Report

Filters for washing machines

Mitigation of microplastic pollution

The Swedish Environmental Protection Agency

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About the report

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Summary

This report describes filters for washing machines designed to remove either microplastic fibres or lint from laundry water and investigates possibilities and challenges with such filters from a practical and environmental perspective. The report includes results from a literature study and a laboratory study. Other studies on microplastics from laundry water are summarized briefly.

It can be concluded that filtering solutions for washing machines which claim to remove lint and microplastic fibres can be purchased and installed. Three of the filtering solutions were tested in laboratory washing trials and were found to retain some of the microplastic, hence decreasing the amount of microplastic released with the laundry water. The retention was most profound the first time the new fabric was washed. To judge exactly how well the filters remove microplastics during realistic domestic washing conditions would require more comprehensive laboratory work. It is also necessary to further investigate how efficient the filters should be to present an alternative that is technologically, economically feasible as well as environmentally beneficial. Although the filters may retain microplastic fibres it may be necessary to design filtering solutions that are sufficiently user-friendly so that the filters are not by-passed by the user, and that there are good options for emptying or replacing the filters.

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1. Introduction

The Swedish Environmental Protection Agency has identified washing of synthetic textiles as one important source of microplastics in Sweden. Other important sources are roads and tyres, artificial turf pitches, littering, production and management of plastic, and antifouling paint (Swedish Environmental Protection Agency, 2017). It has been estimated that 8-950 tons of microplastic from textiles is released with laundry water annually in Sweden (IVL 2016). Most of the microplastic is removed from the water in waste water treatment plants (WWTPs) where it is retained in the sewage sludge, but 0.2-19 ton remain in the water and is released directly to freshwater and marine water bodies. The sewage sludge containing the retained microplastics is spread on agricultural land (25 %), used in soil production (29 %) or used in landfill cover materials (24 %) (Swedish Environmental Protection Agency, 2017). The research on effects of microplastics and plastics in the oceans is ongoing and has received great attention during the last few years (i.e. Cole et al. 2011). The knowledge about the effect of microplastics and plastics on terrestrial ecosystems is sparse.

There are several approaches to mitigate the release of microplastics from laundry water to aquatic and terrestrial ecosystems, including improved textile production methods, improved or water-free washing methods, and better separation methods at the WWTPs (e.g. MinShed project, Mermaids Life+ project, SIFO - Consumption Research Norway, 2018).

1.1. Project and general method

The overall objective of this study was to evaluate if existing filters for washing machines have a potential to mitigate microplastic pollution from textiles by decreasing the amounts of microplastics in the laundry water that is released to the waste water treatment system. The study has two parts; one literature survey and one laboratory study.

The literature survey has included the following parts:

- Scientific literature and other research project about microplastic shedding by the washing of textiles have been studied and summarized shortly.
- Scientific literature and other research project about filters for washing machines have been studied and summarized.
- Different filters for washing machines and washer-dryers have been described.
- Representatives for washing machine producers have been enquired about filters for washing machines, and any development projects of filters they may have.
- A discussion about challenges with the usage of filters based on the information in the literature study and the laboratory study.

The laboratory study comprised a washing trial where commercially available filters were tested to see if these could catch microplastic fibres.

This work has been commissioned and financed by the Swedish Environmental Protection Agency and Lena Stig has been their contact person. The project has been performed in collaboration between EnviroPlanning and RISE IVF. EnviroPlanning have been responsible for performing the literature survey and RISE IVF have conducted the washing trials.

2. Microplastics from washing

In Sweden, 128 000 tonnes of textiles are consumed annually and 30-40 % of these are estimated to be man-made synthetic fibres (Swedish Environmental Protection Agency, 2017). The most common plastic types in synthetic textile fibres are polyester, nylon, acrylic, and polypropene.

The international research community has been addressing this topic for the last few years, but there are still few studies on the characteristics of microplastics released by washing of textiles. Results from research publications can be somewhat difficult to compare, since different research groups have access to different characterization methods. However, studies on microplastics in laundry water consistently conclude that textiles shed microplastic fibres during washing and that those microfibres are found in the laundry water (e.g. iGEM Lund 2017, Mistra Future Fashion 2017, Folkö 2015, Browne et al. 2011, Hernandez et al. 2017).

It has also been concluded that several parameters in the textile construction process as well as washing parameters (e.g. temperature, detergents) effect the shedding of microplastic fibres from the textiles (e.g. Mermaids Life+ project). Some examples are that fleece fabric shed more than knitted fabrics (Carney Almroth et al. 2018), that loose and worn fabrics shed more (Carney Almroth et al. 2018), that brushing of garments during production increases microfibre shedding (Mistra Future Fashion 2017), and that top-loader washing machines induce several times more shedding than front-loader machines (Hartline et al 2016). Detergents were found to affect the shedding from textiles in some studies (Mermaids Life+ project; Carney Almroth et al. 2018, Hernandez et al. 2017) but were not found to have any significant effect in another study (Pirc et al. 2016).

There are several approaches to mitigate microplastic pollution from textiles. These include changing customer behaviour regarding clothing (i.e. reduced consumption, less frequent washing of cloths), improving or changing textile production methods to methods that result in less microfibre shedding, improving washing methods (i.e. water-free washing methods, better detergent usage, washing programs for less fibre shedding, water filters), and better microplastic separation at the WWTPs. More research will provide more accurate models for reducing microplastic pollution, but there is no uncertainty about that microplastic is spread by human activity, and that there is a need to act if the inflow of microplastic to marine and terrestrial ecosystems shall decline.

3. Washing machine filters

In Sweden, front-loader machines are the most common type of domestic washing machine. This is beneficial since front-loader machines produce less textile shedding compared to top-loader washing machines (Hartline et al 2016). Top-loader machines are sometimes produced with a filter to trap lint that is released from the textiles. In general, front-loader machines are not produced with any such lint filter and therefore has no barrier that keeps microplastic fibres from entering the waste water system.

There are also combined washer/dryer machines on the market although these are less common than separate washing machines. The washer/dryers neither have no lint filter. This is problematic since microplastic fibres both from the washing process and the drying process are released to the waste water system. This can be compared to the usage of a separate drying machine where the lint released during drying is collected in a dry filter and easily removed by the user. The release of fibres during tumble drying has been found to be ~3.5 times higher than during washing (Pirc et al. 2016).

There is one filtering technology that can remove all microfibres from water, called ultra-filtration (Swedish Environmental Protection Agency, 2017). This technology can be integrated at WWTPs and has been suggested to be implemented in combination with other filtering techniques to remove microcompounds at WWTPs (IVL 2017). As far as we know, this technique has not been suggested for implementation in household washing machines. The filters designed for washing machines that are described here, remove less than all microfibres from laundry water.

There are several research and development projects that suggest washing machine filters for mitigating microplastic pollution. Since the technological readiness of filters is important in this overview, we have chosen to include only initiatives where we can find a description of a proposed filter. Other initiatives are assumed to be at a low technological readiness level.

3.1. Commercially available filters for lint and/or microplastic fibres

Most Swedish households are connected to municipal waste water systems and have no practical concerns with lint in the laundry water. However, there are many households worldwide with either under-dimensioned piping or private waste water systems (such as septic systems). For those households there is a market for lint and microfibre filtering solutions since lint and microfibres can cause clogging of the drain piping or of private waste water filtration beds/fields. Some of those filtering solutions are not addressing microplastic fibres (<5 mm) directly and may not be expected to trap the smallest microfibres. However, since the traps mitigate the release of larger plastic fibres, they should still be considered to lessen plastic pollution.

The simplest solution to catch lint from the laundry water is to attach a ***metal wire lint trap*** (commercial product) or even a ***nylon sock*** to the washing machine drain pipe. This requires that the drain pipe is emptied into a sink or bath tub rather than being directly attached to the drain of the house. The wire mesh in such traps is rather open and it is not clear how much of the microfibres are caught and how much are released with the water. There are also more advanced products that claim to perform better at catching lint and even microplastic fibre. The Filtrol 160 and the Lint LUV-R described here are two such products that are commercially available at the company webpages.

Wexco Environmental features a filter for the septic market, the ***Filtrol 160*** (All information from Filtrol 160 webpage). The Filtrol 160 is an external filter that is fixed to the wall and attached to the washing machine drain pipe (Figure 1). The fixed unit has a filter bag made of fabric, through which the water is filtered. Wexco Environmental suggest cleaning the filter bag every 1-3 weeks, to replace it with a new bag after 1-2 years and to avoid using fabric softener as this causes more frequent cleaning. Filtrol 160 is made to remove synthetic fibres, hair/fur, dirt particles, concrete dust, and metal shavings, hence to keep it from entering the drain pipes. Filtrol 160 does not claim to specifically remove fibres of microplastic dimensions (<0.5 mm), but to remove synthetic fibres. Hence, it is likely that microplastic fibres are still released with the laundry water.

Figure 1 The photo of Filtrol 160 (Filtrol 160 webpage).

A similar product, also addressing the septic market is the ***Lint LUV-R*** (Figure 2, All information from Lint LUV-R webpage). The Lint LUV-R is claimed to screen out microplastic and to prevent septic system failure due to lint build-up. The Lint LUV-R has a metal mesh filter that catches lint and should be cleaned every 3 weeks. The filtering unit is mounted at the wall and attached to the drain pipe of the washing machine.

Figure 2 The photo of Lint LUV-R (Lint LUV-R webpage).

3.2. Start-ups launching microplastic filters

PlanetCare have developed a filtering solution for washing machines that can trap ~80 % of the microfibres released when washing textiles (Figure 3, Information from PlanetCare webpage or from Kržan A. 2018). The ***PlanetCare filter*** is composed of different units in a way that it can be installed in the drain pump filter ('add-on filter') or on the drain pipe ('external filter') of domestic washing machines. There is also a solution for industrial washing machines producing larger amounts of laundry water. During commercialization the filters are custom made for each customer to fit their washing machine. PlanetCare plan to also establish a recycling system for their filter where used filter cartridges are re-sent to PlanetCare for recycling. The PlanetCare add-on filters are commercially available during 2018 but are not in large-scale production.

Figure 3 The photos of PlanetCare filters were found on the PlanetCare webpage.

Xeros Technologies launched a filter for washing machines in 2018, the ***XFiltra*** (Figure 4, All information from Xfiltra webpage or Xfiltra Press release). The XFiltra is designed to remove microplastic fibres from laundry water with an integrated pump, a dewatering device and a filter where the microfibres are trapped. Xeros Technologies does not report how efficient their filters are on their webpage. Cleaning and maintenance of the filters appears to be easy since the tapped fibres are spun dry. It is not clear whether the XFiltra is under production and it does not appear to be commercially available. Representatives for Xfiltra have been contacted for discussion and comments but have not responded.

Figure 4 The photos of XFiltra were found on the XFiltra webpage.

The start-up Mimbly has developed a system for reuse of laundry water, the Mimbox (All information from Mimbly webpage). ***The Mimbox has a filter*** that removes microfibres from the laundry water, although there is no specific claim regarding the efficiency of those filters on the Mimbly webpage. The Mimbox appears to be under development and is not commercially available.

3.3. Ready-to-use consumer products

There are some products for trapping microplastic fibres in laundry water that are commercially available and does not require any installation.

The ***Guppyfriend*** is a washing bag in which the textiles are put before washing as usual (Figure 5, All information from Guppyfriend webpage, Guppyfriend brouchure 2018 or Nolte A. 2018). Compared to ordinary washing bags the Guppyfriend is made of a material that does not let microfibres through such that the microfibres can be removed from inside the bag after washing. The bag can retain at least 90 % of released microfibres larger than 50 µm inside, according the company webpage. In addition to retaining microfibres, textiles shed less when washed in Guppyfriend due to less mechanical wear. Customers are asked to return their Guppyfriend when they wish to discard it, so that it can be reused and recycled.

The ***Cora Ball*** is a laundry ball that is put into the washing machine together with the textiles (Figure 5, All information from CoraBall webpage). The Cora Ball has many stalks and microfibres are caught between them. Recycling is possible, and customers are asked to contact Cora Ball when they wish to discard it. However, the Cora Ball is durable and should last for many years of laundry.

For top-loader machines using large amounts of water covering the textiles, there are also ***floating lint catchers*** which the user can put into the washing machine basin and that filters the water during washing.

Figure 5 The photos of Guppyfriend (left) and CoraBall (right) were found on the company webpages.

3.4. Washing machine producers

Representatives for eleven washing machine producers were contacted to learn about any development of filtering solutions that they may be involved in and to hear their opinions and possible concerns about integrated filters for washing machines or washer-dryers. Six responded to the e-mails or phone calls and four kindly provided answers with varied detail. The following section summaries their input.

One representative described that they are working with the development of a filter for washing machines and that the filter can hopefully be seen on the market by 2020. The other representatives did not know of any such initiatives for washing machines or washer-dryers in their companies. On the general question of mitigation of microplastics from laundry water one representative answered that this is a more complex issue and that it is important to learn more about sources of microplastic fibres before deciding what actions or measures should be taken. This washing machine producer is also involved in such an initiative. One representative considered it likely that a filter or other cleansing process at the textile production site or at the waste water treatment plant would be a more powerful tool. He also pointed out that the introduction of filters in household machines would take time since washing machines are not replaced very often. Two representatives pointed out that machines with a filter would be more expensive and that it is important that any legislation is international, to avoid that customers buy their machines abroad. One representative pointed out the importance of a demand for machines with filters on the market, for such a production to be successful. One representative expressed concerns for an increased energy demand due to the pressure drop over the filter.

To conclude, there is at least one initiative to produce filters for washing machines within the home appliance industry. The producers, however, do not seem convinced that filters for household machines is the best approach to mitigate microplastic pollution from textiles, and prefer that legislation regarding such filters should be international to avoid instability on the market.

4. Washing trials

There is a variety of parameters to take into consideration when conducting a washing trial. The choice of washing machine, detergent, dosage of detergent, water hardness, the choice of different soiling, weight of the ballast, which ballast to choose, the age of the ballast, water consumption, choice of washing programme (e.g. temperature, duration of the programme, number of rinses, mechanical action, spinning speed) – all of which has more or less impact of the result.
There are studies that claims that the detergent increases the fibre shedding (De Falco et al. 2017; Carney Almroth et al. 2018, Hernandez et al. 2017). The load itself may also have an impact on the shedding due to increased mechanical action and friction between the textiles. The test set-up was discussed with the manufacturers of the selected filters who also gave recommendations of different set-ups that would better visualise the efficiency of their filters.

To show the full potential and limitations of filters for washing machines would require a very comprehensive study. In this case the aim of the study is not to investigate the washing machine, the fabric or the detergent, but to make a first evaluation of the potential to reduce the release of microfibres that reaches the WWTPs if installing a filter to a domestic washing machine. Therefore, the influencing parameters has been set to a minimum. This study does not include detergent, ballast or any life length estimations of the different filters. No tests regarding removal of stains has been included in the study.

4.1. Experimental

Three commercial filters were tested at RISE IVF in Mölndal (formerly Swerea IVF) and the following experiments were set up:

- A blank with just inlet tap water
- Reference fleece fabric with no filter
- Reference fleece fabric with a “PlanetCare external filter”
- Reference fleece fabric with a “Guppyfriend washing bag“
- Reference fleece fabric with a “Filtrol 160™ external filter”

The results from the different filter are anonymised and results are displayed randomly given the names B, C and D. The reference fleece fabric tested with no filter is called A in the results.

The reference fabric (Figure 6) is a 100% polyester two-sided brushed virgin fleece (article KW-3028A) and was obtained from the company Kingwhale in Taiwan. This is the same fabric that is used in the research project MinShed at RISE IVF and the MICROFIBRE project at SINTEF, Norway. Samples of approximately 300 grams were cut out and overlocked. Since the aim in this study was to test the filters and not the fabric, there were no need to close the edges with an ultrasonic sound equipment to prevent extra shedding.

Figure 6 The reference fleece fabric

The *washing trials* were performed four times for each washing set-up with the same reference sample in a previously unused new Electrolux W555H (Figure 7), programme 40°C mild wash. After each washing cycle the reference fleece fabric was line dried at ambient temperature (approximately 20 °C) in the laboratory. During each wash cycle the outlet water was collected in a barrel from which a water sample of approximately 500 ml was collected after stirring the water with a mixer for 20 seconds to get a representative sample for the microscopy analysis. After each washing cycle a rinse cycle was performed and after every filter type the mild 40 °C wash programme without detergent was performed and checked for remaining particles.

Figure 7 Electrolux W555H

The *fleece fabric and the filters* were weighed (conditioned at 20°C and 65% RH) before and after the four wash cycles and the fibre loss and fibre retention was calculated. The fleece fabrics and the filters were not further analysed.

Each *outlet water sample* was mixed by pouring it back and forth 10 times between two beakers. While the water was still in motion a representative water sample of 5 ml or 50 ml (depending of the degree of pollution of particles) were collected for filtration through a Durapore® Membrane Filter, 0.65 µm (DVPP04700). The back of the membrane filter was then dipped with YES (washing-up liquid) to avoid static electricity. Rinsing of the bottle, beakers and funnel was conducted with the Bonderite 5088/water solution with addition of a little YES.

After drying the membrane filters, the particles were counted automatically in a light microscope (Equipment: Leica DM4000M microscope. Software: Leica Cleanliness Expert V. 4.9). The microscope analysis identified the quantity of fibre shaped and non-fibre shaped particles in different size classes. The parameters used for fibre detection was a fibre length-width ratio of 10:1. Additional manual analysis of particles was conducted of the 100 largest non-fibre shaped particles as well the largest fibre shaped particles and for fibre shaped particles larger than 500 µm.

4.2. Results from the washing trials

The results from the microscopic counting indicates that the filters catch a considerable number of particles (Figure 8 and Figure 9).

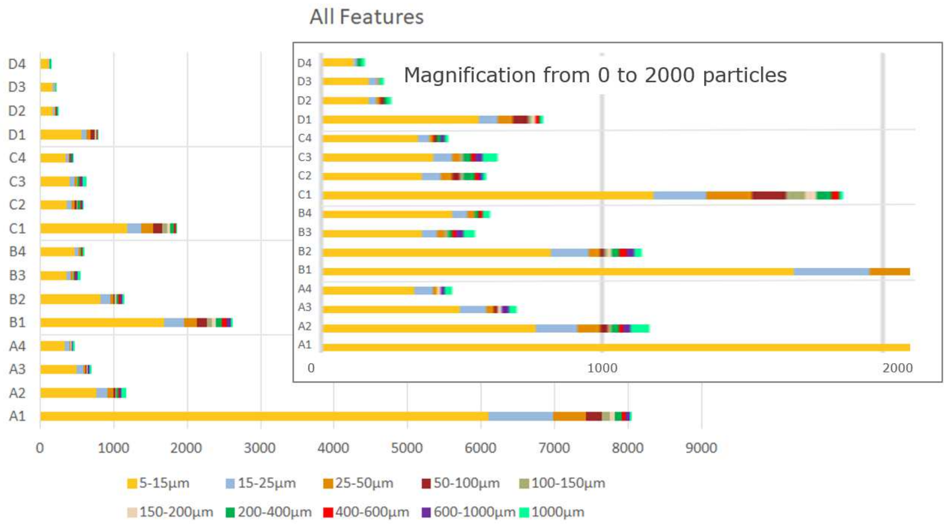

Figure 8 The results from the microscopic particle counting shows the numbers of particles (x-axis) and their size-fractions in the outlet water from the washing trials. A1 to A4 is the amount of fibre shaped particles and non-fibre shaped particles in total after washing cycles 1 to 4 when no filter was used. B1-4, C1-4 and D1-4 are results from the trials with the three different filters.

The first washing cycle is releasing much more particles, fibre shaped and non fibre shaped, than the following three washing cycles. Set-up A "fabric with no filter" releases more than three times as many particles (regardless of shape) in total after the first washing cycle than any of the filters do taking into account all four washing cycles. This indicates that there are a lot of loose particles (fibre shaped and non fibre shaped) from the manufacturing process and perhaps also other sources than the fabric itself.

All four set-ups (with and without filter) show a decline regarding particle content (both fibre shaped and non fibre shaped) from washing cycle 1 to 4. This overall decline of shed particles can be due to less shedding from the fabric.

When assessing all particles in the outlet water it was found that the range from 5-15 µm dominates all four washing cycles and that all filters retain more than half of the particles in this size-range (Figure 8). It is interesting to note that at least two of the filters are not designed to retain microparticles of this size. The Guppyfriend washing bag retains 90 % of microplastics larger than 50 µm and the Filtrol160 external filter is also not designed to retain the smallest particles (Guppyfriend brochure; Filtrol160 webpage).

Fibre shaped particles (i.e. particles with a fibre length-width ratio larger than 10:1) were also assessed separately and the results show that the number of particles in the outlet water that are fibre shaped are rather few (Figure 9). As an example, the total number of particles in A1 was ~8000 (Figure 8) and of these only ~375 were fibre shaped (Figure 9) according to the fibre definition used in these calculations.

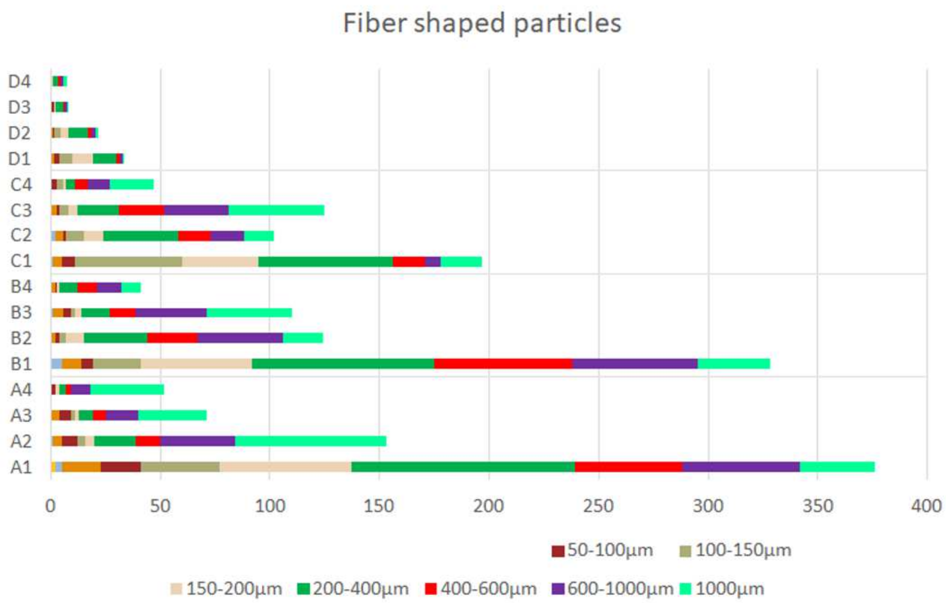

Figure 9 The results from the microscopic particle counting shows the numbers of fibre shaped particles (x-axis) and their size-fractions in the outlet water from the washing trials. A1 to A4 are the number of fibre shaped particles in the outlet water fibre after washing cycles 1 through 4 when no filter was used. B1-4, C1-4 and D1-4 are results from the trials with the three different filters. Since the lower limit for analysis is 5 µm and since the fibre length-width ratio is 10:1, no particles smaller than 50 µm can be defined as fibres in these calculations.

One should be careful not to compare the filters with each other at this stage, since the experiments are run in just one replicate and since there could be differences in shedding from different parts of the fabric.

The result from the weighing indicates that the filters catches particles from approximately 30 weight percent up to 60 weight percent in this study (Table 1). One should keep in mind that these are very small differences and weights, also weighing can include different contaminations even though for example the detergent was excluded. Therefore, the results from the weighing in this study should not be used to compare the filters. Therefore, general conclusions are shown in Table 1 rather than reporting results for each filter. Further studies concerning different filters will be performed with in the MinShed project.

Table 1 Weight loss and retained particles after 4 washing cycles

	Results
Approximate weight loss of the fleece fabrics after 4 washings	0,7-1,2 g
Approximate weight loss of the fleece fabrics after 4 washings	0,2-0,4 %
Approximate retention of particles in the filters	30-60 %

4.3. User friendliness

After the washing trials the laboratory technicians at RISE IVF was interviewed about how they experienced the practical aspects of using the filters. Their comments are summarized here.

Both external filters (Planet Care and Filtrol 160) were easy to install and the installation took no more than 10 minutes. The hoses that were to be connected were of the right dimensions for the washing machine used. The Filtrol 160 needed to be fixed to a wall whereas the Planet Care filter could be attached only at the drain hose from the washing machine. The Guppyfriend bag require no installation. However, putting textiles in bags can be perceived as inconvenient and there is a risk is that the consumer chooses not using the bag.

It is easier to see when the Filtrol 160 filter needs to be changed or cleaned versus the Planet Care filter due to the transparent housing. In the instructions for the Planet Care filter it is written that “a single cartridge filter can be used for a minimum of 20 washes and a maximum of 30 washes: 20 if you have full load, use high temperatures and more dirt is present”. For the Filtrol 160 it is recommended to clean the filter (turned upside down over a garbage container) every 1-3 weeks. No filter is actively giving the consumer a message (sound or light) when it is time to either clean or change the filter, which would enhance the user friendliness. The Guppyfriend bag also needs to be cleaned from time to time.

It does take some effort the change the cartridge then using the Planet Care filter since one has to open the filter housing and make sure that there is no leakage after replacing the cartridge. The Filtrol 160 requires some technical skill to open the lid in the right way. To some, this manual handling and maintenance could be a holdback of buying the Filtrol 160 or Planet Care filter. It is not difficult to empty the Guppyfriend bag, but it can take a little time since the fibres and lint gets caught in the corners of the bag. This happens especially at the corners by the zipper where there is less space and harder to get hold of all the fibres/lint.

5. Discussion

There are filter solutions that can remove a considerable amount of microplastic fibres from laundry water. The experimental trials (Chapter 4) indicated that ~30-60 % by weight of particles in outlet water could be removed by the filters studied. However, the laboratory study has not aimed at elucidating exactly how well each of the filters can retain microplastics, but just if they are at all able to retain particles of these small dimensions. At this point none of the producers of filters suggested for usage with washing machines claim to remove all microplastic fibres shed from the washed textiles. The filter solutions are under development and can be expected to perform better in the future. When considering if a filtering solution should be absolute (i.e. removing 100 % of the microplastic fibres shed from the textiles during washing) one also need to consider what other consequences this may have for environmental and economic sustainability of washing textiles as well as practical aspects such as user friendliness.

All plastic fibres that are shed from textiles and released with laundry water, poses a risk of polluting aquatic or terrestrial ecosystems. There is a risk that larger plastics fibres can degrade into so called secondary microplastic. Consequently, the removal of major weight fractions of the plastic fibres has a potential to mitigate microplastic pollution, even if not all fibres are of microplastic size. Nevertheless, the experimental trial (Chapter 4) showed that filters could decrease the numbers of particles in the whole size-range of 5-1000 µm that was studied.

The results from the washing trials (Chapter 4) show that microplastic shedding is most severe during the first washing cycle. These fibres could potentially be removed by using filters at the textile production facility. However, since filters can decrease the release of microplastics also during the 2nd, 3rd and 4th washing cycles, the use of filters for washing machines is a way to prevent microplastic release from many more washing cycles.

The usage of washing machine filters that collects major parts of microplastic fibres before the water reaches the WWTP, can be a way to decrease the amount that end up in WWTP sludge. The remaining microparticles can be removed with one of the integrated ultra-filtration methods proposed in the Handbook for removal of microcontaminants at WWTPs (IVL 2017). This would not stop the problem of microplastic fibres from laundry water completely but would decrease the amounts ending up in the ecosystem.

There are some practical issues to consider when using a washing machine filter. When water is pumped through a filter there will be a pressure drop and it will be necessary to add more energy to pump the water through. Typically, the finer and the more clogged with microfibre the filter is, the more energy will be needed to pump the water through it. It is necessary to address this increased energy consumption when concluding of the economic and environmental sustainability of a filter. There would have to be a trade-off between having a finer filter that traps more microplastic and having a less fine filter that consumes less energy.

The filters described in this report are extra equipment that the consumer can choose to use. Some of them can be installed inside washing machines. However, the consumers at this point are users of washing machines that are self-motivated by lint problems or by environmental concern to filter their laundry water. Hence, the filter solutions are designed to be attachable to any washing machine.

When addressing all users of washing machines there are additional concerns that need to be considered. Installing, replacing and emptying the filters was found to be easily done during the washing trials. The operations did however take some effort. To change or empty a washing machine filter could be a discomfort to some users, and a reason for them to omit buying a machine with a filter and if they already have such a machine, a reason to neglect cleaning or replacing it. Therefore, legislation that obligates the usage of filters may be necessary to make it economically sustainable for a washing machine producer to include filters in their appliances. For the same reason it is important that the filter cannot be removed or by-passed by the user, and it is obviously preferable that filter maintenance is as simple, quick and clean as possible. When making a filtering solution that cannot be removed or by-passed by the user, the support from washing machine producers would be desirable.

No initiatives and no literature have been found regarding filters for so called washer/dryers (combined washing machines and dryers). As mentioned in Chapter 3, these machines releases microplastics both from the washing and the drying processes with the laundry water. Due to the higher release of microplastic fibres from washer/dryers those machines should be included in any legislation regarding washing machine filters.

All the filters in the study need to be cleaned or replaced frequently and it is likely that an un-willing user will neglect doing so. It is also important that the microplastics removed by cleaning are deposited adequately and not rinsed off in the sink where it would end up in the waste water. If the filter needs to be replaced regularly its end-of-life is also relevant when estimating its environmental performance. As an example, a filter made of fossil-based plastic that is incinerated with energy recovery, will have a shortened carbon cycle and contribute to climate change. A better option could be to recycle the material into new items. Either way, it is better if the replaced filter part is made of as little material as possible. For some of the filtering solutions, it is suggested that the customer returns the replaced item to the producer for recycling. This method raises doubts on the effectiveness as it will be difficult to have all consumers to return their used filters without incentives.

6. Conclusions

There are filters on the market that can be installed in washing machines or adjacent to washing machines, and which may remove microplastic fibres and larger plastic fibres from laundry water. The washing trials support that filters can remove microplastics from the water. To elucidate exactly how efficient those filters are at removing microplastic fibres would require more comprehensive laboratory work.

There are some questions which may influence choices of technologies and legislation for filtering solutions for domestic washing machines, and which may need further attention.

- Are larger plastic fibres decomposed into secondary microplastics at some point? Does this effect the possibility to remove them at the production facility, from laundry water or at the WWTPs?
- There is an ongoing build-up of research and information on the effects of microplastics in the oceans. However, the knowledge about how microplastics affect agricultural lands and other terrestrial ecosystems is sparse. To what extent do microplastics and larger plastic fibres from textiles affect terrestrial ecosystems (for example when WWTP sludge is spread)?
- What are the total positive and negative environmental impacts (e.g. more material use, adequate recycling systems, increased energy consumption) of filtering solutions for washing machines?
- How efficient do the filters need to be to have a positive impact on the environment?
- How can the filtering solutions be designed to be more user-friendly and to make the maintenance as simple as possible?
- How can washing machine producers, filter producers, entrepreneurs and start-ups collaborate to make filtering solutions that are integrated in the washing machine and that are easily maintained by the customer?

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