Volume 3, No. 1 January 2024 (34-46)
p-ISSN 2980-4868 | e-ISSN 2980-4841
https://ajesh.ph/index.php/gp

THE EFFECT OF TOP-LOADING WASHING MACHINE OPERATIONAL SETTING ON MICROPLASTIC FIBERS RELEASED FROM CLOTH DURING THE WASHING MACHINE AND FILTERED BY FILTER CLOTH

Muh. Farid[1], Emenda Sembiring[2]
[1,2]Faculty of Civil and Environmental Engineering Bandung Institute of Technology
Email: 25321028@mahasiswa.itb.ac.id[1], emenda@ftsl.itb.ac.id[2]

ABSTRACT
Microplastics have been commonly found in wastewater, especially from laundry waste and wastewater treatment. Efforts to prevent microplastics in domestic washing activities are important so that microplastics can be removed from the source. The washing machine filters can collect most of the microplastic fibers before the water reaches the WWTP. The research carried out aimed to determine the effect of washing machine spin speed, operation time, and the intensity of repeated washing of textile materials on the microplastics released during the washing process as well as the influence of filter cloth porosity, operation time, and the intensity of repeated washing of textile materials on the filter cloth's ability in the filtering process of microplastic. There are three main stages in this research, the preparation stage, the research stage which consists of running the reactor to identify microplastics released during the washing process, running the reactor to determine the ability of the filter cloth to filter microplastics, and identifying microplastics. The data generated from the test is analyzed using a regression multiple linear. The results of identifying the amount of microplastic released from all samples had an average concentration of 281.24 particles/L and the average amount of microplastic filtered by the filter cloth was 78.8 mg/cycle. Spin speed, operation time, and washing repetition intensity simultaneously influence the released microplastics by 93.5%. The size of the filter cloth mesh, operation time, and the intensity of repeated washing simultaneously influence the filtered microplastics by 86.4%.
Keywords: Microplastic, fiber microplastic, domestic washing water, filter, washing machine

INTRODUCTION

Microplastic or what is usually called microplastic has a size of > 1 mm but not more than 5 mm (Gouin et al., 2011). Microplastics are often found in wastewater, especially laundry waste and wastewater treatment (Yang et al, 2019). This wastewater not only contains detergent, but it also contains fabric fibers and threads in it. (Wright et al., 2013)i were the first to identfy domestic washing processes as a source of pollution with plastic fibers. They report that a single shirt can release more than 1900 fibers per wash and all clothing releases more than 100 fibers per liter of waste. Research from(Alam et al., 2019)., (Sembiring, Fajar, et al., 2021), also states that microplastics in fiber form dominate the form of microplastics found in the Ciwalengke River located in Majalaya, Indonesia which is dominated by slum areas and industrial area, with sizes ranging from 50 mm to 2000 mm. The average concentration of microplastics in river water was found to be 5.85 ± 3.28 particles per liter. The abundance of microplastics in the Ciwalengke River could result from the washing process in industry and laundry activities by household residents in slum areas.

The use of washing machine filters, which collect most microplastic fibers before the wastewater reaches the WWTP, could be a way to reduce the amount that ends up in the WWTP sludge (IVL 2017). The operational setting carried out in the washing machine can regulate the operation time and spin speed so that the operational setting of the washing machine can also influence the amount of microplastics released during the washing process and the efficiency of microplastic filtering. Therefore, efforts to prevent microplastics in domestic washing activities are important so that we can find out quantitative data on the release of microplastics from commercial synthetic clothing during washing in household washing machines and filtering microplastics from the source.

RESEARCH METHODS

In this research, there are three main stages in general, they are the preparation, the research stage which consists of running the reactor to identify microplastics released during the washing process, and running the reactor to determine the ability of the filter cloth to filter microplastics, and identifying microplastics.

Preparation

At this stage, literature studies were carried out, and interviews with washing machine technicians to find out more about the technical workings of washing machines, the preparation of tools and materials, and the identification of microplastics in washing water sources. This identification is carried out to determine the amount of microplastic contaminants originating from the water used for the washing process. The water used for washing comes from PDAM water. This identification will be carried out in triplicate by taking 1-liter water samples that had been operated without using cloth from the washing tube.

Research Stage

Reactor running research for released microplastics was carried out by testing cloth washing with variations in machine spin speed and different washing operation times according to the washing machine options, with a spin speed of 60 rpm (gentle), 80 rpm (normal), 90 rpm (strong) and operation times of 5 minutes, 10 minutes and 15 minutes. This process used 2 kg of 100% polyester fleece with 5 washing cycles for each variation. The sample taken is 1 liter of washing water in the washing machine reactor after the washing process is complete using the grab sampling method. Before being used for sampling, the sampling bottle is cleaned first with aquades and then rinsed again using washing water. An illustration of the water cycle that occurs during the washing process in a washing machine can be seen in the figure 1.

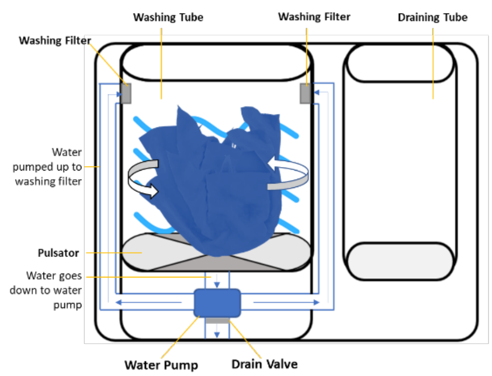

Figure 1. The water cycle in a 2 drum washing machine during the washing process.

This experiment used a washing machine as a reactor equipped with a built-in washing filter. The operational setting variables observed included filter porosity, operation time, and washing repetition intensity consisting of 5 washing cycles. The washing filter section built into the washing machine is modified with 3 different types of porosity variations with mesh 100, 200, and 400. The operation time variations are 5 minutes, 10 minutes, and 15 minutes. The spin speed used is 80 rpm (normal) using 2 kg of fleece for washing. The operational setting that has been carried out can bee seen in

engine spin speed used to run the reactor using filter cloth was not varied because based on the results of interviews and the author's observations, the speed cycle of water rising through the filter remained the same at each engine spin speed so that variations in engine spin speed would not affect the work performance of the filter cloth. The filter will be removed after the washing process and the microplastics filtered through the filter cloth then be dried and stored in airtight packaging to be weighed. Water samples in the reactor after washing using a filter cloth were also taken to determine the amount of unfiltered microplastics.

Microplastics Identification

The washing water samples and filter results from the filter cloth that have been collected will then be filtered with Whatman GF/C paper using a vacuum filter. The filter paper is transferred to a petri dish and dried using an oven at 1050C for approximately 30 minutes to remove the water content in the filter paper. This condition refers to previous research conducted by Alam et al., 2019. The dried filter paper will be identified the number of microplastics using a binocular microscope. The steps carried out refer to the technical guidelines and provisions of (Campanale et al., 2020)regarding the identification of microplastics based on SCS (Size and Color Sorting System) techniques. Based on research limitations, the microplastics that were counted were only fibers that matched the color of the textile material used. The unit for the number of microplastics observed is the particle/L of sample for released microplastics (Qiu et al, 2016).

RESULTS AND DISCUSSION

Characteristics of the water used for washing

The results of the analysis on PDAM water samples used for washing showed that microplastics were identified in all samples. TSS measurements carried out in triplicate showed quite low values. The results of the analysis of the characteristics of the water used for washing are shown in the following table.

Table 1. Measurement Results Quality of water used for washing.

Sample	Microplastic (particle/litre)	TSS (mg/L)
Sample 1	11	61,5
Sample 2	8	26,4
Sample 3	12	44,4
Average	10,33	44,1

The results of water quality measurements showed that there were microplastics with an average concentration of 10.33 particles/L and a TSS of 44.1 mg/L in the water used for washing. The amount of microplastics will not be counted when identifying microplastics in samples resulting from the washing process and there is no need to remove suspended solids because the number is still below the quality standard. Based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.16/MENLHK/ SETJEN/KUM.1/4/2019 concerning the Second Amendment to the Regulation of the Minister of the Environment Number 5 of 2014 concerning Waste Water Quality Standards, the total suspended solids (TSS) parameter is 50mg/L.

Microplastics released during the washing process

The results of analysis on samples from 45 washing processes tested in this study showed varying concentrations of microplastics. The smallest microplastic concentration was found in samples with the Gentle washing operational setting for 5 minutes in the fifth cycle, amounting to 107 particles/L. Meanwhile, the largest concentration was in the sample with the Strong washing operational setting for 15 minutes in the first washing cycle, amounting to 513 particles/L. The average microplastic concentration of all samples analyzed was 281.24 particles/L. The comparison of microplastic concentrations.

Based on variations in the speed of the washing cycle carried out, the highest average microplastic concentration was in the strong washing cycle with a concentration of 320,267 particles/L, the second highest average microplastic concentration was in the normal washing cycle with a concentration of 294,867 particles/L, and the lowest microplastic concentration is the Gentle wash cycle with a concentration of 228.6 particles/L. The results of comparing microplastic concentrations with variations in engine spin speed show similarities with research by (Liu et al., 2019) and (Volgare et al., 2021)which states that the movement of fabric in a washing machine produces a large amount of mechanical action on the cloth such as flow through the cloth which causes a decrease in pressure on the cloth and shear forces as the cloth rubs against each other. Top-loading washing machine researched also have a pulsator whose mechanical action can cause an increase in the concentration of fibers found (Rathinamoorthy & Raja Balasaraswathi, 2021).

Based on variations in the operation time of washing carried out without using a filter cloth, the highest average microplastic concentration was in a 15-minute washing cycle with a concentration of 378,333 particles/L, the second highest average microplastic concentration was 10-minute washing cycle with a concentration of 255,733 particles /L, and the lowest microplastic concentration was the 5-minute washing cycle with a concentration of 209,667 particles/L.

Research by (Napper et al., 2023)who conducted a similar experiment with 6 kg of textiles made from synthetic fabrics (polyester, polyester cotton, and acrylic fabric) showed that these fabrics could release 140,000-700,000 fibers or 23,333,333 fibers/kg/ washing, whereas this research shows that 2 kg of polyester fleece can release up to 513 particles/L using 49 liters of washing water so it can be said that 1 kg of polyester fleece can release 12,568.5 particles/kg/washing. This difference in numbers occurs because there are differences in spin speed and washing operation time. Research carried out a washing process with a spin speed of up to 1400 rpm for 45 minutes(Napper & Thompson, 2016). Meanwhile, in this research, there was only a washing process with a maximum spin speed of 90 rpm (strong) for 15 minutes.

The factors that were focused on in (Napper & Thompson, 2016)research were fabric type, temperature, and presence of detergent and/or conditioner so machine spin speed and operation time that were also potentially relevant factors were not varied. Meanwhile, in this research, these 2 factors were the main focus for identifying released microplastic fibers so that variations in cloth type, temperature, presence of detergent, and/or conditioner were not carried out. Napper and Thompson's research showed the influence of cloth type and temperature on polyester fabrics which released more fiber microplastics than acrylic at 400C, and each also released more when compared to 300C. There is also some effect of conditioner use, with cotton-polyester blends consistently releasing more fibers when conditioner is used.

Microplastics filtered during the washing process

The results of analysis on samples from 45 washing processes tested in this study showed varying amounts of microplastics. The largest mass of filtered microplastics was found in samples with a 15-minute washing operational setting using a 400 mesh filter cloth in the first cycle, amounting to 206.5 mg/cycle. Meanwhile, the smallest average mass was in the sample with a 5-minute operational setting using a 100 mesh filter cloth in the fifth washing cycle, amounting to 14.2 mg/cycle. The average mass of microplastics from all samples analyzed was 78.8 mg/cycle. A comparison of the mass of microplastics filtered in each sample can be seen in Figure 2(b).

Based on variations in the size of the filter media porosity carried out, the highest average microplastic mass was in the washing cycle using a 400 cloth mesh filter with a weight of 88.6 mg/cycle, the second highest average microplastic mass was in the washing cycle using a 200 cloth mesh filter with 75.21 mg/cycle, and the lowest microplastic mass was the washing cycle using a 100 mesh filter cloth with a weight of 72.63 mg/cycle. The results of the comparative analysis of the weight of filtered microplastics show similar results to research by (Sembiring, Fajar, et al., 2021);(Sembiring, Mahapati, et al., 2021) which analyzed the effectiveness and mechanism of filter cloth in removing microplastics, showing that the smaller the porosity of the filter, the greater its ability to remove microplastics. Mesh 400 has the smallest filter porosity among the three types of filters used so it has a higher filtering ability.

Based on variations in the operation time of washing carried out using filter cloths, the highest average mass of microplastics filtered was in a 15-minute washing cycle with a mass of 102.39 mg/cycle, the second highest average mass of microplastics was in a 10-minute washing cycle with a mass of 73,70 mg/cycle, and the lowest microplastic mass was a 5-minute washing cycle with a mass of 60.40 mg/cycle. Research by (Sembiring, Fajar, et al., 2021) stated that the highest microplastic filtration occurred after the reactor had been operating for 1 hour, while the lowest filtration was found after the reactor had been operating for 30 minutes. This also shows a similar trend to research by (Bruce et al., 2016) that found between 705 mg/cycle and 1,286 mg/cycle of microfibers were lost with every wash for 20 minutes to 30 minutes.

This number is quite different compared to this research because the location of the filter cloth can be a potential variable in this case. In this study, the filter cloth was located in the washing tub and occurred during the washing process, while in the research by (Bruce et al., 2016) the filter used to filter microplastics is located in the wastewater channel of the washing machine so it is possible that microplastics that are also released during the drying process of textile materials can also be filtered out.

Microplastics unfiltered during the washing process

The results of analysis on samples from 45 washing processes tested in this study showed varying amounts of unfiltered microplastics. The smallest average concentration of microplastics was found in samples with a 5-minute washing operational setting using the 400 mesh filter cloth in the fifth cycle at 53 particles/L. Meanwhile, the highest average concentration was in the sample with a 15-minute washing operational setting using 100 mesh filter cloth in the first washing cycle at 225 particles/L. The average microplastic concentration of all samples analyzed was 118.29 particles/L. Comparison of the concentration of unfiltered microplastics in each sample can be seen in Figure 2(c).

Based on variations in the porosity size of the filter media applied, the highest average concentration of unfiltered microplastics was in the washing cycle using 100 mesh media porosity with a concentration of 132.33 particles/L, the second highest average concentration of unfiltered microplastics was The washing cycle used a media porosity of 200 mesh with a concentration of 128.67 particles/L, and the lowest concentration of unfiltered microplastics was the washing cycle using a media porosity of 400 mesh with a concentration of 94.3 particles/L. The results of the comparative analysis of the weight of unfiltered microplastics show similar results to research by (Sembiring, Mahapati, et al., 2021)which analyzed the effectiveness and mechanism of filter cloth in removing microplastics, showing that the greater the porosity of the filter, the lower its ability to remove microplastics. Mesh 100 has the greatest porosity among the three types of filters used so it has a lower filtering ability

Based on variations in the operation time of washing carried out using filter cloths, the highest average mass of unfiltered microplastics was in the 15-minute washing cycle with a concentration of 142.13 particles/L, the second highest average concentration of unfiltered microplastics was in the operation time of 10-minutes washing cycle with average concentration of 116.33 particles/L, and the lowest concentration of unfiltered microplastics was a washing cycle with a operation time of 5-minutes with a average concentration of 96.4 particles/L.

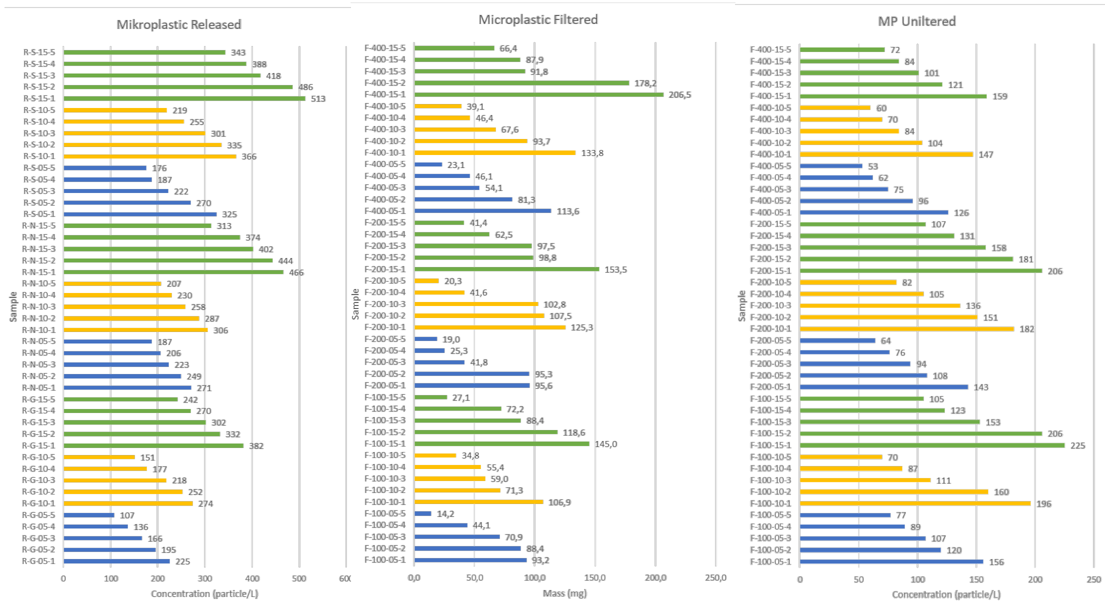

Figure 3. Comparison of microplastic identification (a) concentration of released microplastics, (b) mass of filtered microplastics, (c) concentration of unfiltered microplastics

Based on the microplastic comparison graph in Figure 3, the concentration and mass ratio of microplastics decreases from one washing cycle to the next. These results are in accordance with previous researches conducted by (De Falco et al., 2019), (De Falco et al., 2020), and(Napper & Thompson, 2016), which stated that old clothes may release less fiber than new clothes. However, different results were found in research by (Dalla Fontana et al., 2021), which showed that the microplastics released did not decrease in the next washing cycle. This may be caused by the scrubbing activity on textile materials that have been used previously which removes loose fibers and dust and eliminates differences between clothes used in various washing conditions, whereas in this study new clothes with the same conditions were used for each cycle with the same washing operational setting.

Based on variations in the operation time of washing carried out, the longer textile materials are washed, the more microplastics are produced. This is also in accordance with research by (Pirc et al., 2016) that stated that the release of microfibers from various textile materials is also related to operation time.

Effect of washing operational setting on released microplastics

Multiple linear regression test is used to test whether X1 (spin speed), X2 (operation time), and X3 (repetition intensity) affect Y (microplastics released). The results of the linear regression test can be seen in table 2.

Table 2. Multiple linear regression test results for each variable

Model		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics	
							Tolerance	VIF
1	(Constant)	-24,738	26,543		-0,932	0,357	1,000	1,000
	Spin Soeed	3,092	0,303	0,406	10,201	0,000	1,000	1,000
	Operation Time	16,867	0,926	0,725	18,212	0,000	1,000	1,000
	Repetition intensity	-33.256	2,673	-0,495	-12,439	0,000	1,000	1,000

In multiple linear regression, the data is assumed to have no high correlation between predictor variables. In the collinearity statistics section, the VIF value for variables X1, X2, and X3 are < 10 so it can be concluded that there is no multicollinearity in the regression model.

Based on the table above, the sig value for the influence X1 on Y is 0,000 <0.05 and t calculated value of 10.201> t Table 2,01954 (0.025; 41) so it can be concluded that there is an influence of spin speed on the released microplastics. The sig value for the influence of X2 on Y is 0.000<0.05 and the calculated t value is 18.212 > t table 2.01954 (0.025;41) so it can be concluded that there is an influence of operation time on the released microplastics. The sig value for the influence of X3 on Y is 0.000<0.05 and the calculated t value is -12.439 < t table -2.01954 (0.025;41) in the negative area, so it can be concluded that there is an influence of the intensity of washing repetition on the released microplastics negatively. To find out whether X1, X2, and X3 simultaneously influence Y, it is shown in the following table.

Table 3. Simultaneous multiple linear regression test results

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	379836,951	3	126612,317	196,831	0,000
	Residual	26373,360	41	643,253		
	Total	406210,311	44			

Based on this table, the significance value for the influence of X1, X2, and X3 simultaneously for Y is 0.000<0.05 and the calculated F value is 196.831 > F Table 1.42 (3;42), So it can be concluded that X1, X2, and X3 simultaneously influence Y. To find out how big the influence of variables X1, X2, and X3 simultaneously on Y, it can be seen from the R Square value in Table 4 is 93.5%. Other factors that can influence the microplastics released are the type of washing machine, temperature, use of detergent and/or conditioner, and the material and age of the fabric.

Table 4. Determination of coefficient

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0,967	0,935	0,930	25,362

Effect of washing operational setting on filtered microplastics

Multiple linear regression test is used to test whether X1 (filter cloth mesh size), X2 (operation time), and X3 (repetition intensity) affect on Y (filtered microplastics). The results of the linear regression test can be seen in the following table.

Table 5. Multiple linear regression test results for each variable

s

Model		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	98,187	9,479		10,359	0,000	1,000	1,000
	Filter cloth mesh size	0,055	0,020	0,162	2,819	0,007	1,000	1,000
	Waktu Operasi	4,199	0,599	0,403	7,004	0,000	1,000	1,000
	Repetition Intensity	-24,751	1,731	-0,822	-14,303	0,000	1,000	1,000

In the collinearity statistics section, the VIF value for variables X1, X2, and X3 is < 10 so it can be concluded that there is no multicollinearity in the regression model.

Based on the table above, the sig value for the influence of X1 on Y is 0.007 <0.05 and the calculated t value is 2.819 > t table 2.01954 (0.025; 41) so it can be concluded that there is an influence of filter mesh size on the filtered microplastics. The sig value for the effect of X2 on Y is 0.000<0.05 and the calculated t value is 7.004 > t table 2.01954 (0.025;41) So it can be concluded that there is an influence of operation time on filtered microplastics. The sig value for the effect of X3 on Y is 0.000<0.05 and the calculated t value is -14.303 < t table -2.01954 (0.025;41) in the negative area so it can be concluded that there is an influence of the intensity of repeated washing on filtered microplastics. negatively. To find out whether X1, X2, and X3 simultaneously influence Y as can be seen in the following table.

Table 6. Simultaneous multiple linear regression test results

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	70499,683	3	23499,894	87,188	0,000
	Residual	11050,729	41	269,530		
	Total	81550,412	44			

Based on this table, the significance value for influence X1, X2, and X3 simultaneously on Y is 0.000<0.05 and the calculated F value is 87.188 > F table 1.42 (3;42), so it can be concluded that X1, X2, and X3, simultaneously influence on Y. To find out how big the influence of variables X1, X2, and X3 simultaneously with Y, it can be seen from the R Square value in Table 7 is 86,4%. Other factors that can influence the microplastics filtered are the design of the washing machine and the type of filter used.

Table 7. Determination of coefficient

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0,930	0,864	0,855	16,4174

CONCLUSION

The results of identifying the amount of microplastic released from all samples had an average concentration of 281.24 particles/L and the average amount of microplastic filtered by the filter cloth was 78.8 mg/cycle. Spin speed, operation time, and washing repetition intensity simultaneously influenced the microplastics released by 93.5%. The mesh size of the filter cloth, operation time, and the intensity of repeated washing simultaneously influence the microplastics filtered by 86.4%. The washing machine operational setting that produces the minimum microplastics is the washing operational setting at gentle speed for 5 minutes in the fifth cyclle at 107 particles/L. The washing operational setting using a 400 mesh filter cloth for 15 minutes in the first cycle was able to filter the largest amount of microplastics at 206.5 mg/cycle.

BIBLIOGRAPHY

Alam, F. C., Sembiring, E., Muntalif, B. S., & Suendo, V. (2019). Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalaya district, Indonesia). *Chemosphere*, *224*, 637–645.

Bruce, N., Hartline, N., Karba, S., Ruff, B., Sonar, S., & Holden, P. (2016). Microfiber pollution and the apparel industry. *University of California Santa Barbara, Bren School of Environmental Science & Management (Accessed 19 Aug 2016) Http://Brenmicroplastics. Weebly. Com/Uploads/5/1/7/0/51702815/Bren-Patagonia_final_report. Pdf*.

Campanale, C., Savino, I., Pojar, I., Massarelli, C., & Uricchio, V. F. (2020). A practical overview of methodologies for sampling and analysis of microplastics in riverine environments. *Sustainability*, *12*(17), 6755.

Dalla Fontana, G., Mossotti, R., & Montarsolo, A. (2021). Influence of sewing on microplastic release from textiles during washing. *Water, Air, & Soil Pollution*, *232*(2), 50.

De Falco, F., Cocca, M., Avella, M., & Thompson, R. C. (2020). Microfiber release to water, via laundering, and to air, via everyday use: a comparison between polyester clothing with differing textile parameters. *Environmental Science & Technology*, *54*(6), 3288–3296.

De Falco, F., Di Pace, E., Cocca, M., & Avella, M. (2019). The contribution of washing processes of synthetic clothes to microplastic pollution. *Scientific Reports*, *9*(1), 6633.

Gouin, T., Roche, N., Lohmann, R., & Hodges, G. (2011). A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. *Environmental Science & Technology*, *45*(4), 1466–1472.

Liu, H., Gong, H., Xu, P., Ding, X., & Wu, X. (2019). The mechanism of wrinkling of cotton fabric in a front-loading washer: The effect of mechanical action. *Textile Research Journal*, *89*(18), 3802–3810.

Napper, I. E., Parker-Jurd, F. N. F., Wright, S. L., & Thompson, R. C. (2023). Examining the release of synthetic microfibres to the environment via two major pathways: Atmospheric deposition and treated wastewater effluent. *Science of The Total Environment*, *857*, 159317.

Napper, I. E., & Thompson, R. C. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Marine Pollution Bulletin*, *112*(1–2), 39–45.

Pirc, U., Vidmar, M., Mozer, A., & Kržan, A. (2016). Emissions of microplastic fibers from microfiber fleece during domestic washing. *Environmental Science and Pollution Research*, *23*, 22206–22211.

Rathinamoorthy, R., & Raja Balasaraswathi, S. (2021). Domestic laundry and microfiber shedding of synthetic textiles. *Microplastic Pollution*, 127–155.

Sembiring, E., Fajar, M., & Handajani, M. (2021). Performance of rapid sand filter–single media to remove microplastics. *Water Supply*, *21*(5), 2273–2284.

Sembiring, E., Mahapati, W. O. S. W., & Hidayat, S. (2021). Microplastics particle size affects cloth filter performance. *Journal of Water Process Engineering*, *42*, 102166.

Volgare, M., De Falco, F., Avolio, R., Castaldo, R., Errico, M. E., Gentile, G., Ambrogi, V., & Cocca, M. (2021). Washing load influences the microplastic release from polyester fabrics by affecting wettability and mechanical stress. *Scientific Reports*, *11*(1), 19479.

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: a review. *Environmental Pollution*, *178*, 483–492.