiled water.	-
3.	To compare microplastics occurrence in different groups of electric kettles and water filter machines.	One-way ANOVA
4.	To assess the suitability of boiled water as drinking water.	-

CHAPTER 4

RESULTS

4.1 Occurrence of Microplastics Particles in Boiled Water from Different Electric Kettles & Water Filter Machines

4.1.1 Size of microplastics particles in boiled water from different electric kettles

Based on the data in **Table 4.1**, the range of microplastics sizes for samples from plastic electric kettles (sample A1 until C3) was 55.036 μm to 1746.284 μm . Stainless steel electric kettles (sample D1 until F3) on the other hand had a range of microplastics sizes from 64.182 μm to 1729.447 μm . While the range of microplastics sizes for samples from glass electric kettles (sample G1 until I3) was 97.088 μm to 1795.833 μm . As for blank samples, it had six samples with the microplastics size range of 82.826 μm until 1768.791 μm .

Table 4.1: Size of microplastics particles in boiled water from different electric kettles

Sample	Mean (µm)	SD	Min (µm)	Max (µm)
Plastics Electric Kettles				
A1	622.072	530.440	105.347	1678.390
A2	488.861	366.700	169.739	1409.990
A3	563.904	561.065	83.683	1629.728
B1	462.342	464.106	83.828	1708.720
B2	400.329	289.573	61.679	1021.236
B3	565.783	399.332	55.036	1602.605
C1	850.743	635.906	119.162	1746.284
C2	507.208	482.818	84.976	1509.265
C3	572.105	538.065	84.691	1706.485
Stainless Steel Electric Kettle				
D1	704.331	599.737	124.629	1694.458
D2	348.410	341.502	66.954	1630.397
D3	439.960	339.795	64.182	1482.864
E1	562.010	464.558	137.919	1710.619
E2	765.699	540.578	125.501	1485.444
E3	754.140	575.155	150.681	1729.447
F1	422.874	414.127	186.798	1506.412
F2	736.053	565.808	108.408	1636.197
F3	384.576	339.029	114.918	1446.367
Glass Electric Kettle				
G1	659.946	645.194	105.232	1795.833
G2	639.206	451.169	131.350	1420.579
G3	444.621	452.363	103.374	1525.299
H1	364.224	357.637	128.835	1352.331
H2	665.789	560.664	112.251	1484.505
H3	443.377	340.282	129.492	1327.273
I1	499.832	384.174	136.772	1471.545
I2	591.633	579.787	97.088	1587.856
I3	653.492	540.415	98.451	1623.404
Blank				
1	844.581	522.764	82.826	1418.305
2	457.397	395.490	121.877	1437.089
3	795.184	444.281	227.292	1768.791
4	785.548	453.811	251.580	1469.106
5	315.706	228.793	134.450	908.113
6	395.136	350.818	111.602	1176.777

4.1.2 Size of microplastics particles in boiled water from different water filter machines

Table 4.2 shows the range of microplastics sizes for samples from water filter machine J (sample J1 until J3) was 83.828 μm to 1587.794 μm . Water filter machine K (sample K1 until K3) on the other hand had a range of microplastics sizes from 77.050 μm to 1602.129 μm . While the range of microplastics sizes for samples from water filter machine L (sample L1 until L3) was 55.692 μm to 1748.828 μm . As for samples from water filter machine M (sample M1 until M2), it had a microplastics' size range of 42.058 μm until 1647.885 μm . Meanwhile, water filter machine N (sample N1 until N3) samples had a range of microplastics sizes from 68.916 μm to 1705.022 μm .

Table 4.2: Size of microplastics particles in boiled water from different water filter machines

Sample	Mean (μm)	SD	Min (μm)	Max (μm)
J				
J1	613.563	429.361	108.072	1514.330
J2	599.733	447.917	83.828	1491.085
J3	699.459	523.023	94.045	1587.794
K				
K1	208.403	106.362	86.109	434.580
K2	730.349	483.994	149.713	1602.129
K3	751.564	586.186	77.050	1944.556
L				
L1	285.879	312.405	98.081	1487.204
L2	531.405	472.579	55.692	1686.129
L3	462.134	495.354	69.615	1748.828
M				
M1	536.805	435.524	83.828	1647.885
M2	452.540	420.601	48.481	1616.853
M3	396.783	508.272	42.058	1379.798
N				
N1	456.585	415.617	68.916	1705.022
N2	438.510	411.008	98.574	1681.985
N3	479.450	365.520	97.088	1454.286

4.2 Colour, Shape and Polymer Types of Microplastics Particles in Boiled Water from Different Electric Kettles and Water Filter Machines

4.2.1 Colour of microplastics particles in boiled water from different electric kettles

Based on **Figure 4.1**, plastic electric kettles samples contain transparent colour (71.25%) microplastics particles which was the highest percentage while the lowest percentage was red colour (1.25%) microplastics particles. In plastic electric kettles samples, there were also green colour (2.5%) and blue colour (6.88%) microplastics particles. For stainless steel electric kettles, **Figure 4.1** also shows transparent colour (63.24%) microplastics particles were the dominant colour with the highest percentage while the lowest percentage was yellow colour (0.7%) and green colour (0.7%). Red colour microplastics particles had a percentage of 7.69%, black was 4.2% and orange was 3.5%. As for glass electric kettles, transparent microplastics particles (66.86%) was the major colour while black colour microplastics (4.14%) was the minor (**Figure 4.1**).

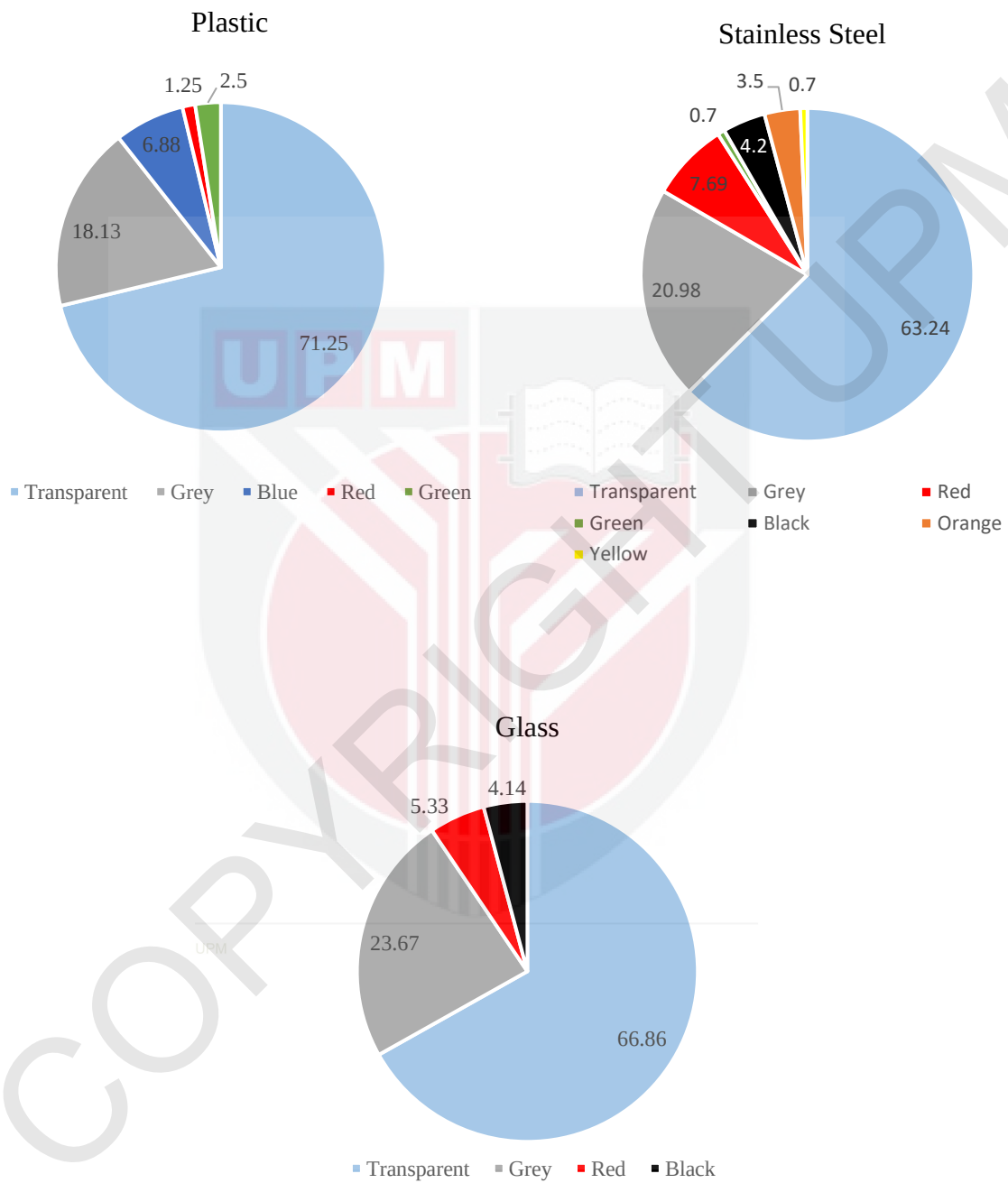


Figure 4.1: Colour of microplastics particles in boiled water from different electric kettles

4.2.2 Colour of microplastics particles in boiled water from different water filter machines

Figure 4.2 shows the percentage of microplastics' colour in samples from water filter machines J, K, L, M and N. Transparent microplastics were found to be the major colour in all water samples (J: 76.67%; K: 75.8%; L: 68.75%; M: 62.63%; N: 55.38%) while grey microplastic particles (J: 16.67%; K: 12.9%; L: 17.19%; M: 115.63%; N: 35.38%). Only samples from the water filter machines L and M contained black microplastics particles which were 3.13% and 1.56% respectively. There were also blue microplastics occurrences in samples from water filter machines K (4.84%) and M (1.56%). In water filter machine L, there was yellow (1.56%) microplastics particles detected in the samples while green (1.56%) microplastics particles were detected in water filter machine M.

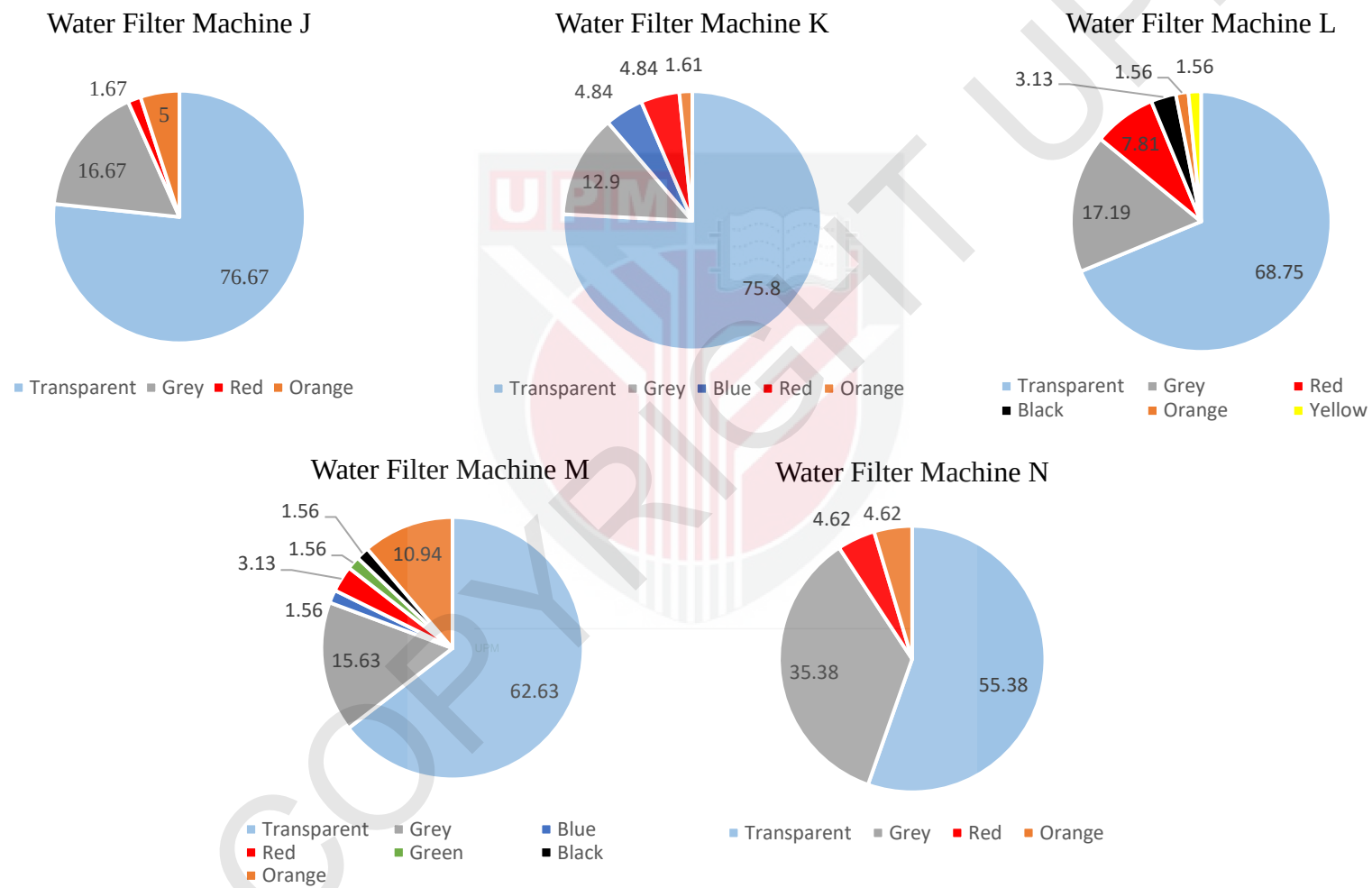


Figure 4.2: Colour of microplastics particles in boiled water from different electric kettles

4.2.3 The shape of microplastics particles in boiled water from different electric kettles

Figure 4.3 shows the percentage of types of shapes found in electric kettles samples. There were four types of shapes found in the samples which were fibre, film, fragment and foam. For plastic electric kettles **Figure 4.3**, the major microplastics shape found was fragments (54.38%), followed by fibre (26.25%), film (11.88%) and foam (7.5%). Stainless steel electric kettles also had fragments (58.74%) as the major microplastics shape found in the samples. The second major shape was fibre (32.17%) then, foam (8.4%) and film (0.7%). Fragment-shaped (61.54%) microplastics particles also dominate the shape found in the samples from glass electric kettles. Then, the following shapes were fibre (31.95%), foam (4.73%) and film (1.78%).

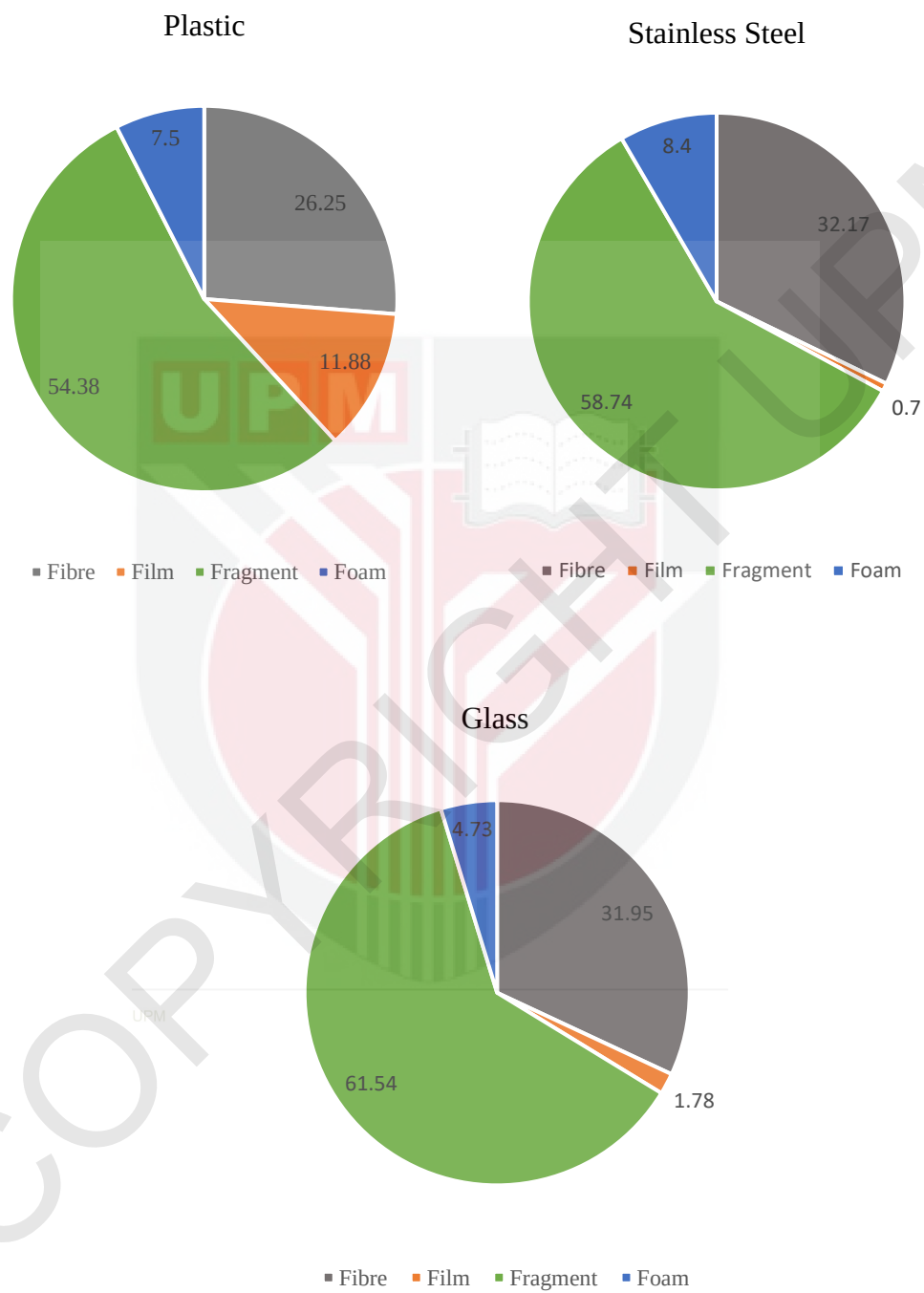
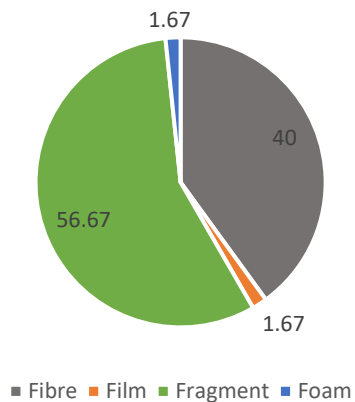


Figure 4.3: Shape of microplastics particles in boiled water from different electric kettles

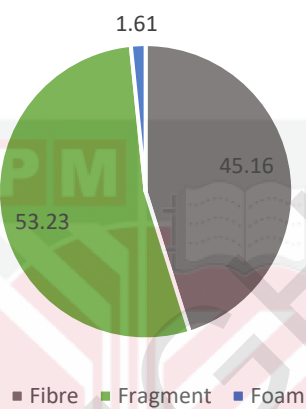
4.2.4 The shape of microplastics particles in boiled water from different water filter machines

Figure 4.4 shows the percentage of microplastics shapes found in samples from water filter machines J, K, L, M and N. There were four types of shapes found in the samples which were fibre, film, fragment, foam and pellet. In water filter machine J samples, fragment (56.67%) was the dominant shape. Followed by fibre (40%), film (1.67%) and foam (1.67%). Next, water filter machine K samples have fragment (53.23%) as the major shape and followed by fibre (45.16%) and foam (1.61%). For water filter machine L, the major microplastics shape in samples was fragment (59.35%) as well. Then, the second major was fibre (29.69%), followed by film and foam with a similar percentage (4.69%), and spherical (1.56%). Fragment (65.63%) microplastics were also the dominant shape in samples from water filter machine M following the fibre (32.81%) and film (1.56%). Lastly, water filter machine N had fragment (75.56%) as the major micro-plastics shape in the samples while fragment being the second major (17.19%), followed by the film (4.69%) and foam (1.56%).

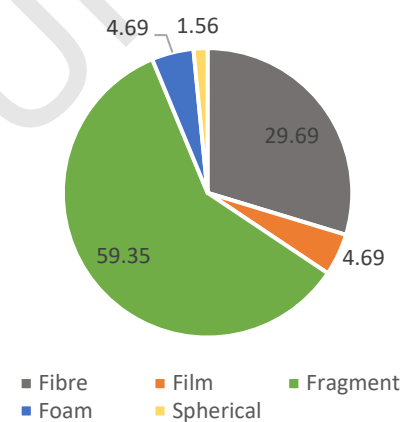
Water Filter Machine J



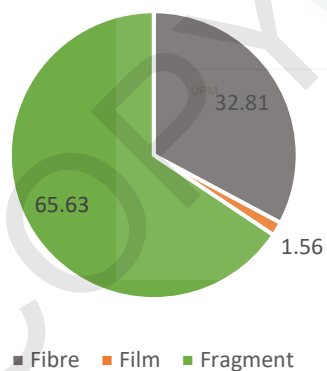
Water Filter Machine K



Water Filter Machine L



Water Filter Machine M



Water Filter Machine N

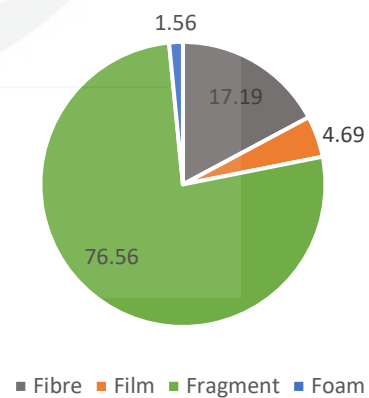


Figure 4.4: Shape of microplastics particles in boiled water from different water filter machine

4.2.5 Polymer type of microplastics particles in boiled water from different electric kettles

The results from FTIR show only polyethylene terephthalate (PETE) and polycarbonate (PC) were detected in electric kettles water samples. The PETE polymer type was detected in water samples A1, B2, C1, & D2 while PC only detected in water sample E1.

4.2.6 Polymer type of microplastics particles in boiled water from different water filter machines

FTIR results show three types of polymer were detected in the water samples from water filter machines which were polyethylene terephthalate (PETE) polycarbonate (PC) and polyvinyl chloride (PVC). The PETE polymer type was detected in water samples K2, L1 & M2, PC polymer was only detected in water sample N3 and PVC were detected in sample J2.

4.3 Comparison of Microplastics in Boiled Water from Different Groups of Electric Kettles and Water Filter Machines

4.3.1 Comparison between the mean of microplastics size in boiled water from different types of electric kettles

Table 4.3 shows the comparison between the mean of microplastics size in boiled water from different electric kettles and types of electric kettles. The result from one-way ANOVA statistical analysis shows that the null hypothesis was not rejected. There was no significant difference in the size of microplastics particles in boiled water from different types of electric kettles because $p=0.967$ was more than $\alpha=0.05$.

Table 4.3: Comparison between the mean of microplastics size in boiled water from different electric kettles and types of electric kettles (N=27)

Mean of microplastics size					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1354.203	2	677.102	0.034	0.967
Within Groups	476750.327	24	19864.597		
Total	478104.530	26			

4.3.2 Comparison between the mean of microplastics size in boiled water from different types of water filter machines

Table 4.4 shows the comparison between the mean of microplastics size in boiled water from different water filter machines and brands of water filter machines. The result showed that the null hypothesis was not rejected. There was no significant difference in the size of microplastics particles in boiled water from different brands of water filter machines because $p=0.461$ was more than $\alpha=0.05$.

Table 4.4: Comparison between the mean of microplastics size in boiled water from different water filter machines and brands (N=15)

Mean of microplastics size					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	93283.335	4	23320.834	0.980	0.461
Within Groups	237968.249	10	23796.825		
Total	331251.584	14			

CHAPTER 5

DISCUSSION

5.1 Occurrence of Microplastics Particles in Boiled Water from Different Electric Kettles and Water Filter Machines

5.1.1 Size of microplastics particles in boiled water from different electric kettles

Based on **Table 4.1**, the highest average length of microplastics particles was from plastic electric kettle sample C1 which was 850.743 μm while the lowest average length was from stainless steel electric kettle sample D2 which was 348.410 μm . The plastic electric kettle had the highest average length of microplastic particles that may be due to the boiled water exposed to more plastic surfaces since plastic electric kettles body has more plastic materials compared to glass and stainless steel electric kettles. Thus, there will be is a high tendency for a breakdown of plastic into the boiled water during the boiling process (Sturm et al., 2019). While stainless steel had the lowest length of microplastic particles might be due to the boiled water exposed to fewer plastic surfaces. It was because the stainless steel electric kettles have fewer plastic materials compared to plastics electric kettles which the body of stainless steel electric kettles is mostly made of stainless steel. Only the top lid is made of plastics. But sometimes there are also stainless steel electric kettles that have their top lids made of stainless steel. Thus, the tendency for

a breakdown of plastics into the boiled water was lower when the boiled water made less contact with plastic surfaces in the electric kettles (Sturm et al., 2019).

5.1.2 Size of microplastics particles in boiled water from different water filter machines

Based on **Table 4.2**, the highest average length of microplastics particles was from water filter machine K, sample K3 (751.564 μm) while the lowest average length was from water filter machine K as well, sample K1 (208.403 μm). Water filter machine K had the highest average length of microplastic particles might be due to the boiled water exposed to plastic surfaces during the boiling process since most of the water filter machines body parts were made of plastics. Besides, water filter machine K was also located outdoor compared to other selected water filter machines located indoors. Therefore, this location was expected to cause water filter machine K to become more vulnerable to external factors such as being exposed more to environmental factors including light (UV) and heat that could affect the biodegradation or breakdown of microplastics (Yuan et al., 2020). Water filter machine K also had the lowest length of microplastic particles which might be due to the higher rate of microplastics degradation that causes the microplastics to be continuously broken into smaller fragments. Factors like UV radiation from sunlight, mechanical abrasion, and microbial action could also induce the continuation of microplastics degradation into smaller pieces of secondary microplastics (Barnes et al., 2009; Cole et al., 2011; Julianne et al., 2019).

5.2 Colour, Shape and Polymer Types of Microplastics Particles in Boiled Water from Different Electric Kettles and Water Filter Machines

5.2.1 Colour of microplastics particles in boiled water from different electric kettles

In electric kettles' water samples, the potential source for green colour microplastics particles in the water samples was the lid of plastic electric kettle C which was made with entirely green plastics (**Figure 5.1**). Meanwhile, the potential source of red/pink colour microplastics particles was the body of plastic electric kettle B (**Figure 5.2**). However, there were no potential sources observed for blue microplastics from the three plastic electric kettles tested. Hence, those blue microplastics particles could only be suspected originate from the tap water. Based on a study by Carr et al. (2016), the most microplastics colour found in grab samples from primary skimmer in wastewater treatment plant were blue polyethelene fragments. Although most of wastewater treatment plants have high efficiency of removing microplastics ($> 90\%$), but millions of microplastics continue to be introduced into the aquatic environment every day (Cristaldi et al., 2020). This is because further fragmentation of the particles may occur following natural processes or during treatment and this will cause difficulties in their removal (Cristaldi et al., 2020).



Figure 5.1: Green plastic lid of plastic electric kettle C



Figure 5.2: Several pink plastics on the body of plastic electric kettle B

For stainless steel electric kettles, the potential source of microplastics particles was from the top lid and the part that hold between the lid and its body (**Figure 5.3 & 5.4**).



Figure 5.3: Plastic parts in stainless steel electric kettle E



Figure 5.4: Plastic parts in stainless steel electric kettle F

Meanwhile, the potential source of black (4.14%) and grey (23.67%) microplastics particles of glass electric kettles might be from the top lids and the parts that hold between the lid and its body same as the stainless steel kettles **(Figure 5.5 & 5.6)**.



Figure 5.5: Plastic parts in glass electric kettle H



Figure 5.6: Plastic parts in glass electric kettle I

Overall, the percentage of transparent microplastics in water samples from all types of electric kettles was higher compared to other colours in the electric kettles' samples was due to the type of plastics used in manufacturing the plastics parts of the electric kettles. Mostly, the types of plastics used are heat resistant plastics such as polypropylene (PP) and these kinds of microplastics we found to be abundant in transparent colour (ScienceDaily, 2019). Specifically, plastic electric kettles had the highest percentage of transparent microplastics (71.25%) particles compared to stainless steel electric kettles (63.24%) and glass electric kettles (66.86%). This may be due to plastic electric kettles

having higher plastic surfaces compared to other types of electric kettles. From the information obtained on electric kettles' age, all plastic electric kettles were older than stainless steel and glass electric kettles. Hence, this could be one of the potential factors that cause the higher microplastics breakdown from the plastic parts into the boiled water since all polymers will experience some degradation during their service life due to the induction by heat (thermal degradation), oxygen (oxidative and thermal-oxidative degradation), light (photo degradation), weathering (generally UV/ozone degradation) (Sturm et al., 2019).

5.2.2 Colour of microplastics particles in boiled water from different water filter machines

There were two potential sources of microplastics occurrence in water filter machines samples which were the plastic parts in water filter machine and tap water. Water filter machines were considered as the primary potential sources since these appliances have many parts made of various kinds of plastics including their tubes and tanks (Figures 5.7 and 5.8).



Figure 5.7: Plastic parts in water filter machine J



Figure 5.8: Plastic parts in water filter machine K

Water filter machine J had the highest transparent (76.67%) colour of microplastics particles compared to other selected water filter machines. For grey microplastics particles, water filter machine N had the highest percentage (35.38%) compared to other water filter machines. Besides, among five selected water filter machines, only water filter machine L had yellow (1.56%) microplastics and only water filter machine M had green (1.56%) microplastics. Other than that, the percentage of blue (4.84%) microplastics particles were higher in water filter machine K samples compared to blue microplastics particles in water filter machine J (1.56%) samples. Black microplastics particles in the water filter machine L (3.13%) was also higher than black microplastics particles in water filter machine J (1.56%) samples. However, it was difficult to confirm whether the microplastics particles occurrence were ascribed from the water filter machines or tap water since many colours found were not able to relate with the water filter machines parts. Moreover, the complexity of water filter machines built and various types of plastics used in one water filter machine have limited the identification of microplastics particles that may be sourced from the water filter machines.

5.2.3 The shape of microplastics particles in boiled water from different electric kettles

Stainless steel electric kettles had the highest percentage of fibre-shape microplastics particles compared to other samples. According to the observation of the stainless steel electric kettles, fibre-shaped microplastics were not expected to exist in the boiling water, since fibre-shaped microplastics are often present in the environment and come from synthetic fibres such as clothes, upholstery, or carpet (Zhang et al., 2020). On the other hand, plastic electric kettles had the highest film-shaped (11.88%) of microplastics compared to samples from other electric kettles. According to Mohamed Nor & Obbard (2014) polymers such as polypropylene and polyethylene were the potential source of film-shape microplastics particles. Overall, fragment-shaped microplastics was found to has the highest percentage among all water samples from electric kettles. This founding was considered to be in line with previous study by Zhang et al. (2020) where fragments microplastics are one of the most reported shapes in the environment.

5.2.4 The shape of microplastics particles in boiled water from different water filter machines

Microplastics fragments were found to be the most prevalent form in all samples from all chosen water filter machines followed by fibre. Water filter machine N had the highest percentage of fragment microplastics (76.56%) followed by fibre microplastics (17.19%) in the water samples. This may be due to how frequent the water machine filter has been serviced since its last service was in the year 2018 which was already 3 years ago. Hence, this factor may also affect the degradation of thermoplastics because there are some parts like filters or certain plastic parts that need to be replaced in order for them to function efficiently. Hence, these two types of shapes, fragments and fibres were the most commonly reported shapes and the types of plastic generally align with world plastic demand (Zhang et al., 2020). It was determined that the fragment and fibre microplastics morphologies are the most prevalent in the environment, including our drinking water.

Other than that, spherical microplastic was only found in water filter machine L (1.56%). Film microplastics on the other hand was higher in water filter machines L (4.69%) and N (4.69%) compared to water filter machines J (1.67%) and M (1.56%). Based on the previous study, the plastic used in water filter machines parts were commonly made of polypropylene, polyethylene and polyvinyl chloride (Park et al., 2019). Due to various types of thermoplastics used in water filter machines, it was difficult

to identify the specific sources of microplastics found in the samples. However, considering the types of thermoplastics used in water filter machine manufacturing, they all had a high potential to degrade after a long time of usage. In other words, they are susceptible to thermal ageing of polymer where the overheating can cause molecular deterioration due to the presence of tertiary hydrogen atoms in polymer chain (Raji et al., 2018).



5.2.5 Polymer type of microplastics particles in boiled water from different electric kettles

Figures 5.9, 5.10 and 5.11 illustrate the FTIR findings and the possible presence of microplastics in their samples of plastic and stainless steel electric kettles. From the FTIR result, the polymer that has been detected in these samples was polyethelene terephthalate (PETE). PETE is one of the most common thermoplastic polymer resins of the polyester family. Its application is used in a wide range including packaging, fabrics, film to moulded parts for automotive, electronics and many more. It is also labelled as number “1” as one of the most recycled thermoplastics. PET is highly flexible, colourless and semi-crystalline resin in its natural state while it can be semi-rigid to rigid depending on how it is processed. It also shows good dimensional stability, resistance to impact, moisture, alcohols and solvents (SpecialChem, n.d.). Besides, SpecialChem, (n.d.) stated that PET usually blends with other thermoplastics and thermosets. This blending is done to improve performance with beneficial cost profiles to meet specific application demands. Polyethelene, polypropylene, polycarbonates, polystyrene, ethyl vinyl acetate and acrylonitrile butadiene styrene are the most thermoplastic polymers used to blend with PETE. Thus, the plastic body part of those electric kettles might have a mixture of PETE plastics and this could be the potential source of PETE occurrence in the sample. **Figure 5.12** also shows the FTIR result for sample D2 which PETE polymer types was found. However, there were no potential sources of microplastics from the electric kettle since

the boiled water did not make any contact with any plastic parts. Therefore, it can only be assumed that the potential source was from the tap water itself.

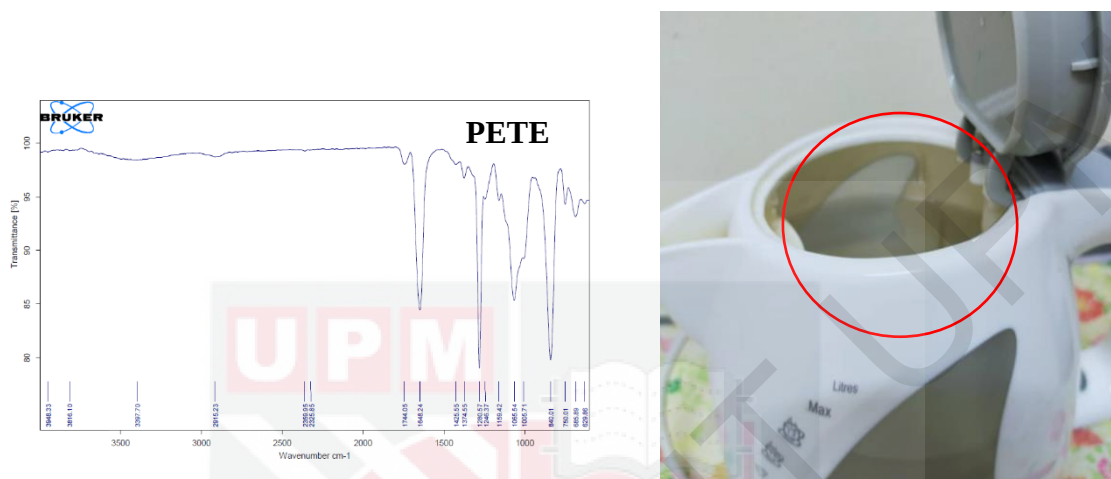


Figure 5.9: FTIR and location of the possibility of microplastics presence in sample A1

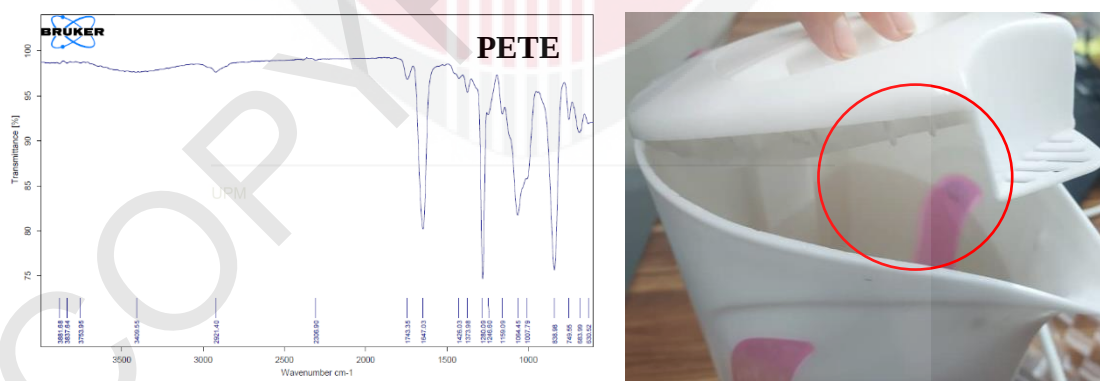


Figure 5.10: FTIR and location of the possibility of microplastics presence in sample B2

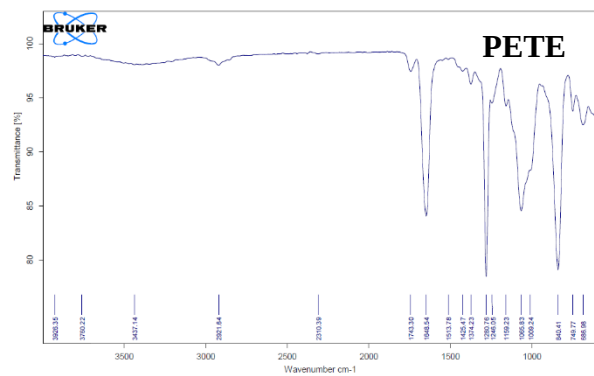


Figure 5.11: FTIR and location of the possibility of microplastics presence in sample C1

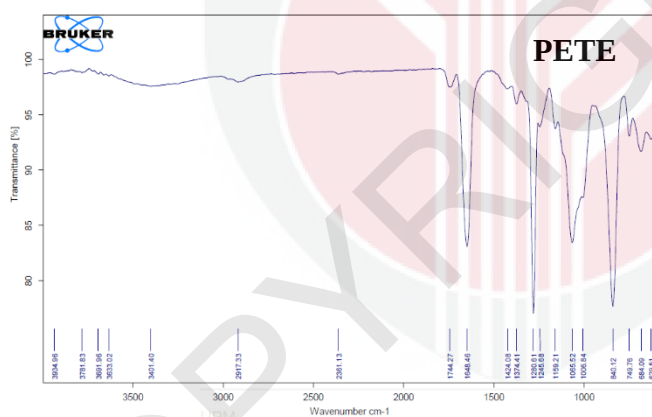


Figure 5.12: FTIR and location of the possibility of microplastics presence in sample D2

Besides, polycarbonate (PC) was detected in sample E1 (**Figure 5.13**) which was from stainless steel electric kettle. Polycarbonate is one of the common thermoplastics used in manufacturing specifically usually used in blends such as PC/ABS, PC/PET, PC/PMMA. Some examples of the application are compact disc, safety helmets, bullet-proof glass, car headlamp lenses, baby feeding bottles, roofing, glazing and many more (SpecialChem, n.d.). PC unique's features are like high impact strength, high dimensional stability and can provide good electrical properties amongst other thermoplastics. Thus, the PC occurrence in the water samples may be due to the contact of boiling water with the plastic surfaces in the stainless steel electric kettle which is the top lid and the plastic part between the top lid and the body. It is because there are also electric kettles that have plastic parts made of polycarbonate (Electric Kettles Guide, 2021).

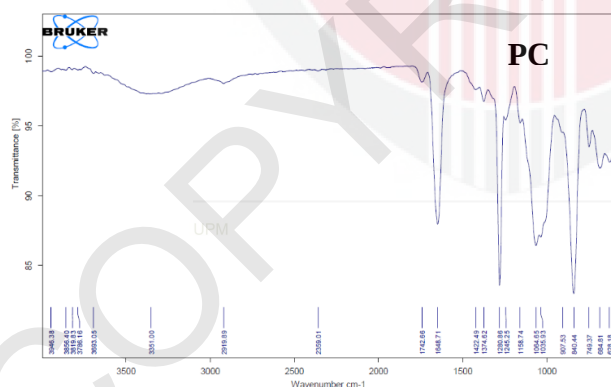


Figure 5.13: FTIR and location of the possibility of microplastics presence in sample E1

5.2.6 Polymer type of microplastics particles in boiled water from different water filter machines

Figure 5.14 shows the FTIR result and location of the possible source of microplastics presence in the sample J2. The type of polymer detected was polyvinyl chloride (PVC) which the potential source was the water tubes used in that water filter machines. Usually, PVC that has been used for piping materials is unplasticised-PVC. This type of PVC is hard, rigid and is resistant to most chemicals which can also be used at temperatures up to 60°C, although the actual temperature limit is dependent on stress and environmental conditions (Vinidex Pty Ltd, n.d.).

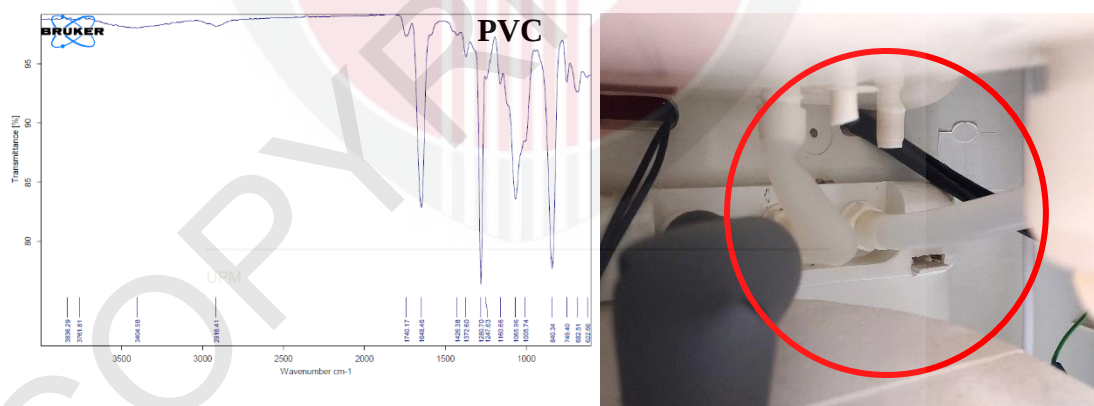


Figure 5.14: FTIR and location of the possibility of microplastics presence in sample J2

Meanwhile, **Figures 5.15, 5.16** and **5.17** show the FTIR results and the potential sources of microplastics occurrence in the samples. The type of polymer detected in those samples was PETE. Based on the observation, the PETE might be sourced from the water tubes and water containers in the water filter machines. In water filter machines, many tubes are made of plastics. Polyethelene (PE) especially was also used abundantly in manufacturing the water filter machines plastic parts and these thermoplastics were usually blended with PETE to improve the quality and the performance of the products. Besides, blending PETE with PE can also improve cost-effectiveness and properties such as mechanical strength, flame retardancy, toughness, processability and many more (SpecialChem, n.d.).



Figure 5.15: FTIR and location of the possibility of microplastics presence in sample K2

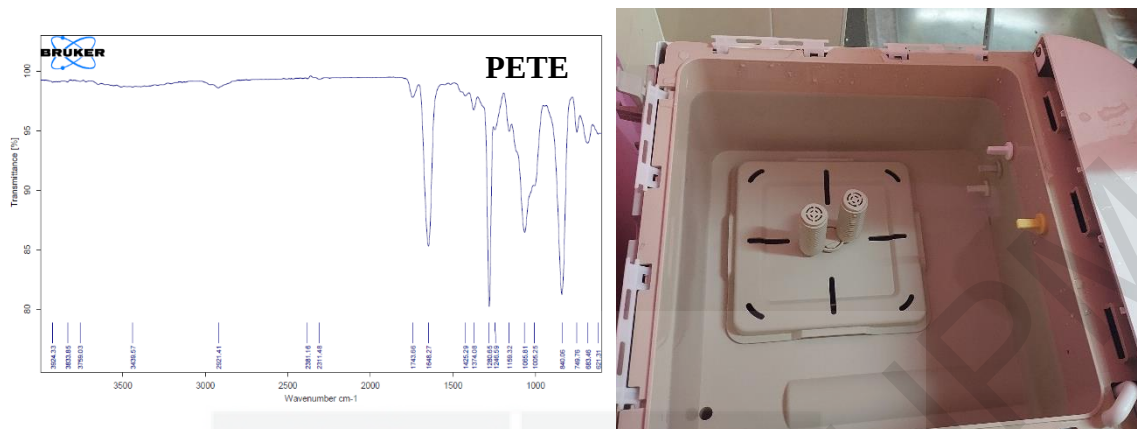


Figure 5.16: FTIR and location of the possibility of microplastics presence in sample L1

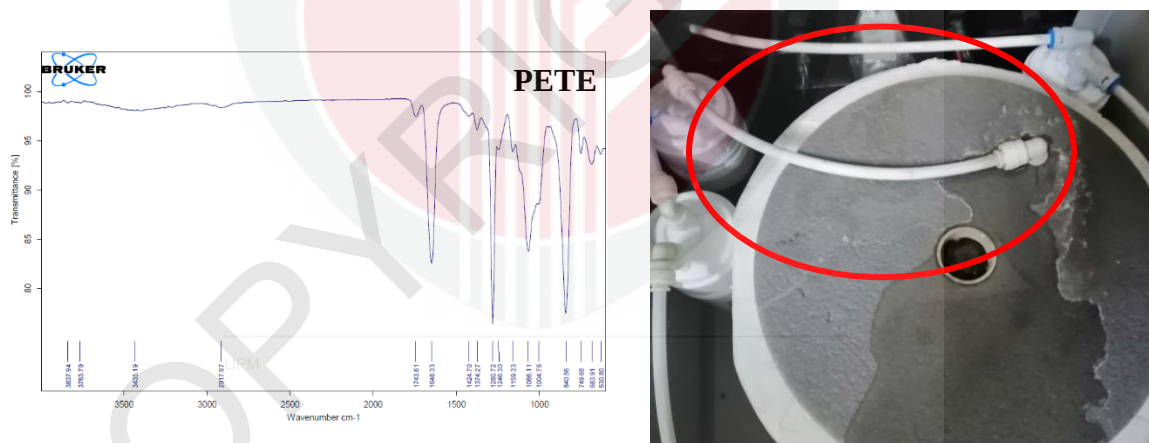


Figure 5.17: FTIR and location of the possibility of microplastics presence in sample M2

On the other hand, **Figure 5.18** depicts the FTIR result and the potential source of polycarbonate (PC) from sample N3. Polycarbonate is also one of the popular thermoplastics used in manufacturing because of its properties such as strong, stiff, hard, tough, and transparent engineering thermoplastics which can maintain rigidity up to 140 °C and toughness down to -20 °C or special grades even lower (British Plastics Federation, n.d.). According to the observation, water came in touch with the plastic within the tank. It allowed water to fill the tank and was capable of shutting off the incoming water and RO system when the water level reached the top. This float valve, on the other hand, was composed of plastic. However, this float valve was commonly made of polyethylene (PE) and acrylonitrile butadiene styrene (ABS) plastics. Therefore, it can only be assumed that there was a blend of PE or ABS with Polycarbonate during the manufacturing of the float valve since the blends of these two types of plastics was possible (SpecialChem, n.d.; Xia et al., 2014).

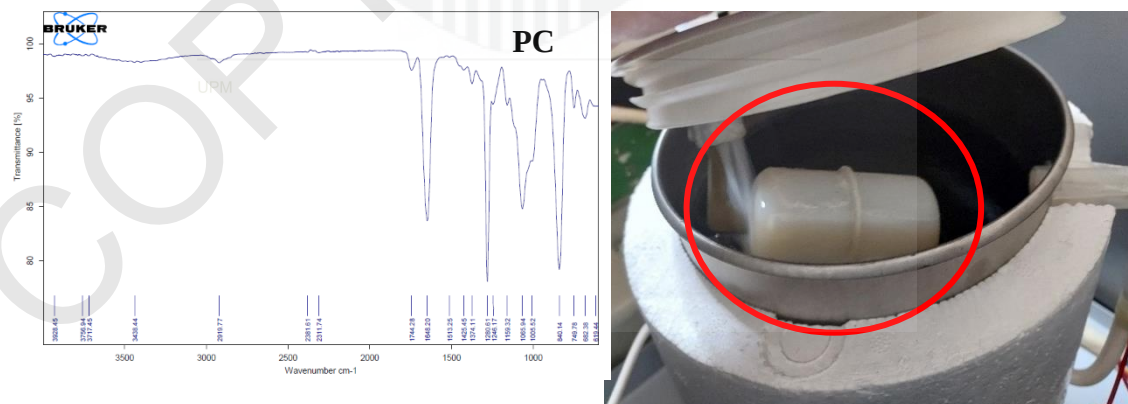


Figure 5.18: FTIR and location of the possibility of microplastics presence in sample N3

5.3 Comparison of Microplastics in Boiled Water from Different Groups of Electric Kettles and Water Filter Machines

5.3.1 Comparison between the mean of microplastics size in boiled water from different types of electric kettles

Based on **Table 4.3**, there was no significant difference in the size of microplastics particles in boiled water from different types of electric kettles because $p=0.967$ was more than $\alpha=0.05$. Thus, types of electric kettles which were plastic, stainless steel and glass electric kettles were considered not to influence the size of microplastics particles in the boiled water. On the contrary, the size of microplastics particles might be influenced by the materials of the plastics such as polypropylene or polyethelene. Based on a previous study, the size of microplastics of polypropylene, polyethylene and polystyrene detected have ranged from $32\mu\text{m}$ to $651\mu\text{m}$ (Pabortsava & Lampitt, 2020). As a result, this might imply that the microplastics produced by various types of thermoplastics are essentially within the given range, resulting in a non-significant difference in the size of microplastics particles.

5.3.2 Comparison between the mean of microplastics size in different water filter machines and brands

According to **Table 4.4**, there was no significant difference in the size of microplastics particles in boiled water from different brands of water filter machines because $p=0.461$ was more than $\alpha=0.05$. Thus, the brands of water filter machines which were brand J, brand K, brand L, brand M, and brand N were considered not to influence the size of microplastics particles in the boiled water. Similar to electric kettles, where the size of microplastics particles from the water filter machines might be influenced by the materials of the plastics themselves such as polypropylene or polyethelene. Water filter machines also usually consist of many plastic parts including polypropylene and polyethelene where the size of microplastics was in the range from $32\mu\text{m}$ to $651\mu\text{m}$ (Pabortsava & Lampitt, 2020; Park et al., 2019).

5.4 Suitability of Boiled Water as Drinking Water

Based on the results from both **Table 5.1** & **Table 5.2**, microplastics particles were present in both electric kettles and water filter machines. Therefore, it looks like the boiled water from these appliances is not suitable to be used. Nevertheless, the toxicity effects of microplastics were not been studied in this study. Hence, there should be an appropriate toxicity test needed to be conducted before the final confirmation is finalized.

Table 5.1: Suitability of Boiled Water from Electric Kettles as Drinking Water

Types of electric kettles	Suitability of Drinking Water (Yes/No)
Plastics	No
Stainless Steel	No
Glass	No

Table 5.2: Suitability of Boiled Water from Water Filter Machines as Drinking Water

Brand of water filter machines	Suitability of Drinking Water (Yes/No)
Brand J	No
Brand K	No
Brand L	No
Brand M	No
Brand N	No

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

To summarise, an abundance of particles was identified in a variety of electric kettles and water filter machines available in Malaysia, including plastic, stainless and glass electric kettles (27 samples) and five distinct brands of water filter machines (15 samples). The highest average length of microplastics particles was from plastic electric kettle samples which were 850.743 μm while the highest average length of microplastics particles from the water filter machine was 751.564 μm . As for microplastics' colours from the water samples of electric kettles and water filter machines, transparent colour (Electric Kettles: Plastic=71.25%; Stainless Steel=63.24%; Glass=66.86%) (Water filter machines: J=76.67%; K=75.8%; L=68.75%, M=62.63%; N=55.38%) was found to be the dominant colours. Meanwhile, the dominant shapes of microplastics found in water samples from electric kettles and water filter machines were fragments (Electric Kettles: Plastic=54.38%; Stainless Steel=58.74%; Glass=61.54%) (Water filter machines: J=56.67%; K=53.23%; L=59.35%, M=65.63%; N=76.56%). From all the results, microplastics particles were found to be present in both electric kettles and water filter machines boiled water. Therefore, the boiled water from these appliances was considered not suitable to be used as drinking water.

6.2 Recommendations

Further study involving appropriate toxicity testing was recommended in order to investigate the toxicity effects of microplastics which can give the final confirmation of its suitability as drinking water.



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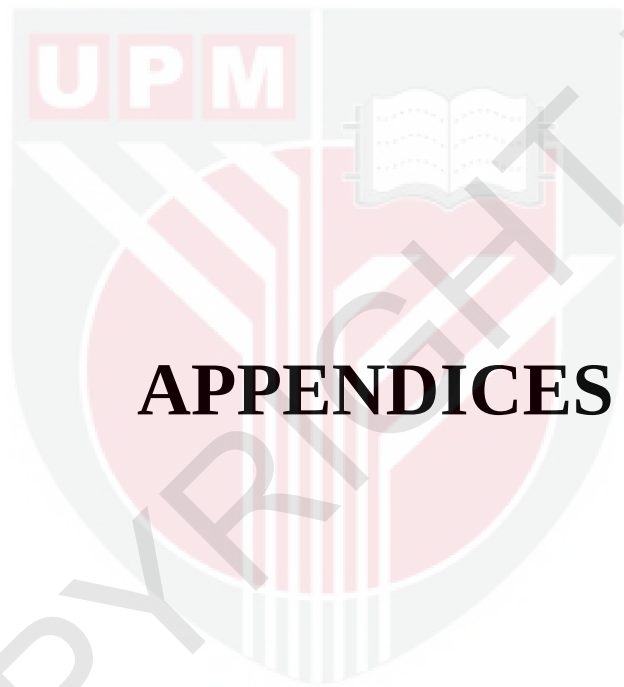
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APPENDICES

**APPENDIX 1: Microscopic Images of Particles Extracted from Water Samples of
Selected Electric Kettle**

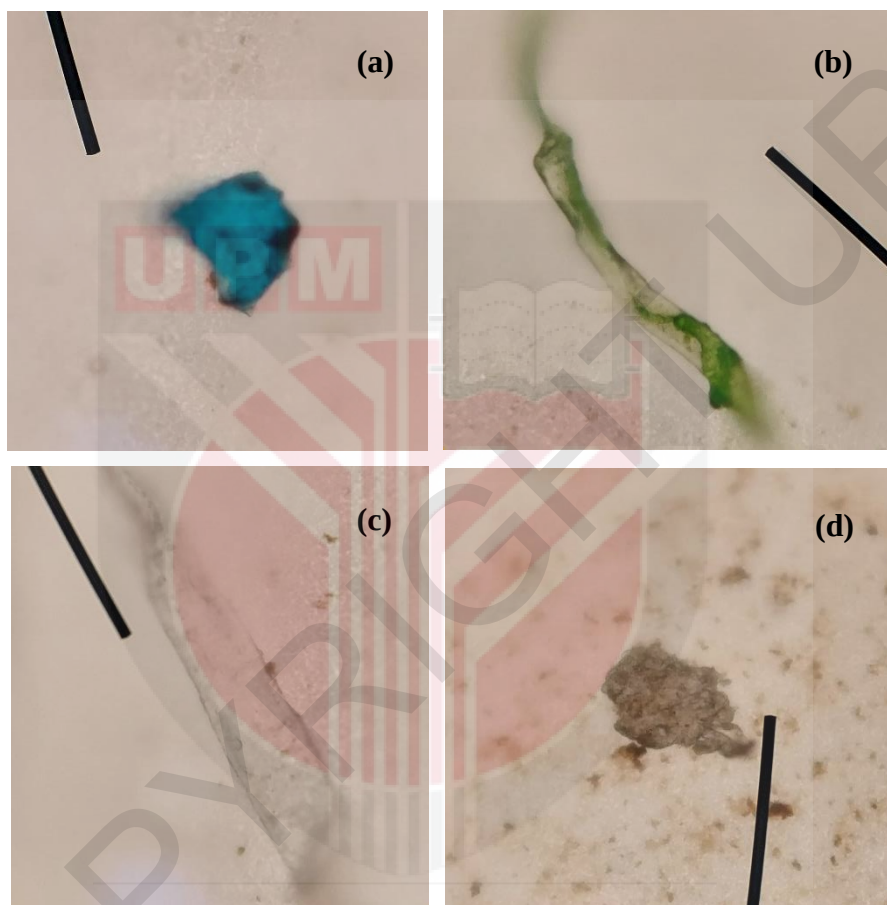


Figure 1: Microscopic image of particles extracted from water samples of selected electric kettles: (a) fragment, (b) fibre, (c) film (d) foam.

**APPENDIX 2: Microscopic Images of Particles Extracted from Water Samples of
Selected Water Filter Machines**

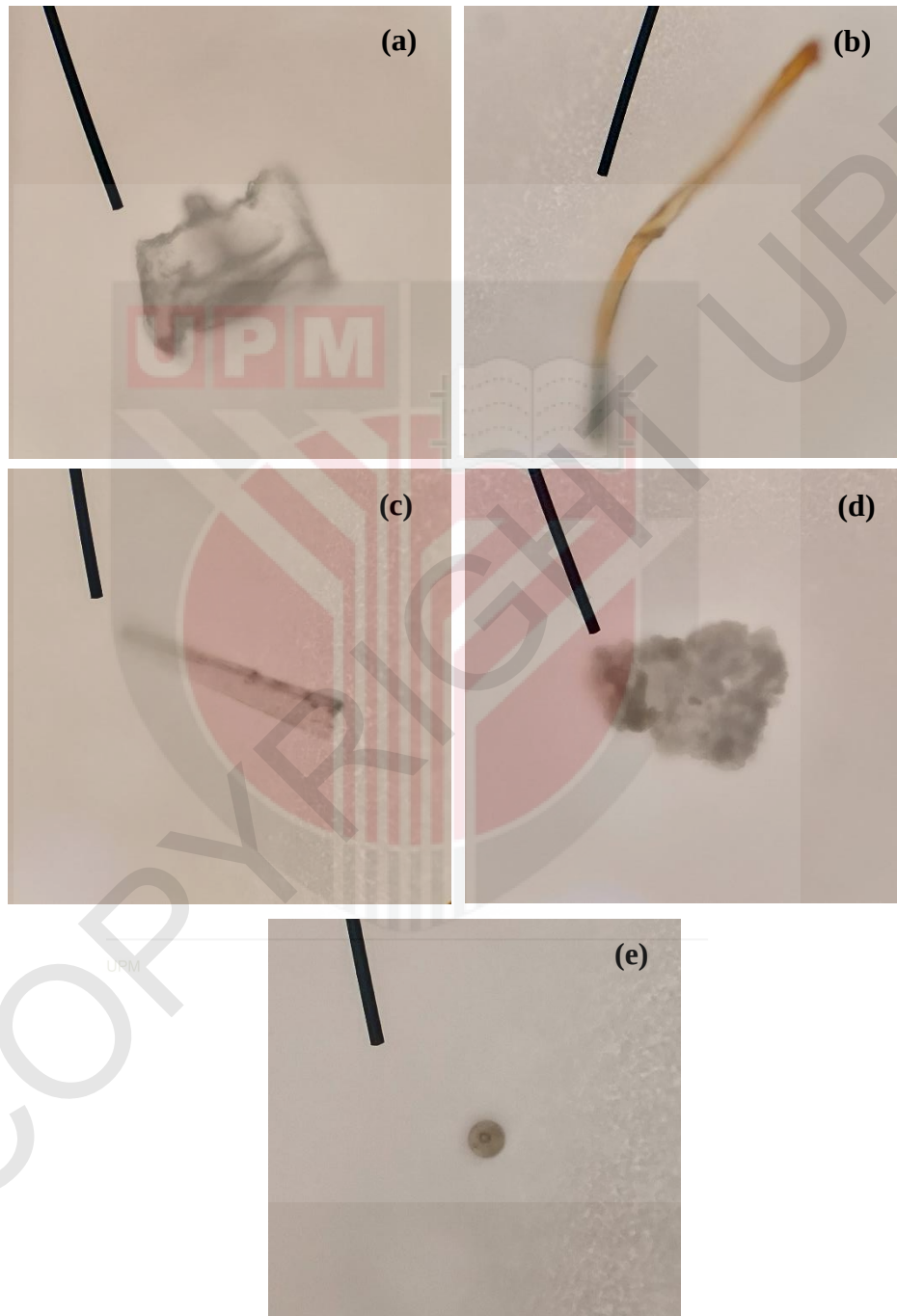


Figure 2: Microscopic image of particles extracted from water samples of selected water filter machines: (a) fragment, (b) fibre, (c) film (d) foam (e) spherical.