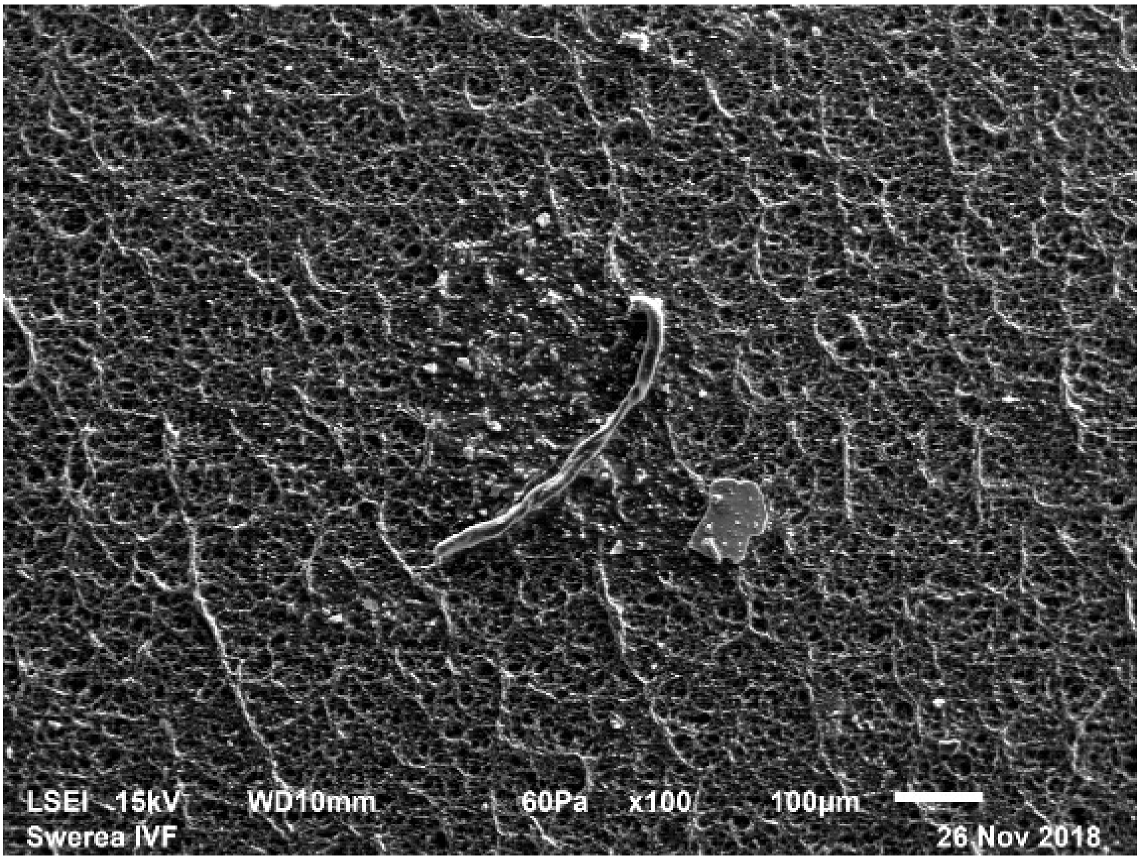
Report

Microplastics from industrial laundries

A study of laundry effluents

The Swedish Environmental Protection Agency



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About the report

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Summary

There is little knowledge about the release of microplastics from industrial laundries. This study was carried out to provide information about microplastics released in waste water from laundries. Six Swedish industrial laundries participated in the study. Of these two mainly washed hospital laundry, two mainly work wear, one mainly hotel laundry and one mainly mats.

Small particles between 5-15 µm were dominant in this study, regardless of types of textiles washed or whether the laundry had a waste water treatment facility. From the microscopic, FTIR and SEM analyses it could be concluded that microplastics were not dominant in this size range. Most of the particles (in the 5 to 15 µm range) were of other materials (for example minerals, metal fragments, silica, aluminium silicate, yeast, starch).

From the results from the measurements, calculations were made to estimate the number of released microplastic particles. The release varied significantly between the different laundries. If the calculations were based on an assumed best-case scenario, between 5 000 and 4 550 000 of microplastic particles were released per kg of washed textile. If a worst-case scenario was assumed, between 15 000 and 5 375 000 microplastic particles were released per kg of washed textile.

Three laundries with either chemical or biological waste water treatment adjacent to the production facilities were involved in the study. The water treatment had a significant impact on reducing the numbers of particles. The numbers of fibre-shaped particles released were reduced by 65, 96 and 97% for the different facilities. This shows that waste water treatment at the laundry can be an efficient way of reducing the levels of particles released to the WWTP.

Contents

1. Introduction

The Swedish Environmental Protection Agency has identified washing of synthetic textiles as an 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). The Swedish Environmental Protection Agency wishes to investigate different sources of microplastics in Sweden and evaluate different measures to reduce their release. One source of microplastics is industrial laundries, and the Swedish Environmental Protection Agency wishes to evaluate the level of microplastic fibres released from this source, how this varies between laundries, and whether release is reduced by waste water treatment.

In this work, the microplastic release from six industrial laundry facilities has been investigated. The work has included the collection and analysis of waste water samples from laundries washing different types of textiles and having different waste water treatment facilities.

2. Background

It has been estimated that between roughly 8 and 950 tonnes of microplastic fibres are released annually in Sweden with household laundry water (IVL, 2016). In addition to this, microplastics are also released with waste water from textile production plants (Swerea IVF, 18004) and from industrial laundries (as this report will show). Conventional water treatment methods can remove a large percentage of the microplastics entering waste water treatment plants (WWTPs) (e.g. Talvitie et al. 2015; Michielssen et al. 2016). In Sweden, most of the microplastic is retained in the waste sludge at WWTPs, but 0.2-19 tonnes remain in the water and are released directly to freshwater and marine water bodies (IVL, 2016). The sewage sludge containing the retained microplastics is spread on agricultural land (25 %), used in soil production (29 %) or used in landfill capping materials (24 %) (Swedish Environmental Protection Agency, 2017). There are different approaches to mitigate the release of microplastics from textiles to aquatic and terrestrial ecosystems, including better separation methods at the WWTPs, filtration of laundry water, improved textile production methods, improved laundry processes (e.g. Talvitie et al. 2017; Swedish Environmental Protection Agency, 2018; MERMAIDS Life+ project).

We have found no studies addressing the release of microplastic fibres from industrial laundries. There are several parameters at industrial laundries that could be expected to affect microplastic release, such as different washing machines, use of the counterflow washing processes, source of soiling for different work wear, use of different laundry chemicals for different levels of soiling, degree of reuse of water, and storage tanks for waste water where sedimentation may take place. Some of these parameters could be considered for study in a laboratory setting, whereas others would need to be investigated in controlled pilot studies at industrial laundries. The study at hand does not include any controlled variation of these parameters.

2.1. Methods for analysis of microplastics

There is no standardised method for analysing microplastics as yet, and it is therefore difficult to compare results obtained from different studies and reports. In the literature the collected microplastics are usually weighed or counted or both. To obtain statistical reliable results when weighing, the sample needs to be cleaned of other material, for example other particles, humus and organic matter. There are different ways of achieving this: dilution and filtering combined with pretreatment, for example sulphuric acid or hydrogen peroxide. When counting has been done, provided that the sample is clean, another challenge is that transparent and very light fibres are not easily detected with an optical microscope. In some studies, the microplastics are counted manually, which makes it is even harder to obtain statistically reliable numbers. Another challenge when counting is when the fibres are tied up in bundles (Li et al. 2018).

FT-IR, µFT-IR, Py GC/MS, Raman and density separation are mentioned in the literature for analysis of the content of the microplastics, regardless of origin (Li et al. 2018; Cincinelli et al. 2017; Dümichen et al. 2017, Di and Wang, 2018; Nuelle et al. 2014). Many studies focus on measuring microplastics in different recipients. Identification is default, and quantification appears to be more difficult. In this study sulphuric acid was chosen as pretreatment as there is a standard method for separation of cotton from polyester in polycotton blends (ISO 1833). However, high concentration of sulfuric acid dissolves polyamide and therefore copper diethylamide were chosen for those two laundries (Work wear 1 and Mats) as they also had some polyamide in their textile stock.

In this study, the same method was used as in a previous study on waste water from different textile production facilities (Swerea IVF, 18004). When analysing water samples from, RISE IVF filtrated the samples and then analysed the filtrate with its microscope with automatic counting. Additional FTIR analysis was used to identify the content of some of the counted non-fibre-shaped and the fibre-shaped particles. The waste water from laundries is much more soiled, and additional FTIR and SEM-EDS, for example, analysis was needed to identify the material composition of some selected particles.
In order to analyse the microplastics, there was a need for a pretreatment to remove the cellulosic debris. This was especially the case for water samples from hospital and hotel laundries with a high content of cotton in their textile stock.

3. Materials and Method

Water samples from the laundries were collected and analysed for their microplastic content. Waste water samples were collected daily at the laundries, and these were mixed to give weekly flow proportional samples at the laboratory. Residues containing microplastics were isolated by filtration and acid treatment. Chemical and morphological properties of the residues were studied to elucidate the content of microplastics in the water samples. The microplastic content of the chemicals used at the laundries and the waste water treatment facilities was assessed.

3.1. Selection of industrial laundries

Six industrial laundries in Sweden were selected for the study. The laundries vary in washing capacity between 4.3 and 41.3 tonnes of washed textile items on average per day, each facility washing roughly the same amounts every week. To enable comparison between waste water from the washing of different types of textiles, laundries washing mainly one type of textile were selected. For an overview of the laundries in the study, see Table 1. Information about the washed items and the washing chemicals is summarised in Table 2.

Table 1 Overview of the industrial laundry facilities in the study.

Laundry	Washers	Type of textile	Waste water treatment [i]
Work wear 1	Washer extractors	Mainly industrial workwear	Biological
Work wear 2	Washer extractors	Mainly industrial workwear	Chemical
Hospital 1	Continuous batch washers Washer extractors	Mainly healthcare workwear	-
Hospital 2	Continuous batch washers Washer extractors	Mainly healthcare workwear and textiles	-
Mats	Continuous batch washers Washer extractors	Mats and mops	Chemical
Hotel	Continuous batch washers Washer extractors	Mainly textiles for hotels and restaurants	-

[i] Refers to waste water treatment at the laundry facility, before the water is discharged to the external WWTP. [ii] Calculated average over the four weeks assessed. Reported by laundries per day.

Four of the laundries use continuous batch washers combined with smaller washer stations with washer extractors for delicate items or for stain removal. Two of the laundries use only washer extractors of different sizes. Two of the laundries have chemical treatment of the waste water before it enters the WWTP. One has biological waste water treatment. The waste water streams from the other three laundries are treated at external/municipal waste water treatment plants (WWTP). Some of the laundries have requirements for the content of their effluents. These requirements are set by the local authorities.

Table 2 Data from the laundries

Laundry	**Textile material**	**Amount of washed goods [i] (ton/day)**	**Water consumption [i] (liter/kg textile)**	**Chemicals consumption [ii] (g/kg textile)**
Work wear 1	Polyester Cotton Polycotton[iii] Nylon-mix	4.3	14.7	29
Work wear 2	Polyester Cotton Polycotton[iii]	5.1	11.8	23
Hospital 1	Polycotton[iii]	39.4	6.9	6.8
Hospital 2	Polycotton[iii]	41.3	9.4	10
Mats	Cotton Nylon Rubber	5.8	2.1	1.6
Hotel	Cotton Polycotton[iii]	22.7	4.9	11.5

[i] Calculated average over the four weeks assessed. Reported by laundries per day. [ii] All laundry chemicals including detergent. [iii] Polycotton is a textile mixture of approx. 50 % polyester and 50 % cotton.

3.2. Collection and preparation of samples

Water samples were collected by the laundries, and flow proportional samples were mixed at the laboratory. The samples were filtered to isolate a residue containing the microplastics. Cellulose originating from cotton and polycotton blends was removed from the filter membranes by dissolution.

3.2.1. Collection of samples

The washing process and water distribution layout were different at each laundry. Sampling points for the study were selected in dialogue with the laundries in order to make it feasible for the personnel to take representative samples.

Personnel at the laundries collected samples from the water ejected to WWTP every Monday to Friday for four consecutive weeks. At one laundry an autosampler was used to collect representative samples each working day. At the other laundries one sample was collected every day from a sampling point just before the waste water was ejected from the laundry. All laundries except one had water discharge facilities where water was collected in cisterns (e.g. for sedimentation of suspended particles or for chemical/biological treatment) before ejection to an external WWTP.

At the three laundries with waste water treatment (Workwear 1, Workwear 2 and Mats, see Table 1), samples were also collected before water treatment for five consecutive days. At two of the laundries the samples were taken directly in the effluent from the washing facility. At one laundry the samples were taken in a buffer cistern where the water was stored before chemical treatment.

The samples were stored in a fridge before weekly shipping to the testing laboratory where sample preparation was performed. The laundries kept a daily record of their water consumption and the amount of washed items. The chemical consumption and information about the washed items and the water treatment systems were also provided.

3.2.2. Preparation of weekly flow proportional samples

Daily water samples were mixed to a weekly flow proportional sample for each laundry. (Figure 1, Table 3). The pH value of the weekly water sample was checked with pH strips.

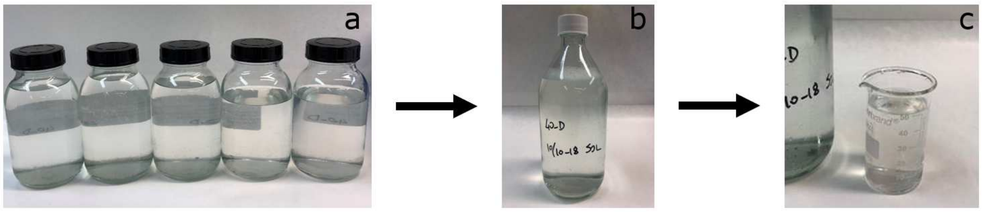

Figure 1 Example from week 40 for one of the laundries. Daily water samples (a) were mixed to one weekly flow proportional sample (b). A smaller potion is used for analysis (c).

Table 3 Example from week 40 for one of the laundries. The table describes how the flow proportional water sample was mixed.

	Washed items (kg)	Daily ratio (%)	Amount of water from each day (mL)
Monday	6115	25	123
Tuesday	4540	18	92
Wednesday	5559	22	112
Thursday	4700	19	95
Friday	3864	16	78
Sum	24778	100	500

3.2.3. Filtration of water samples and dissolution of cellulose fibres

The weekly water sample was vacuum-filtrated through 0.65 µm PVDF membrane. A filter membrane with particles is shown in Figure 2. The aim was to filtrate as much of each sample as possible. When there were too many particles and fibres on the filter membrane the software could not calculate them in an efficient way. Therefore, different amounts (between 10-50 ml) of the weekly water samples from the laundries were filtrated. To make the results comparable, the data was calculated to represent the same scale.

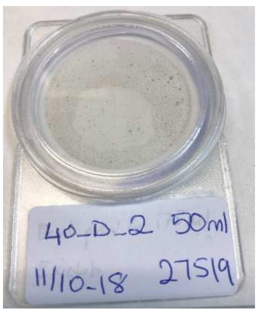

Figure 2 Filter membrane with particles.

Many of the fibres in the laundry water are natural cellulose fibres from cotton fabrics. It is time-consuming to distinguish cellulose fibres from microplastics by microscopic methods. Therefore, the cellulose fibres were removed from the filtrated mass with either 75% sulfuric acid or copper diethylamide. Sulphuric acid was used for 'hotel' and 'hospital laundry items which contain predominantly a polycotton material (cotton and polyester blend). For 'work wear' and 'mats laundry items, copper diethylamide was used.

Sulphuric acid method: The method is based on ISO 1833. 5 ml of 75 % sulphuric acid was poured onto the filtrated mass in the membrane container. The container was then maintained at ambient temperature (approx. 20 °C) for 60 minutes. The contents of the container were filtered through the membrane using vacuum filtration. The residue was rinsed three times with distilled water at ambient temperature (approx. 20 °C) and by draining using vacuum filtration after each addition.

Copper diethylamide method: 5 ml of Copper diethylamide was poured onto the filtrated mass in the membrane container. The container was then maintained at ambient temperature (approx. 20 °C) for 20 minutes. The contents of the container were filtered through the membrane using vacuum-filtration. The residue was rinsed several times (until the blue colour disappeared) with distilled water at ambient temperature (approx. 20 °C) and by draining using vacuum filtration after each addition.

The filter membranes with the remaining microplastic particles were dried in a desiccator at ambient temperature (approx. 20 °C) to avoid contamination.

3.3. Characterisation of microfibres

The morphological and chemical properties of the microparticles in the water effluents were assessed. The number of particles on the membrane filters was characterised using microscopic particle counting. The chemical properties of the particles on the membrane filters were studied using Fourier transfer infrared spectrometry (FTIR) and a scanning electron microscopy (SEM) method with detection of chemical elements. The chemical analysis was used to distinguish between microplastic particles and other microparticles on the membrane filters.

3.3.1. Microscopic Particle Counting

The equipment used was Leica DM4000M microscope and Leica Cleanliness Expert V. 4.9 software.
All particles (equal to or larger than 5 µm) regardless of shape were counted automatically by a light microscope.

In the standards ISO 18413 and ISO 16232 it is stated that pore size is crucial to be able count the particles in a reliable way. It is often mentioned that the pore size should be 25 % of the size of the particles to be counted, for example a pore size of 1.2 µm for counting 5 µm particles. In this study all samples were filtered through PVDF filters with a pore size of 0.65 µm.

The analysis system (microscope and software) identified the quantity of fibre-shaped and non-fibre-shaped particles in different size classes including longest non-fibre-shaped particles as well as the longest fibre-shaped particles. The size range used in this study was 5-1 000 µm and above. "And above" means that all particles with a size larger 1 000 µm are reported in the category ">1 000 µm"

The parameters used for fibre-shaped particles detection was a minimum fibre aspect ratio of 10:1 (10 times longer than the fibre diameter). The shortest reliable length for the microscope to count and define a particle as a fibre is 50 µm. The detection limit is 5 µm for particles, and to be classified as a fibre the particle has to be 10 times longer than its diameter, hence 50 µm.

Some manual changes were made to the largest detected fibre and non-fibre-shaped particles and after the automatic detection due to several half-detected fibre-shaped particles and some transparent non-fibre-shaped particles that had been counted as a fibre-shaped particle. In addition, all particles and fibres larger than 200 µm were manually analysed and re-categorised or modified when needed.

3.3.2. FTIR analysis

Fourier transfer infrared spectroscopy (FTIR) was used to analyse the chemical content of individual particles. A Bruker Lumos FTIR microscope was used in ATR mode for the analysis.

3.3.3. SEM-EDS analysis

Images of the membranes are taken with a Scanning Electron Microscope (SEM) from JEOL, model JSM-6610LV, operated at low vacuum with a chamber pressure of 60 Pa. Elemental analysis is performed with an Energy Dispersive X-Ray Spectroscopy (EDS) detector from Bruker (XFlash 5010) and ESPRIT software version 2.1. SEM images and EDS analysis are performed using an accelerating voltage of 15 kV at a working distance of 10 mm.

3.4. Chemicals assessment

The material safety data sheets for the chemicals used in the laundry processes and waste water treatment was collected from the laundries or the manufacturers of the chemicals. The information about the chemical content given in the material safety data sheet was checked to see if there were any insoluble polymeric substances present that may contribute to microplastics. The chemical names and CAS numbers were checked with data from ECHA to see whether there was any doubt as to whether a substance was considered an insoluble polymeric substance.

The laundries took samples of the detergent stock solutions that were sent to the testing laboratory for analysis (FTIR).

3.5. Limitations and uncertainties

This is the first study of investigating the release of microplastics in the waste water from industrial laundries in Sweden. However, all the results apply only to the participating laundries and cannot be regarded as an average for the whole Swedish laundry industry. The results differ between laundries even in the same category. In this study only one or two laundries are from the same category, which gives a plausible indication, but are too few to make a national average.

<u>Sample collection:</u> Studies on household laundry and laboratory tests have shown that the type of washing machine, the detergent and the type of textiles affect microplastic shedding (Hartline et al 2016; Hernandez et al. 2017; Carney Almroth et al. 2018). The laundries in the study differ with regard to these parameters i.e. the types and combinations of washing machines, laundry and laundry chemicals, but also in water infrastructure such as the usage of water storage tanks or sedimentation tanks. Samples could only be collected where there was an opening in a tank, a tap from the piping, or similar. Consequently, it was not possible to collect samples that were absolutely comparable between the laundries. As an example, the water samples were collected just once a day from a pipe where the water was flushed directly from the laundry machines at one laundry, whereas another laundry used an autosampler that collected flow proportional samples throughout the production week. During the visits at the laundries, effort was focused on selecting sample collection points in production that were as representative as possible of the effluents of each laundry.

<u>Pretreatment:</u> Although sulphuric acid is used as a way of dissolving cellulose from polyester in polycotton blends in order to establish the percentage of each fibre (ISO 1833), experience of using this method on waste water is limited. It has been proven to work, but can obviously be further optimised. The situation is the same for copper diethylamide. This application is quite novel.

Filtering and microscopy: The same technique is used by the automotive industry when investigating contaminations (i.e. particles regardless of shape) in engine parts. The challenge with waste water is that the samples are 100-10 000 times more contaminated.

A light microscope has difficulty in analysing very light and transparent fibres, even though it is possible to change to black background. Another challenge is when the filter contains too many particles, especially if the particles are fibre-shaped and tangled. There is then a need to dilute the water sample to separate the particles.

If the fibres are stuck in bundles the microscope cannot count the individual fibres, and if the fibres and /or particles are fixed in clods (as we have seen for example in the samples after purification from work wear) the microscope will count the whole clod as one particle.

FTIR analysis: FTIR is primarily used for identification, not quantification. Since the response is not linear, there is a need to identify each selected particle separately, which means that it is basically impossible to analyse all particles in a filter containing several thousands of particles. Some particles from each facility was analysed with FTIR which gave an indication of whether there were a large amount of polyester /polyamide/polypropylene/polyurethane etc. containing particles on the filter. But it is not an all-embracing methodology which can produce a result that can conclude that X % of the present particles on a filter are of polyester origin.

SEM analysis: This analysis can provide an exact picture of which basic elements are present. The only limitation is that a small part of the filter can be analysed at the same time, so this will be a spot-check when analysing a filter with thousands of particles. If the particles/fibres are hidden in a clod the instrument will not see it – just the elements in the surface of the clod.

Calculation of the number of particles: With the large amounts of particles that come with the waste water from laundries and taking into account the various uncertainties, the numbers should be viewed as a screening result and not as an exact number of released particles or microplastics.

4. Results

In this section, results from the analysis of microplastics in effluents from industrial laundries are presented. The results from microscopic particle counting as well as from chemical analysis of the microparticles (FTIR/SEM) are presented and used to estimate the release of microplastics from industrial laundries. The impact of chemical and biological waste water facilities at the laundries is also presented. A comparison with data from other studies of microplastics from different sources is also included.

4.1. Microparticles in the effluent water

4.1.1. Microscopic particle counting

The results from the microscopic counting of non-fibre-shaped and fibre-shaped particles in different size intervals are shown in Figure 3 and Figure 4. In general, there are fewer particles of the fibre-shaped type (note the different scales on the x-axes in the figures). The 5-15 µm size interval dominated the result (see Figure 3). The number of particles released from the laundries varied from week to week. The results from the laundry with biological waste water treatment (Work wear 1) are reported separately (see 4.3).

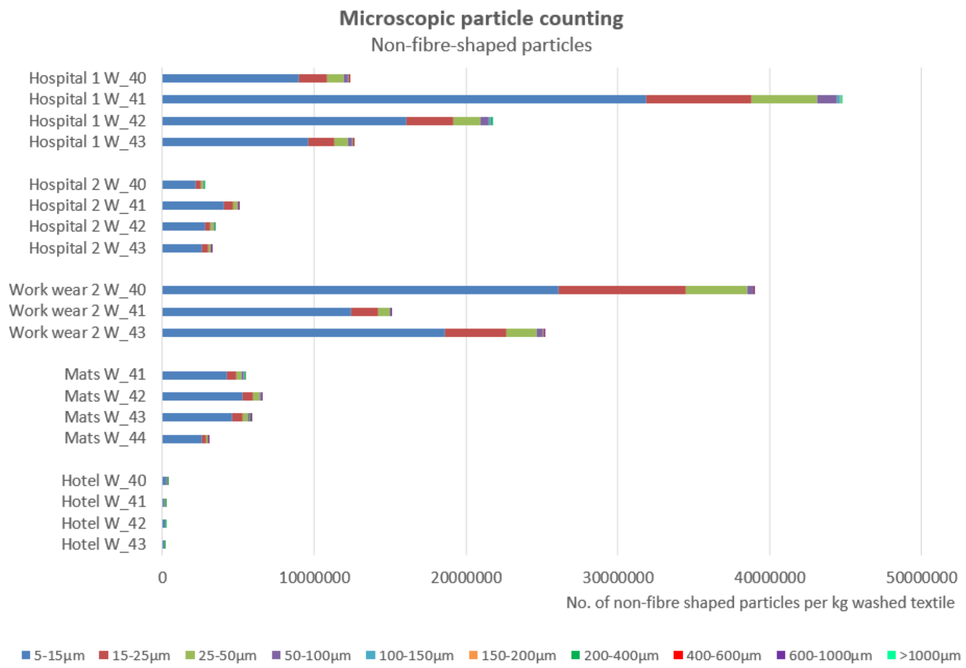

Figure 3 Numbers of non-fibre-shaped particles in different size intervals in the effluent. Note that not all particles are microplastics.

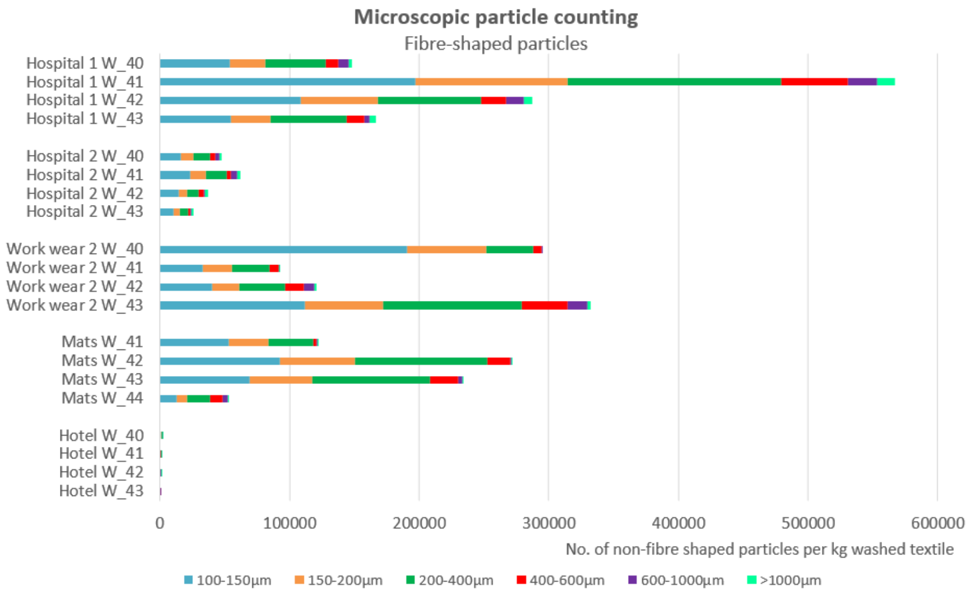

Figure 4 Numbers of fibre-shaped particles in different size intervals in the effluent. Note that not all particles are microplastics.

4.1.2. Comparison between different laundries

In Figure 5 and Figure 6 the average numbers of particles in the water effluent from the laundries over the four weeks is presented. The numbers of particles varied significantly between the different laundries. There was also a significant difference between laundries washing similar types of textiles (see 'Hospitals' in the figures). The number of non-fibre-shaped particles varied between approximately 200 000 (Hotel) and approximately 23 000 000 (Hospital 1) per kg textile, and the number of fibre-shaped particles released varied between approximately 2 000 (Hotel) and 500 000 (Hospital 1) per kg textile.

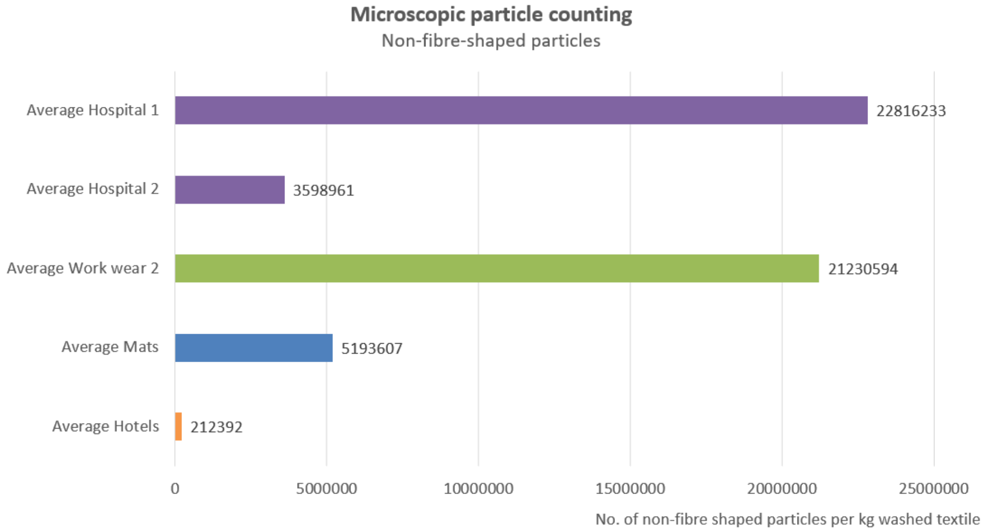

Figure 5 Average numbers of non-fibre-shaped particles in the effluent from the laundries. The average has been calculated over the four weeks sampled.

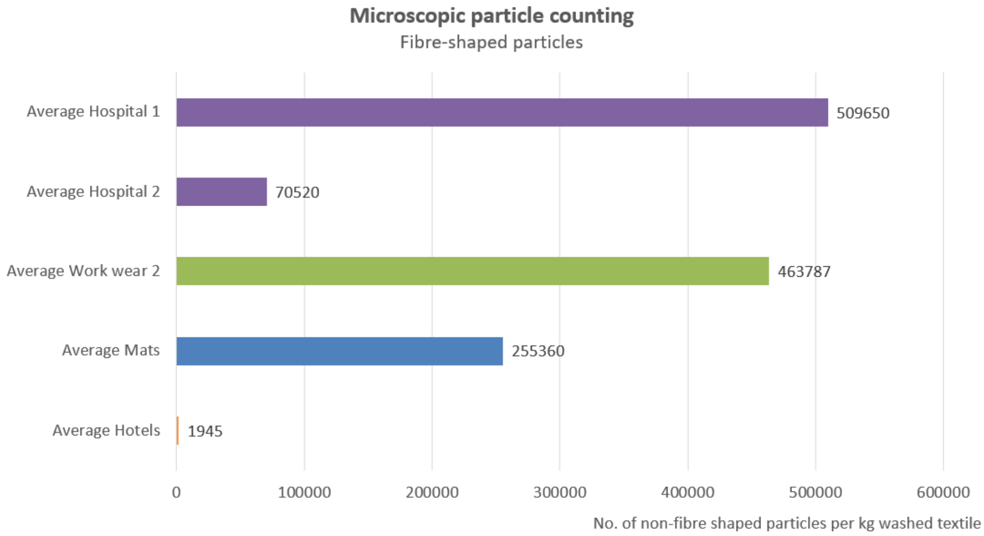

Figure 6 Average numbers of fibre-shaped particles in the effluent from the laundries. The average has been calculated over the four weeks sampled.

4.1.3. FTIR

Results from the FTIR analysis are presented in Table 4, Table 5, and Table 6. The overall result for the two hospital laundries and the work wear laundries show that polyester dominates the fibre-shaped particles content. For the hospital laundries inorganic matter dominates the non-fibre-shaped particles. The particles found were mainly of inorganic content, with occasional polyester. Occasional polyurethane, silica and polyethylene and aluminium silicate content were also identified.

When non-fibre-shaped particles from the two work wear laundries were identified, the analysis was interfered with by fluffy as well as clod-like structures in the sample. For the fibre-shaped particles the FTIR results for Mats and Hotel were difficult to analyse due to too much fluffy structures. Therefore, the FTIR analysis was complemented by SEM-EDS (3.3.3).

The detected aluminium silicate is probably residues from the complexing agent in the detergent. The FTIR analysis also detected PTFE (polytetrafluoroethylene) from Work wear 2.

Table 4 Detected content of some of the non-fibre-shaped particles using FTIR microscope.

Laundry	Content of some non-fibre-shaped particles
Work wear 1	Occasional yeast, EVA (ethylene vinyl acetate) Difficulties with a lot of fluff/clods
Work wear 2	Occasional PET/Polyester and PE (polyethylene) Difficulties with a lot of fluff/clods
Hospital 1	Predominately inorganic particles like talc, silica. Occasional single PET/polyester, EVA (ethylene vinyl acetate)
Hospital 2	Predominately inorganic particles like silica. Occasional single PET/polyester, PUR (polyurethane), silicone
Mats	Occasional copper sulphate, aluminum silicate
Hotel	Occasional metal, silicone, hydrocarbon, PET/polyester, aluminum silicate

Table 5 Detected content of some of the fibre-shaped particles using FTIR microscope.

Laundry	Content of some fibre-shaped particles
Work wear 1	Predominately polyester fibres Occasional single cellulose, silicates
Work wear 2	Predominately polyester fibres Occasional single cellulose, PTFE (polytetrafluoroethylene)
Hospital 1	Predominately polyester fibres Occasional single silicates
Hospital 2	Predominately polyester fibres Occasional single cellulose, silicates
Mats	Too much fluff interfered with the analysis
Hotel	Due to vague results

Table 6 Additional comments to table 4 and 5.

Laundry	Week 1	Week 2	Week 3
Work wear 1	Very small particles, single fibres	Very small particles, few fibres	Very small particles, fluff /clods
Work wear 2	Nn	A lot of small particles	Fluffy small black particles, single blue fibres
Hospital 1	Few particles, single fibres	Small black and light particles, mixed fibres	Different particles and fibres
Hospital 2	Few particles, few fibres	nn	Few particles, few fibres
Mats	Nn	nn	Plenty of particles, fluff and short fibres
Hotel	Single particles, no fibres	nn	Very few particles and fibres (diffuse)

Examples of FTIR spectra are shown in Figure 7, Figure 8 and Figure 9.

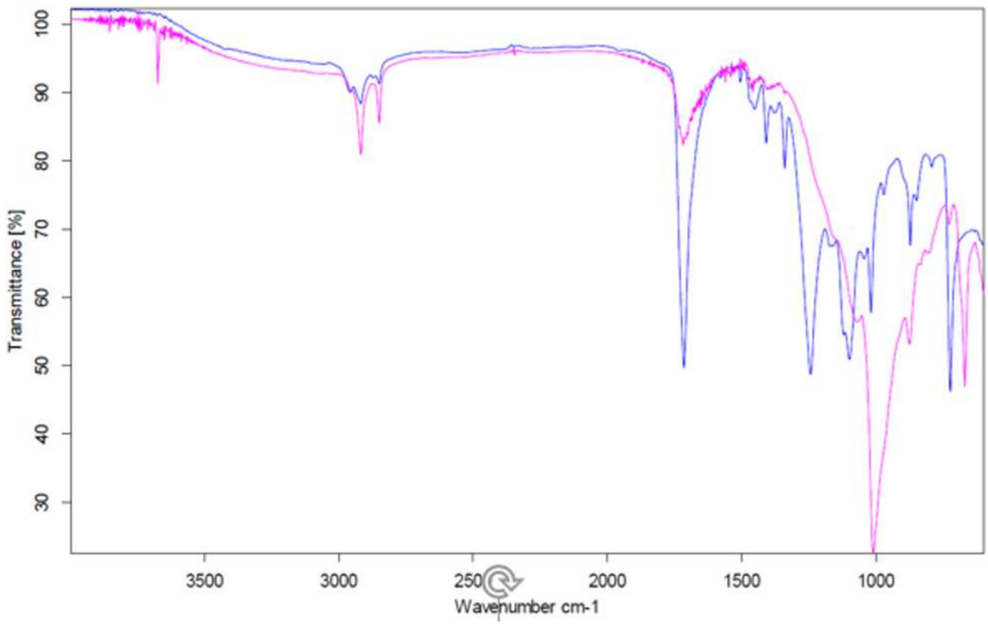

Figure 7 Hospital 1, inorganic particles such as talc (pink curve) and fibre-shaped particles of polyester (blue curve) were identified. Polyester has typical absorption bands at wave number 1715 cm^{-1}, 1243 cm^{-1}, 1098 cm^{-1} (ester) and 720 cm^{-1} (hydrocarbon). Talc has typical absorption bands at wave number 1010 cm^{-1} (SiO2) and 3675 cm^{-1} plus 669 cm^{-1} (MgO).

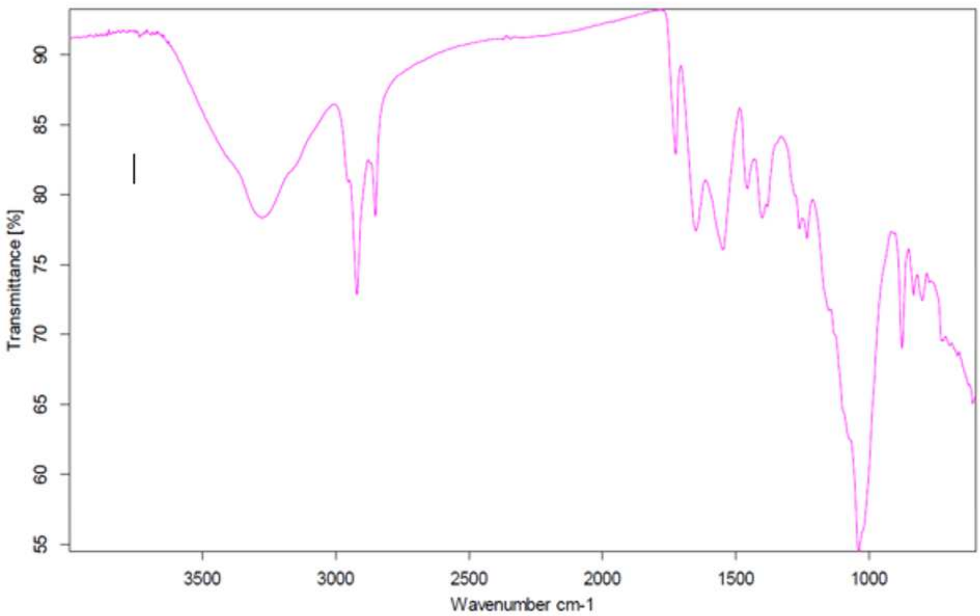

Figure 8 Work wear 1, non-fibre-shaped particles such as yeast and starch were identified. Typical absorption band in the spectrum are wave number 3280 $cm^{-1}$and 1038 cm^{-1} (hydroxide) and 2920 cm^{-1} and 2851 cm^{-1} (hydrocarbon).

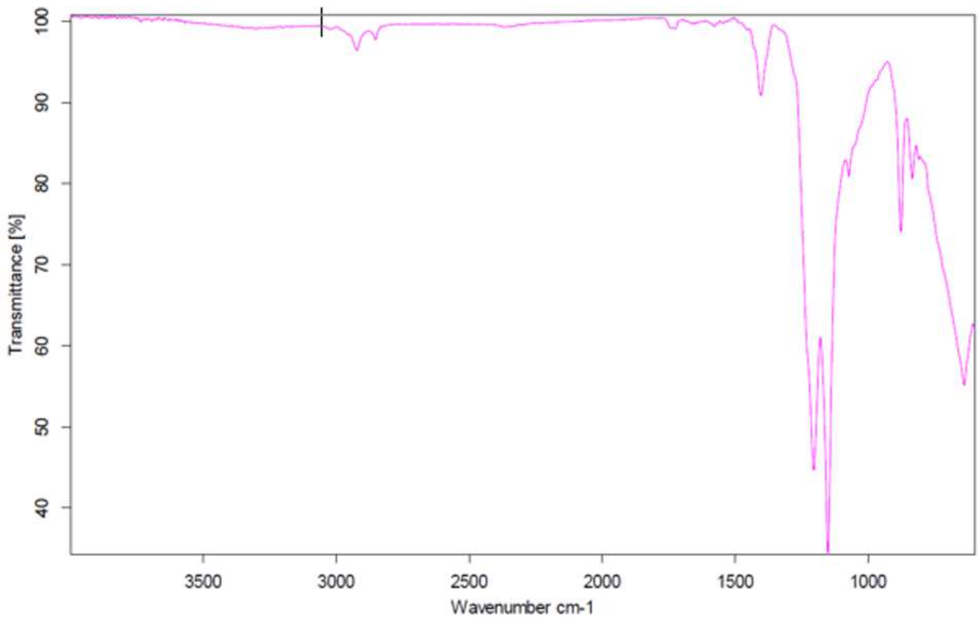

Figure 9 Work wear 2, non-fibre-shaped particles with PTFD (polytetrafluoroethylene) were identified. The distribution and characteristics of the double band absorption at 1204 $cm^{-1}$and 1150 $cm^{-1}$and the absorption band at 635 cm^{-1} is typical for PTFE and Teflon.

4.1.4. Scanning electron microscopy (SEM)

When investigating the presence of different chemical elements in the SEM analysis the results showed that the following elements were present: aluminium (Al), carbon (C), oxygen (O), potassium (K), magnesium (Mg), silicon (Si), iron (Fe), sodium (Na), copper (Cu), and sulphur (S). The sulphur is most likely residues from the sulphuric acid pretreatment.

The synthetic fibres washed at the industrial laundries are predominantly polyester and polyamide (Table 2). Both polyester and polyamide contain both oxygen and carbon. Therefore, both carbon and oxygen need to be present in the SEM images representing different chemical elements for it to be possible to say that a particle is of microplastic origin. The method is exemplified in Figure 10. The grey image in Figure 10 shows the filter with one distinct fibre and a large amount of small particles of various sizes and geometries. The filter medium is the mesh visible in the background. Blue is the colour of oxygen and pink is the colour of carbon in this analysis, and the more intense and highlighted the colour, the more of the element is present. The dark spots indicate that the element analysed is not present. From this it can be concluded that the fibre is most likely of microplastic origin, whereas most of the particles are not. There may be particles that are so small that they have submerged in the filter medium, and some microparticles might consequently be hidden.

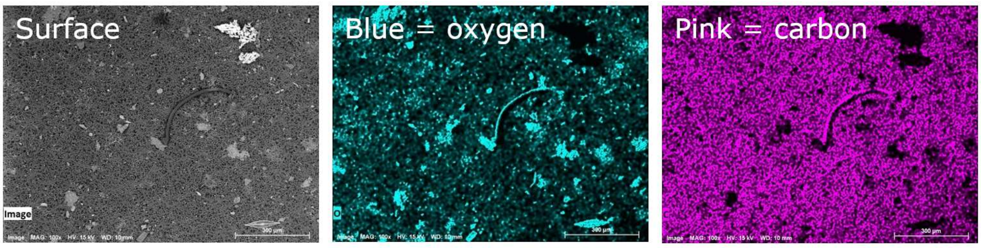

Figure 10 Example of SEM images used for identifying microplastic particles. Microplastics contain both carbon and oxygen. Only particles highlighted both in the blue and in the pink image can be microplastics. The filter media itself also contains carbon which is why there is a lot of pink areas in the carbon image

The SEM analysis was performed according to the example above for filters representing the different laundries. It could be estimated that only 1-5 % of the non-fibre-shaped particles (5-50 µm) were microplastics. The same analysis revealed that most (approx. 95 %) of the particles defined as fibre-shaped were indeed microplastics. A selection of SEM images from the analysis are shown in Figure 11.

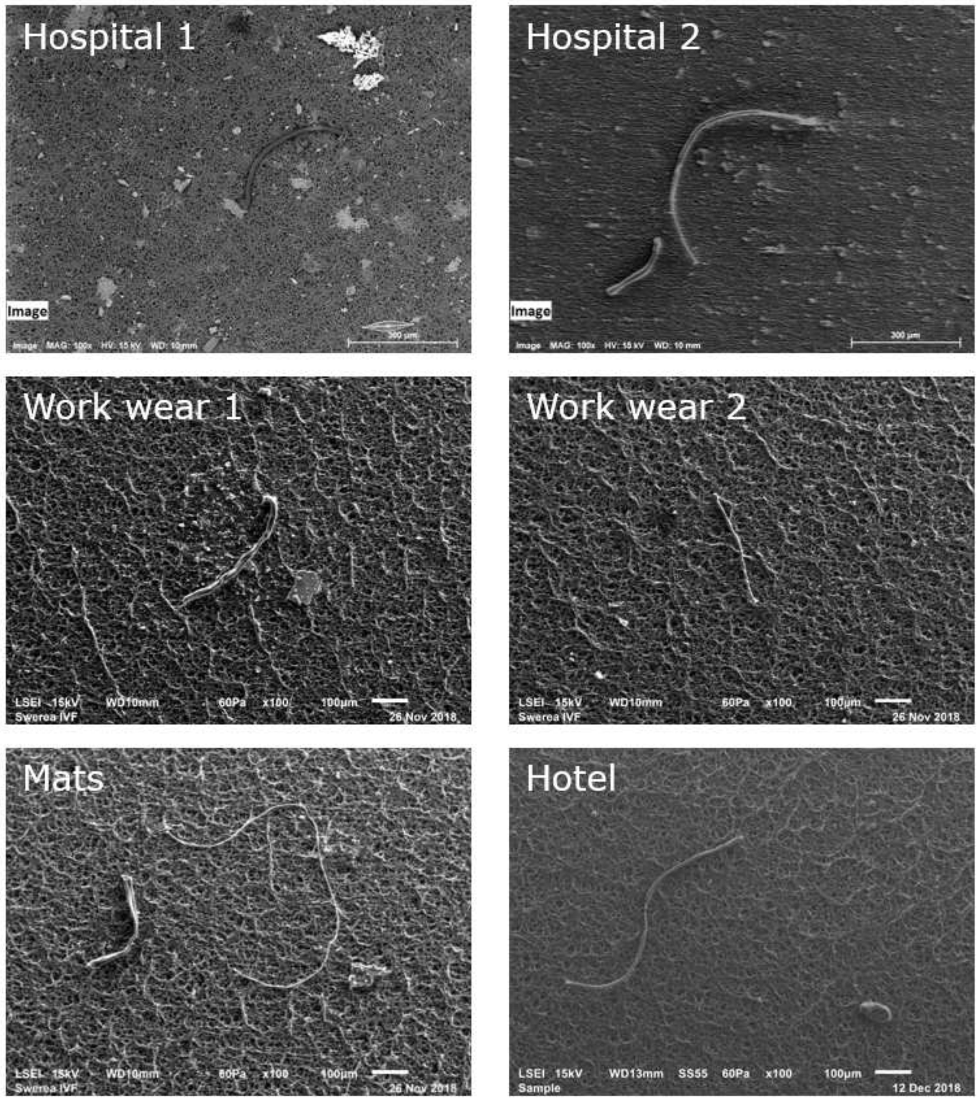

Figure 11 Several SEM images were analysed for each laundry. The figure shows examples of SEM images with microparticles, both fibre shaped and non-fibre-shaped

4.1.5. Estimation of number of microplastics released

The FTIR and SEM analysis showed that not all particles in the effluents were microplastics. To be able to make a good estimate of what fraction of the particles counted as non-fibre-shaped and fibre-shaped were microplastics, FTIR analysis was performed (see 3.3.2). In addition, SEM with visualisation of chemical elements was performed to further ensure that the best possible estimation was made. Based on the FTIR and SEM results a worst-case scenario and a best-case scenario were defined for estimation of the microplastic content in the effluents.

In the worst-case scenario it was assumed (qualitatively from FTIR and SEM analysis) that 5% of the non-fibre-shaped particles and 95 % of the fibre-shaped particles were microplastics. Based on this assumption, the average number of microplastic particles released in a worst-case scenario was calculated, see Table 7.

Table 7 Worst-case scenario. Calculated average numbers of microplastic particles in effluents from the laundries.

Laundry	Concentration of microplastics defined as non-fiber-shaped [i] (no. per liter)	Concentration of microplastics defined as fiber-shaped [ii] (no. per liter)	Total concentration of microplastics in effluent (no. per liter)	Total no. of microplastics released [iii] (no. per kg textile)
Hotel	2 500	500	3 000	15 000
Hospital 1	165 000	70 000	235 000	1 620 000
Hospital 2	19 000	7 500	26 500	249 000
Work wear 2	88 500	367 000	455 500	5 375 000
Mats	129 000	125 500	254 500	534 500

[i] The calculation is based on the assumption that 5% of the non-fibre-shaped particles are microplastics. [ii] The calculation is based on the assumption that 95% of the fibre-shaped particles are microplastic fibres. [iii] Calculated by multiplying the 'Total no. of microplastics in effluent' per litre with the water consumption in Table 2.

Similarly, in the best-case scenario it was assumed that 1% of the non-fibre-shaped particles and 95% of the fibre-shaped particles were microplastics. Based on this assumption, the average number of the microplastic particles released in a best-case scenario was calculated, see Table 8.

Table 8 Best-case scenario. Calculated average numbers of microplastic particles in effluents from the laundries.

Laundry	Concentration of microplastics defined as non-fiber-shaped [i] (no. per liter)	Concentration of microplastics defined as fiber-shaped [ii] (no. per liter)	Total concentration of microplastics in effluent (no. per liter)	Total no. of microplastics released [iii] (per kg textile)
Hotel	500	500	1 000	5 000
Hospital 1	33 000	70 000	103 000	711 000
Hospital 2	3 800	7 500	11 500	106 000
Work wear 2	17 700	367 000	385 000	4 550 000
Mats	26 000	125 500	151 500	318 000

[i] The calculation is based on the assumption that 1% of the non-fibre-shaped particles are microplastics. [ii] The calculation is based on the assumption that 95 % of the fibre-shaped particles are microplastic fibres. [iii] Calculated by multiplying the 'Total no. of microplastics in effluent' per litre with the water consumption in Table 2.

There were large differences between the numbers of microplastics released from the laundries. The release of microplastic particles from the different laundries varied between 15 000 and 5 375 000 per kg of washed textile if assuming the worst-case scenario and between 5 000 and 4 550 000 per kg of washed textiles if assuming the best-case scenario.

4.2. Comparison with other reported data

Assessing the amount of microplastic particles in numerical terms has some implications. Each particle is counted as one, irrespective of whether it is very small (5 µm) or much larger (1000 µm). In view of the risk that larger particles degrade into smaller secondary microplastic particles it would be informative to also measure the amount of microplastics by weight. Reporting the weight of microplastics released (preferably annually in Sweden) would also simplify the comparison with release from other sources and industries.

In this study there was an aim to weigh the microplastic particles. Unfortunately, the samples were found to be heavily contaminated with other materials, and a weight measurement would be greatly influenced by these. It was concluded that the weight of the samples would poorly represent the amount of microplastics in the effluents, and weighing was not carried out.

The weight of the released microfibres can also be calculated. Two reports have attempted to estimate the weight of the microplastics released from domestic laundry based on data from a handful of scientific publications. One report estimated microplastic release to be 12-640 mg/kg of textile, while the other concluded that release was 12-540 mg/kg of textile (IVL, 2016; ICF and Eunomia 2018). Although these numbers have been calculated using many assumptions they are used in this report to calculate the weight of microplastics released from industrial laundries (below).

The Swedish Textile Rental Association has estimated that 180 000 tonnes of textiles are washed annually at industrial laundries (Swedish Textile Rental Association, 2018). The number includes dry cleaning, but this fraction is minor. If microplastic release during industrial laundry is assumed to be the same as release during domestic laundry it can be estimated that 2.2-115 tonnes (calculations: 0.012 g/kg × 180 000 000 kg and 0.640 g/kg × 180 000 000 kg) of microplastics are released annually from industrial laundries in Sweden. As a comparison, IVL Swedish Environmental Research Institute estimated that the release of microplastics from household laundry in Sweden is 8-950 tonnes annually (IVL, 2016).

The concentration of microplastics in the effluents from textile production facilities was 100-1450 per litre (Swerea IVF, 18004). There is no reason to expect that the water consumption at industrial laundries is comparable to that of textile production facilities. These industries perform different operations and use water for different purposes. Therefore, the concentration of microplastics in the effluents from these industries are not comparable. The concentration of microplastics in the effluents from the industrial laundries were 1000-385 000 per litre if using the best-case scenario calculation and 300-455 500 per litre if the worst-case scenario is considered.

4.2.1. Uncertainties in the comparison of microplastics release data

When comparing the results to microplastics in effluent from textile production facilities it can be expected that the laundries release more particles and fibres than the productions facilities. The laundry process is designed to remove loose particles (such as dirt), and the treatment of the textiles can be harsh. There may also be other factors that influence the shedding, for example the fabric itself that is completely new in production compared to aged textiles at the laundry. The results from the study of textile production facilities report the release of particles as a concentration in water (i.e. numbers of microplastics per litre). If an industrial laundry (or a textile production facility) improves its process to reduce water consumption, the concentration of microplastics per litre will increase, although the actual number of microplastics is unchanged. Similarly, a laundry with optimised and low water consumption will misleadingly appear to produce more microplastics if the amount is calculated as a concentration. Nevertheless, we have chosen to compare these industries in the section above (4.2).

4.3. Impact of waste water treatment

Three of the participating laundries had their own waste water treatment facilities installed adjacent to the laundry. For one week those laundries collected water samples both before and after water treatment. The water treatment was found to reduce the release of fibre-shaped as well as non-fibre-shaped particles significantly at all three laundries (Figure 12, Figure 13 and Table 9). Particles between 5-15 µm are also the dominant size range after treatment. However, a large proportion of the particles in this size range are not microplastics, as discussed previously.

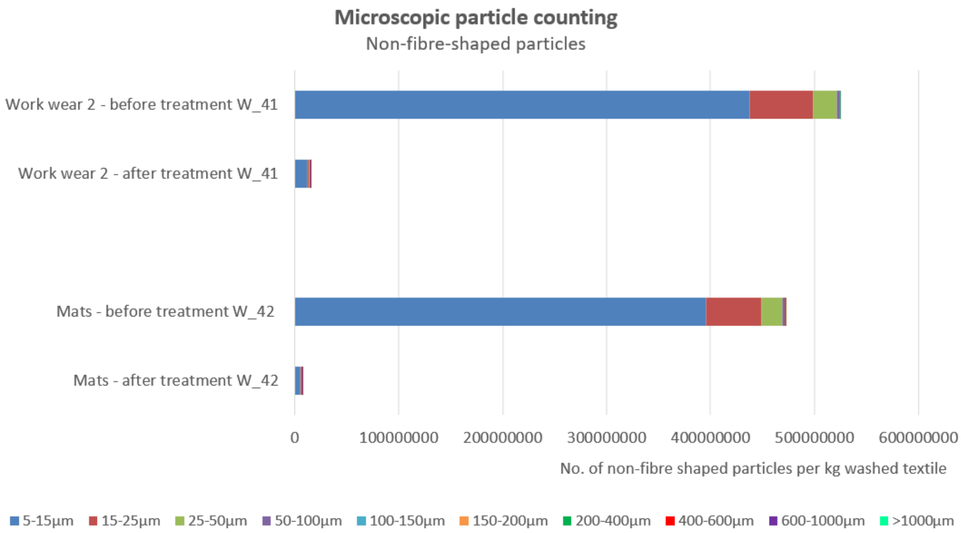

Figure 12 The figure show the number of non-fibre-shaped particles from 5-1000 µm before chemical waste water treatment at the laundry,week 41 (W_41) for Work wear 2 and week 42 (W_2) for Mats versus after treatment from week 41 and week 42 respectively.

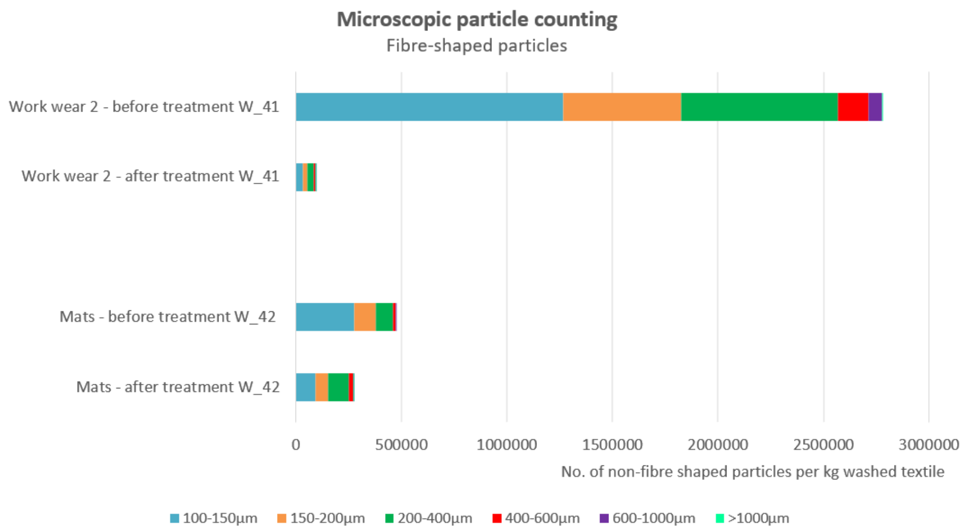

Figure 13 The figure show the number of fibre shaped particles between 100-1000 µm before chemical waste water treatment at the laundry,week 41 (W_41) for Work wear 2 and week 42 (W_2) for Mats versus after treatment from week 41 and week 42 respectively.

Table 9 Waste water treatment facilities greatly reduced the amount of microparticles in the waste water from the laundries.

Laundry	Waste water treatment	Non-fibre-shaped particles	Fibre-shaped particles
Work wear 1[i]	Biological		-97 %[i]
Work wear 2	Chemical	-97 %	-96 %
Mats	Chemical	-98 %	-65 %

[I] Note that the data for Work wear 1 is produced with a different particle counting method.

The biological treatment (i.e. at Work wear 1) generated clods. In this case, the software in the microscope incorrectly regarded large clods as fibre-shaped particles. If there only were a few clods this would not influence the result due to the large number of fibre-shaped particles, but since the biological treatment generates many large clods the result needed to be adjusted (Figure 14). The fibre-shaped particles have therefore been recalculated manually down to 200 µm, but going further to even smaller sizes is not feasible. There is also a possibility that there could be particles, both non-fibre-shaped and fibre-shaped, hiding in the clods.

The result shows that the number of fibre-shaped particles is reduced by 97% (from 232 to 6 fibre-shaped particles) by biological waste water treatment (Figure 15).

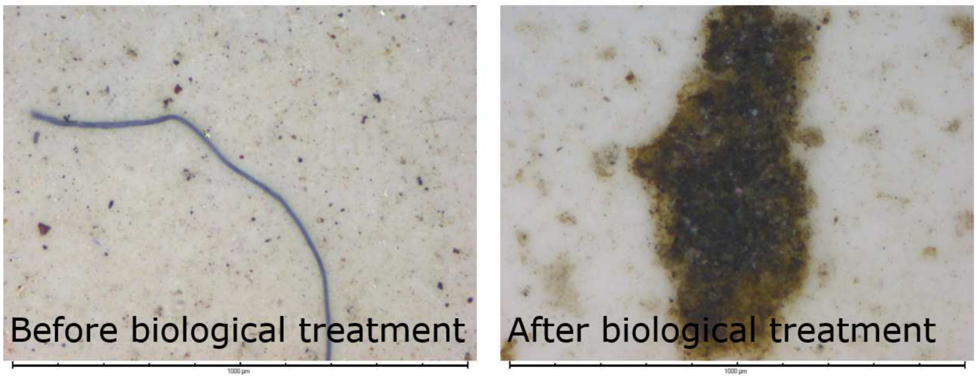

Figure 14 Microscopy images from Work wear 1 before (left) and after (right) biological waste water treatment at the laundry. The small clods before purification have clustered into larger clods after waste water treatment.

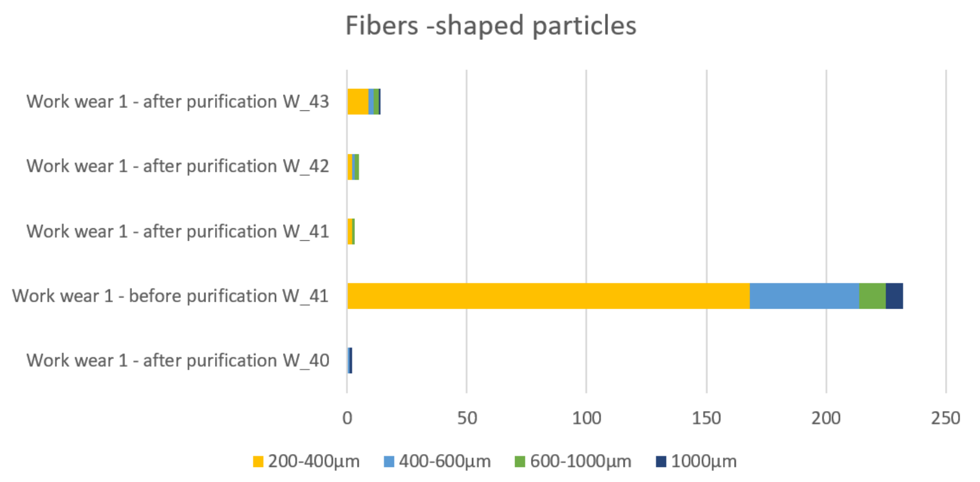

Figure 15 Fibre shaped particles from Work wear 1 between 200 – 1000 µm after waste water treatment at the laundry including week 41 (W_41) when the waste water also was analysed before waste water treatment

4.4. Chemicals assessment

Neither FTIR analysis nor material safety data sheet checks showed any content of plastic material in the detergents used. It is worth noting that the information manufacturers need to publish for professional products is not as detailed as for consumer products. Concerning the information on the safety data sheet, the requirements are the same, but for consumer products all ingredients have to be published on a website for consumer products. As the data sheet has certain concentration limits for when an ingredient has to be mentioned, this means that not all ingredients are necessarily present in a material safety data sheet.

One product was found to contain polyfluorinated compounds, according to its technical data sheet. As this product was an impregnating agent, it is not certain that it is used in all washing programmes.

It is worth mentioning that many products contain ethoxylated surfactants. These are polymeric chains but should not be viewed as microplastics, as they are readily biodegradable.

5. Conclusions

Six industrial laundries participated in the study of microplastics in their waste water. Of these two mainly washed hospital laundry, two mainly work wear, one mainly hotel laundry and one mainly mats. There is little knowledge about the release of microplastics from industrial laundries. This study provides information about the numbers of microplastic particles released.

Small particles between 5-15 µm were dominant in this study, regardless of types of textiles washed or whether the laundry had a waste water treatment facility. From the microscopic, FTIR and SEM analyses it could be concluded that microplastics were not dominant in this size range. Most of the particles (in the 5 to 15 µm range) were of other materials (for example minerals, metal fragments, silica, aluminium silicate, yeast, starch).

The release of microplastic particles varied significantly between the different laundries. If the calculations were based on the assumed best-case scenario, between 5 000 and 4 550 000 of microplastic particles were released per kg of washed textile. If a worst-case scenario was assumed, between 15 000 and 5 375 000 microplastic particles were released per kg of washed textile.

Three laundries with either chemical or biological waste water treatment adjacent to the production facilities were involved in the study. The water treatment had a significant impact on reducing the numbers of particles. The numbers of fibre-shaped particles released were reduced by 65, 96 and 97% for the different facilities. This shows that waste water treatment at the laundry can be an efficient way of reducing the levels of particles released to the WWTP.

No microplastics were found in the detergents used at the laundries. The results were supported by the assessment of the material safety data sheets of the detergents. No ingredients that could be classified as microplastics were reported in any of the data sheets.

Based on the results and the lessons learned from this study the following measures can be recommended.

- Waste water treatment facilities at the laundries can be an efficient way to mitigate the problem of microplastic release from industrial laundries at the source. This study has shown that the treatment facilities captured significant numbers of microplastics, although the treatment methods have never been optimized to target microplastics. It would be interesting to study and optimise water treatment methods for industrial laundries to see if these can reduce microplastic release.

- Removal of microplastics from waste water could be done either at the industrial laundry or at the local WWTP. Which solution is most cost efficient may vary between different locations. Therefore, it would be interesting to study different parameters which could affect the result. Such a study needs to include local conditions, e.g. other sources of microplastics in the waste water, the local recipients, spatial conditions at the laundry and the WWTP.

- The analytical method used in this study measures the microplastic particles in numbers. Another option is to measure the microplastics in weight units. It is unclear if recipients are most sensitive to the number or weight of microplastics. In a future scenario with emission limits, it is important that the limits are set in relevant units. Depending on whether numbers or weight is shown to be the most relevant parameter, it will be important to develop available and accurate characterization methods for microplastics. When analysing contaminated samples (e.g. effluents from industrial laundries) it is also important that the microplastics can be isolated from other contaminants.

6. References

6.1. Reports

ICF and Eunomia 2018, Report for the European Commission, Hann S., Sherrington C., Jamieson O., Hickman M., Kershaw P., Bapasola A., Cole G., ‘Investigating options for reducing releases in the aquatic environment of microplastics emitted by (but not intentionally added in) products’.

IVL, 2016, IVL Swedish Environmental Research Institute, Report no. C183, (Rev. March 2017), Kerstin Magnusson, Karin Eliasson, Anna Fråne, Kalle Haikonen, Johan Hultén, Mikael Olshammar, Johanna Stadmark, Anais Voisin, ‘Swedish sources and pathways for microplastics to the marine environment - A review of existing data’.

Swedish Environmental Protection Agency, 2017, Report no. 6772, ‘Mikroplaster - Redovisning av regeringsuppdrag om källor till mikroplaster och förslag på åtgärder för minskade utsläpp i Sverige’.

Swedish Environmental Protection Agency, 2018, Report, Brodin M., Norin H., Hanning A.-C., Persson C., ‘Filters for washing machines.' (Report for publication in December 2018)

Swerea IVF, 18004, Report no. 18004, Investigation of the occurrence of microplastics from the waste water at five different textile production facilities in Sweden’. (2018, Hanning A.-C. and Landin R.)

6.2. Scientific references

Carney Almroth B. M., Åström L., Roslund S., Petersson H., Johansson M., Persson N.-K., 2018, Quantifying shedding of synthetic fibres from textiles; a source of microplastics released into the environment, Environ Sci Pollut Res 25:1191–1199.

Cincinelli, A., Scopetani C., Chelazzi D., Lombardini E., Martellini T., Katsoyiannis A., Fossi M. C., Corsolini S., 2017, Microplastic in the surface waters of the Ross Sea (Antarctica): Occurrence, distribution and characterization by FTIR, Chemosphere, 175, 391-400 (Supplement C).

Di, M., Wang J., 2018, Microplastics in surface waters and sediments of the Three Gorges Reservoir, China, Science of The Total Environment, 616-617, 1620-1627.

Dümichen, E., Eisentraut P., Bennick C. G., Barthel A. K., Senz R., Braun U., 2017, Fast identification of microplastics in complex environmental samples by a thermal degradation method, Chemosphere, 174, 572-584.

Hartline N. L., Bruce N. J, Karba S. N., Ruff E. O., Sonar S. U., and Holden P. A., 2016, Microfibre Masses Recovered from Conventional Machine Washing of New or Aged Garments, Environ. Sci. Technol., 50 (21), pp 11532–11538.

Hernandez E., Nowack B., Mitrano D. M., 2017, Polyester Textiles as a Source of Microplastics from Households: A Mechanistic Study to Understand Microfibre Release During Washing, Environ. Sci. Technol. 51, 12, 7036-7046.

Li, L., Li M., Deng H., Cai L., Cai H., Yan B., Hu J., Shi H., 2018, A straightforward method for measuring the range of apparent density of microplastics, Science of The Total Environment, 639, 367-373.

Michielssen M. R., Michielssen E. R., Ni J., Duhaime M. B., 2016, Fate of microplastics and other small anthropogenic litter (SAL) in wastewater treatment plants depends on unit processes employed. Environ. Sci.: Water Res. Technol., 2, 1064-1073.

Nuelle, M.-T., Dekiff J. H., Remy D., Fries E., 2014, A new analytical approach for monitoring microplastics in marine sediments, Environmental Pollution, 184, 161-169.

Talvitie J., Heinonen M., Pääkkönen J.-P., Vahtera E., Mikola A., Setälä O., Vahala R., 2015, Do wastewater treatment plants act as a potential point source of microplastics? Preliminary study in the coastal Gulf of Finland, Baltic Sea. Water Sci Technol. 72(9):1495-504.

Talvitie J., Mikola A., Koistinen A., Setälä O., 2017, Solutions to microplastic pollution – Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Water Research, Vol. 123, pp. 401-407.

6.3. Other references

ISO 1833-11, (SS-EN ISO 1833-11:2017), 'Textiles - Quantitative chemical analysis - Part 11: Mixtures of certain cellulose fibres with certain other fibres (method using sulfuric acid)'

ISO 18413, 'Hydraulic fluid power - Cleanliness of components - Inspection document and principles related to contaminant extraction and analysis, and data reporting'

ISO 16232, ‘Road vehicles - Cleanliness of components and systems’

MERMAIDS Life+ project: Handbook for zero microplastics from textiles and laundry. http://life-mermaids.eu/en/deliverables-mermaids-life-2/ (2018-09-04).

Swedish Textile Rental Association 2018. Downloaded 10.12.2018 from: https://www.tvatteriforbundet.se/wp-content/uploads/2018/11/infographic-2018-en.png