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ENVIRONMENT AND SUSTAINABLE CHEMISTRY

Upstream mitigation of microplastics at an industrial laundry and the impact at the wastewater treatment plant

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Content

Content 1
Preface 2
Summary 4
Sammanfattning 5
1 Introduction 6
2 Rimbo wastewater treatment plant 7
2.1 Sampling 9
2.1.1 Sampling of wastewater samples at Textilia 10
2.1.2 Sampling of sludge samples at Rimbo WWTP 11
3 Pilot trial with DynaDrum 12
3.1 Background and choice of filter 12
3.2 Early laboratory tests 13
3.3 Simple cost estimation for DynaDrum filter 15
4 Pilot trial with Ultrafiltration 17
4.1 Background and choice of concept 17
4.2 Description of the method (UF ZW1500) 18
4.3 Installation, testing and challenges when running 20
4.4 Suggestions for improvement 21
4.5 Simple cost estimation for Ultrafiltration 22
5 "Hydro for laundries" 23
5.1 Description of "Hydro for laundries" 23
5.2 Simple cost estimation for HydRO 25
6 Simplifying preparation studying polyester in polycotton blends 26
7 Results 28
7.1 Preparation of wastewater samples 28
7.2 Analysis of microplastics in wastewater, abundance and mass 29
7.2.1 Abundance of microplastics in wastewater samples 29
7.2.2 Mass of microplastics per litre in wastewater samples 30
7.2.3 Analyses of TSS and BOD 31
7.2.4 Conclusions wastewater samples 33
7.3 Analysis of microplastics in sludge samples 33
7.3.1 Size distribution of sludge samples 33
7.3.2 Dry mass of polyester in sludge samples 34
7.4 Final discussions and conclusions 35
8 Questionnarie to Swedish laundries regarding microplastics 39
9 References 45
10 Appendix 46

Preface

Fibre fragments from textiles with synthetic content is regarded as one major source of microplastic (MP) emissions. Industrial laundries are point sources where the effect of upstream mitigation measures is currently discussed. The Swedish Environmental Protection Agency has stated that ”*efficient upstream mitigation work needs to be conducted through cooperation on a local level”*. The large industrial laundry (Textilia in Rimbo, Sweden) washing ca 40 tons of textiles per day, was selected due to the connection to relatively small wastewater treatment plant (WWTP).

The study included two full-scale pilot trials at Textilia in Rimbo for reducing the MP emissions to the outlet wastewater. Samples of wastewater at the laundry as well as sludge samples at the WWTP were collected and analyzed, both as amount and mass. A study visit to a laundry in Belgium was included to collect samples from the system "Hydro for Laundries" - not yet operating in the Nordic countries. A simple cost estimation is included for all three systems. A questionnaire was sent out to the members of the Swedish Laundry Association. The aim was to get an overview of the status regarding the MP issue in the Swedish textile service sector and the readiness for possible coming requirements. The answers from the questionnaire will, together with the analytical results, contribute as a part of the basis to the Swedish Environmental Agency's work to reduce MP emissions to water.

Project partners:
RISE – Research institutes of Sweden, Aalborg University, Textilia – Tvätt- och textilservice AB, Norrtälje Vatten och Avlopp, Nitoves AB, Nordic Water Products AB, Ramson AB and Christeyns AB.

Reference group:
The Swedish Textile Service Association, ”Stockholm Vatten och Avfall" and County Administrative Board of Västra Götaland.

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Summary

This project evaluated two full-scale pilots, drumfilter and ultrafiltration, for mitigating microplastics (MP) emissions to the wastewater at Textilia's industrial laundry in Rimbo, Sweden. The laundry was selected because it is providing ca 20% of the inlet organic load to the relatively small wastewater treatment plant. The contribution of synthetic fibre fragments (MPs) is to a large extent polyester. This would make the analyses of potential differences before and after mitigation measures easier. Samples from the laundry before/after filtration including sludge samples from the WWTP were analyzed. The project also included a visit to an industrial laundry in Belgium to see the concept "Hydro for laundries" (a system for recirculation of process water) in operation and to collect wastewater samples for analysis. Simple cost estimates are included for all three concepts.

The results show that the fibres and fibre fragments /particles from both wastewater and sludge predominantly are in the lower range, 10-100 µm. The filtration measures itself were effective, and the mass of synthetic fibre/fibre fragments were reduced in the range of 83% and 99,5%. However, the reduction from the laundry did not seem to have an effect on the microplastic content in the sludge. One reason can be that the 80% inlet load from households (incl laundry), restaurants etc, "drowned" the impact from the laundry.

Comparing reference samples from Rimbo WWTP to three other WWTPs in Sweden, the result show that Rimbo has a significant higher concentration of polyester. This indicates that the laundry, as a large point source of polyester, contributes to the polyester content in the sludge.

Total suspended solids (TSS) and on-line image analysis are discussed as possibilities for a simpler and cheaper way of monitoring microplastic emissions from laundries.

The project also included a questionnaire to the members of the Swedish Textile Service Association. The aim was to get an overview of the microplastics issue in the Swedish textile service sector and the readiness for possible coming EU-restrictions.

Sammanfattning

Projektet har utvärderat två fullskaliga piloter, trumfilter och ultrafiltrering, med avseende att reducera utsläpp av mikroplaster till avloppsvattnet från Textilia's industritvätt i Rimbo, Sverige. Tvätteriet valdes ut på grund av sitt bidrag på ca 20% av den organiska belastningen hos vattenreningsverket. Tvätteriets bidrag av syntetiska fiberfragment består nästan uteslutande av polyester, vilket torde göra det enklare att analysera potentiella skillnader före och efter filtrering. Prover från tvätteriet före/efter filtrering samt från reningsverkets slam analyserades. Projektet inkluderade också ett studiebesök i Belgien för att se och ta prover på "Hydro for Laundries" (ett system för recirkulering av processvatten). En enkel kostnadsberäkning finns med i rapporten för alla tre systemen.

Resultaten visar att fibrer och fiberfragment/partiklar från både avloppsvattnet och slammet huvudsakligen ligger i det lägre intervallet, 10–100 µm. Själva filtreringen i sig är effektiv, den viktmässiga reduceringen av fibrer/fiberfragment låg mellan 83% upp till 99,5 %. Dock kunde ingen reducering an mikroplaster påvisas i slammet. En orsak kan vara att de övriga 80% av den inkommande organiska belastningen från hushållen (inkl tvätt), restauranger etc "dränkte" påverkan från tvätteriet.

En jämförelse mellan tre olika vattenreningsverk i Sverige med reningsverket i Rimbo visar att Rimbo har en signifikant högre andel polyester i slammet. Detta indikerar att tvätteriet, som en stor punktkälla för mikroplaster av polyester, bidrar till innehållet av polyester i slammet.

Totalt suspenderade ämnen (TSS) och "on-line" monitorering diskuteras som möjligheter till enklare och billigare sätt att övervaka utsläpp av mikroplaster från industriella tvätterier.

I projektet ingick även en enkät till medlemmarna i Sveriges Tvätteriförbund. Syftet var att få en överblick av mikroplastfrågan inom den svenska textilservicesektorn och hur förberedd man är på eventuella kommande restriktioner på EU-nivå.

1 Introduction

Upstream filtration has been mentioned from different sources as one measure to mitigate emissions of microplastics (MPs) close to the source. The Swedish Environment Protection Agency has stated that an" *efficient upstream mitigation work needs to be conducted through cooperation on a local level*". This project completed two full-scale trials at an industrial laundry to evaluate the effect the upstream filtration has regarding mitigating MP emissions. The project investigated if the upstream removal of MPs will reduce the MP load at the wastewater treatment plant (WWTP), the amount of MPs in the sludge including and any other positive effects (TSS-Total Suspended Solids and BOD-Biological Oxygen Demand). RISE reached out to several companies working in Sweden within the filtration area and different levels of filtration. Three different concepts were included in the project, with three different levels of technology. The concepts include a drumfilter, ultrafiltration and a concept which purifies the wastewater into new process water. The practical pilot trials were conducted at Textilia's industrial laundry facility in Rimbo (Sweden) during autumn/ winter 2022. This facility was selected because the inlet organic flow load from Textilia is approximately 20 %. The laundry washes ca 40 tons of textiles per day. The main MP contribution to the wastewater is polyester fragments from washing garments with partly polyester content. This means that with a focus on polyester, it should be easier to measure and evaluate any effects from the mitigating measures. In an earlier report "Microplastics from industrial laundries[…"[1], the results showed that filtration at a laundry has a positive effect on the outlet wastewater. However, that study did not have focus on the filtration concepts – it was a first screening of occurrence of MPs from laundries.

As a complement, a questionnaire was sent out to the members in the Swedish Textile Service Association to get an overview regarding the presence of site wastewater treatment, requirements from WWTS and /or customers. Questions reading general aspects of MPs and readiness for possible coming requirements in the textile service sector in Sweden were also included.

2 Rimbo wastewater treatment plant

As many other Swedish wastewater treatment plants, Rimbo WWTP was built in the late 1960's. The treatment process consisted of mechanical treatment (screens, sand trap and a primary sedimentation tank with chemical precipitation) and a biological treatment consisting of a bio-bed with sedimentation tanks to remove biological sludge.

The recipient is Vallby creek, a small stream with its outlet in the Norrtälje bay. To protect it, an aeration- and retention pond was created to hold and oxygenize the effluent before it was released into the stream. At the time, both the WWTP and the largest contributor (Landstingstvätten, the predecessor of Textilia) had requirements set as to limit the amount of effluent discharged during times of low water flow in the creek. As the removal of nutrients was less efficient than today, they relied on dilution in the recipient to avoid causing damage to the lakes downstream.

As the years have gone by and the requirements on nutrient removal at the WWTP has increased, more treatment steps were added and the requirements to reduce effluent discharge during droughts were dropped.

Today, Rimbo wastewater treatment plant is dimensioned to treat water from 10 000 pe (pe = person equivalents). One pe is defined as 70 mg biological oxygen demand, BOD 7, per day. Plans are under way to ensure that the plant can process the maximal 13 200 pe that its permit allows.

Due to the sensitive nature and periodically low dilution in Vallby creek and the restoration of a bird lake downstream, the plant has the highest emission requirements in Norrtälje municipality.

Table 1. Emission reference and limit at Rimbo WWTP

	Organic matter BOD 7 (mg/l)	Total Phosphorus P-Tot (mg/l)	Ammonium nitrogen NH4-N (mg/l)	Total nitrogen N-Tot (mg/l)
Emission Guide Rimbo	5	0,25	3	15
Emission Limit Rimbo	5	0,25	5	-
Legislated limit values	15	-	-	15

The emission guide values for organic matter, phosphorous and total nitrogen are set per quarter and the emission limit values are set per calendar year, see Table 1. The limits on emission on ammonium nitrogen are only in effect during June to October for both guide and limit values.

Exceeding a guide value is less severe than exceeding a limit value. Exceeding a limit value will have legal ramifications and whilst guide values should not be exceeded on a regular basis, the consequences would be, for example, an order to comply.

The plant 2022-2023

Rimbo wastewater treatment plant receives water from Rimbo town and parts of the Ekebyholm area north of Rimbo. A large part of the nutrient and organic matter load comes from the Textilia laundry plant where they, among other things, receive laundry from hospitals and care facilities of Region Stockholm.

The estimated maximum load on the plant (excluding external incoming flows like septic tank sludge) is calculated to about 7 300 pe. (5 300 pe from residents and 2 000 pe from Textilia) However, the measured load rarely exceeds 5 000 pe. This attributed a large part of the population commuting out of town for work and that the load from Textilia mostly lies around 1 000 pe.

During this project the anaerobic sludge digester and the entire sludge treatment was under renovation and modernization. There was also ongoing work to improve sampling and flow measuring by separating internal flows and installing better flow measurement points. The work on improving the flow-metering and sampling did not affect the sampling setup or results in this project.

The renovations of the sludge digester turned out to be a bonus for the project. The mesophilic sludge digester at Rimbo WWTP has a retention time of about a month. Although we missed out on observing the potential effects of anaerobic digestion on the MP's, it would not have been possible to get well defined samples from the pilot trial periods if digested sludge had been used. This way we were able to get a collected sample of all sludge produced during a 4-5 day period as we sampled the dewatered sludge.

Process

The plants process starts with three inlet-pumps that lift the water from the inlet tank to the two fine step-screens that remove solids, for example rags, wipes and various hygiene products. The water is then led via an aerated sand trap where a small dosage of ferrous chloride is added to improve primary sludge removal in the following primary sedimentation tank. Here, primary removed sludge is pumped to a sludge holding tank.

Afterwards, the water proceeds into the biological treatment, which consists of a pre-denitrification MBBR (Moving bed biofilm reactor) and a bio-bed. The sloughed-off biofilm is then removed in two parallel secondary settling tanks. The sludge from these tanks is recirculated back to the inlet-tank and is ultimately removed with along the primary sludge.

The old oxygenation/retention pond sits in the middle of the process as the next step. Today it serves mainly as a retention magazine to avoid the need to bypass the sand filters at high flows.

From the pond, the water is pumped to the chemical treatment step. After dosing Ferrous Chloride, the water is led through a series of flocculation chambers to allow flocs to from. The flocs then sediment and the chemical sludge is pumped to the sludge holding tank, to be mixed with the primary sludge.

The last step is eight parallel DynaSand filters. They are continuous filtration filters and the wash-water used to clean the filtration media is led back to the inlet. Before the effluent is released to Vallby creek, it passes via a Thompson- overflow for sampling and flow metering.

Sludge treatment

As the sludge digester was undergoing renovations during the project, the sludge in this study is unstabilized. The primary sludge and the chemical sludge are homogenized in the sludge holding tank. As the mixed sludge is pumped into the screw-press, polymer is added to coagulate the sludge for dewatering process.

2.1 Sampling

In the wastewater treatment plant, samples were collected on dewatered sludge, incoming wastewater and effluent.

The incoming water and effluent were sampled with automated samplers. Samples were collected every weekday and a three-day sample were collected over the weekend. The samples were kept refrigerated during sampling and frozen for storage. After a set was collected, the samples were thawed and mixed as flow proportional week composite samples.

The weekly composite samples were conserved with 1% 4M sulphuric acid and stored refrigerated before being sent to RISE for analysis.

Some samples were missed due to technical issues (freezing, clogged or malfunctioning sampler) or human error.

Due to the design and construction limitations at the Rimbo wastewater treatment plant, there has been several factors impacting the sampling. First, all the internal flows at the treatment plant, ie sludge from the biological sedimentation, reject water containing sludge particles and polymer from the sludge dewatering and wash-water from the sandfilters end up in the incoming basin together with the incoming wastewater. Second, the regular sampling point is situated after the step-screens and contain all of these internal flows. To get better quality of the incoming sample, a temporary sampler was set up and its sampling tube was placed as close to the wastewater outlet as possible. The sampler was time-regulated and set to collect samples every 10 minutes.

As the only flow meter is placed at the outlet, the pond affects the proportionality of the incoming composite samples. The pumps from the retention pond are set to increase or decrease their flow due to the levels in the pond so you do get higher flows out as the inlet flow increases. However, there are delays and break points that can result in differences in incoming and outgoing flows.

This can affect the accuracy of the incoming weekly composite samples to a lesser extent as the outlet flows used to calculate the composite samples will be levelled out in comparison to the incoming flow values. However, the flows were comparatively even during the sampling periods so this effect would have had a very minor impact on the composition of the samples.

2.1.1 Sampling of wastewater samples at Textilia

Reference samples

The first samples at Textilia were taken in the outlet flow from the process. As a sampling point, this point had a good flow and was not affected by any flows from non-process water. An automated sampler was set up to take samples every 15 minutes. The samples were taken during working days. For sample collecting information, see Appendix 1

However, as the pilot set-ups were finalized, it became clear that it would not be possible to treat a similar flow of pure process water as the pilots required a retention volume to equalize the flow being filtered. The only option then was to accept a flow of flush-water from sand filters the process water plant. This flow was expected to contain flocs but very little plastic fibre compared to the outgoing process water from the laundry.

Nordic Water DynaDrum pilot

The samples were taken at the inlet and outlet of the DynaDrum-filter. Samples were taken 15 minutes apart by time-regulated automated samplers. The samples were taken during working days.

A sample from incoming water and filtrated water and reject was sent for analysis for suspended solids. The reject water was sampled directly from a holding tank while the other samples were taken from the regular daily samples. For sample collecting information, see Appendix 1

Ramson Ultrafiltration pilot

The pre filtration samples were collected from the retention volume as close to the filtration systems inlet pump as possible. The post filtration samples were collected from a holding tank. Samples were taken 15 minutes apart by time-regulated automated samplers. The samples were taken during working days.

The samples from the pilot runs were collected over three weeks, with the ultra-filtration trial being cut slightly short due to a handling incident causing technical issues. For sample collecting information, see Appendix 1.

2.1.2 Sampling of sludge samples at Rimbo WWTP

As the anaerobic digester on site was undergoing renovations, we did not have an opportunity to take out digested sludge samples for analysis. The positive side of this was that the retention time in the digester is several weeks and we would not have been able to produce discrete digested sludge samples from each pilot trial in our timeframe.

Since the primary sludge and chemical sludge is pumped directly to the sludge holding tank, we could make sure that the sludge holding tank was emptied a few days after a pilot was started. This was done to make sure that any sludge left from before the pilot run would have been pumped to the holding tank. As the tank was re-filled over a few days, it contained sludge collected only during the pilot timeframe and as the dewaterer was started, samples were collected for analysis by Aalborg University. A sample was collected over the course of about 5 minutes, with several composites taken during the sampling time. The samples were kept frozen before shipping. For sample collecting information, see Appendix 1.

3 Pilot trial with DynaDrum

3.1 Background and choice of filter

The DynaDrum filter (see Figure 1) from Nordic Water Products is an automatic self-cleaning microscreen filter designed for removal of suspended solids. It consists of several filter panels attached to a drum. The filter panel is a grid structure with the filter cloth attached. Filtration opening size range from ten micron to several hundred microns, but a size between 10-300 µm is generally used.

Figure 1 DynaDrum filter

The DynaDrum TDD804 is equipped with a tank for freestanding installation. The drum is rotated by a worm gear motor via a plastic chain driving on the periphery of the drum. Reject back wash water is collected in a back wash trough inside the drum and discharged through the centre shaft (see Figure 1 DynaDrum filter).

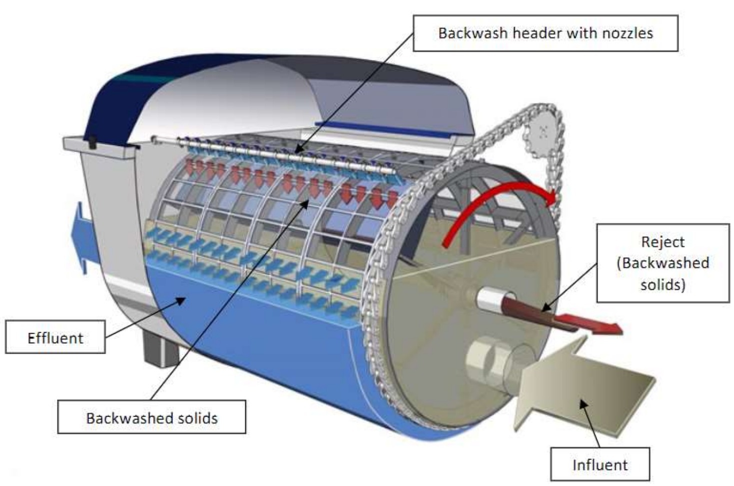


Figure 2 Working principles of the drum filter. Incoming water (gray), reject (brown) and clean water (blue).

The filter has a complete back wash system with pump, piping and spray assembly (see Figure 3).

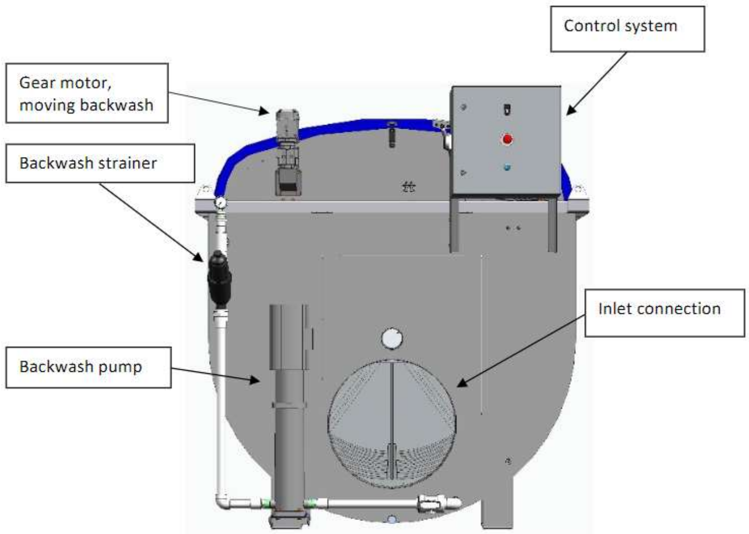


Figure 3 The inlet side of DynaDrum

Incoming water is fed to the filter from the inlet end of the filter rotor and passes by gravity through the filter media of the discs. Suspended solids are separated and accumulated on the filter cloth at the inside of the drum. When the water level inside the filter rotor increases to a pre-set point the filter rotor starts rotating and the back-wash of the filter media starts. The backwash removes the accumulated suspended solids into the reject flume inside the filter. The suspended solids are then discharged via the reject pipe.

The drum is submerged to approximately 65% on the inside of rotor and 50% on the outside. The water level on the outside (filtrate side) is kept by a level weir. Filtrate is used for backwashing by a high-pressure pump and pumped into the backwash header and is then distributed to the spray nozzles.

The filter is designed and manufactured to remove suspended solids from non-pressurized water. The filter is not a pressured vessel. There must be an external bypass; emergency overflow weir or a bypass with a penstock, that bypasses the inlet water in case the alarm signals that the water level is too high inside the drum.

3.2 Early laboratory tests

The aim of the pilot study was to determine if there are possibilities to reduce MPs from the wastewater from the laundry site Textilia, Rimbo. During 2018 samples (see Figure 4) were taken from the wastewater at the Textilia site in Rimbo, and Nordic Water made the first filtering- and capacity test without chemical dosing.

Figure 4 Samples of wastewater from Textilia-Rimbo in 2018

The analytical results showed a significant reduction of micro plastics and fibres at the cloth size 40 µm and lower. The reduction of both suspended material and micro plastics was as predicted largest at a filtering through 10 µm, however the surface loading rate was significantly lower at 10 µm than 40 µm. Because the size of the machine is directly proportional to the flow and to the surface loading rate, it implies that with a low surface loading rate a larger machine is required for the same flow. This is often not an economical and space efficient installation. After the lab scale tests Nordic Water decided that adequate reduction is achieved with 40 µm cloth.

At 40 µm, the lab tests achieved at Nordic Water, a reduction of suspended solids of 82% (see Figure 5) and the reduction of MPs was approximately 55%.

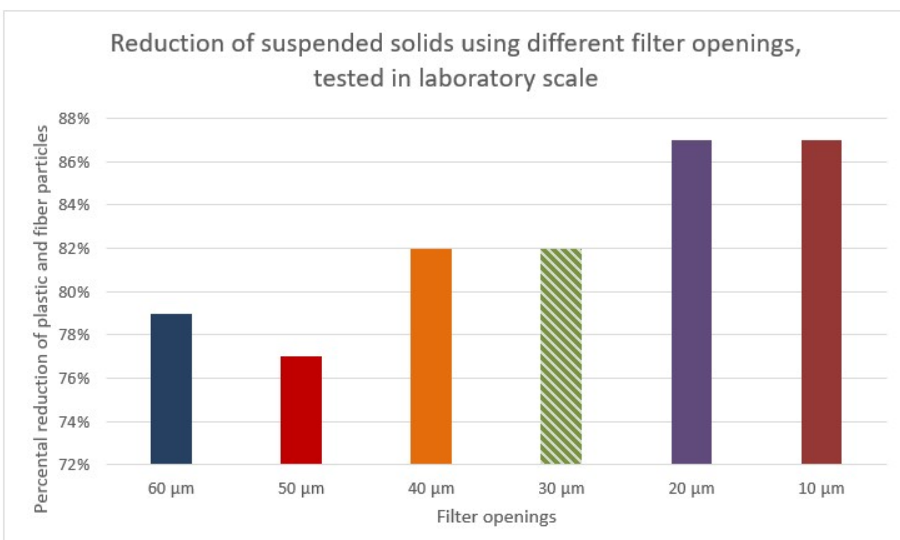


Figure 5 Reduction of suspended material at test with different cloth sizes in lab scale at Nordic Water.

Figure 6 DynaDrum installed at Textilia

During the pilot trial the reject was pumped into a container and a sludge truck regularly transported the content to Norrtälje WWTP.

Other possibilities to treat the reject include:

1. The reject can return to the inlet of the wastewater treatment to be treated again.

2. The reject can be pumped to a sedimentation tank where the particles can settle, the sludge can be removed, and the water can be returned into the wastewater treatment process. The sludge can be incinerated to extract energy, with high-grade purification of air pollution and the ash must be handled in a safe way.

3. Dewater the reject in a filter press machine.

3.3 Simple cost estimation for DynaDrum filter

Estimated operational cost (OpEx) including investment cost for full-scale operation:

For flows between 25 m³/day - 50 m³/day:
A typical solution costs between 530 EUR - 1060 EUR /m³.

For flows between 100 m³/day - 150 m³/day:
A typical solution costs between 200 EUR - 300 EUR /m³.

Installation of one drum filter machine can be completed in two working days, by an electrician and two service engineers.

Lifespan of a DynaDrum is 15-20 years with appropriate service, maintenance and spare parts.

Approximate Energy requirements
Installed power
Drive motor**:** 0,25 kW
Drive motor backwash**:** 0,12 kW
Pump motor**:** 1,1 kW
The pumps and motors are operating approximately 20-100% of the time.

4 Pilot trial with Ultrafiltration

4.1 Background and choice of concept

Laundries use a large portion of water in their processes. The water gets in contact with washing chemicals and all type of materials that are used for clothes and bed sheets.

During the wash process the clothes and sheets are being worn and the parts that are worn off is basically fibres. Together with the ”dirt” from the materials and residuals of cleaning chemicals it is a pretty tough contaminated water. Most of the released particles are fibres (both synthetic and natural fibres) which end up in the municipal wastewater plant. A conventional water treatment plant is not designed to remove MPs, yet functions relatively well for the purpose of removing MPs from the water. However, the MPs will end up in the sludge instead. As a significant part of the Swedish sludge production is used as soil products or as fertilizer, the MPs in the sludge risk being released back into the ecosystem.

Ramson sent a filter technologist to site at Rimbo to make some tests in order to evaluate the best method for removing MPs before leaving the laundry premises as wastewater, i.e. to stop the MPs from reaching the municipal wastewater plant.

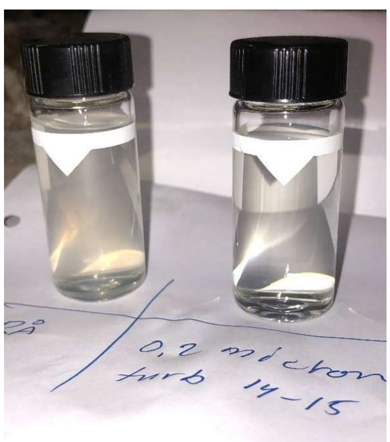


Figure 7 Rimbo test filtration. Left: raw water, Right: filtrated down to 0.2 micron (date 220623)

A large portion of the contamination of the water is fibres. The key is to choose a filtration grade much lower than the smallest diameter of the fibres. This is to avoid the fibre to enter the filtermedia and eventually clog the filter. As a conclusion to this UF filtration was suggested and especially out to in with backflush via air due to the high level of contaminates in the water. Filtration grade for UF is between 0.02-0.04 micron.

4.2 Description of the method (UF ZW1500)

Chosen method: Hollow fibre in PVDF (polyvinylidene fluoride) with a pore size of 0.02 micron. Every fibre has an outer diameter of 1.2 (mm) and an inside diameter of 0.8 (mm). The filter is always standing up and every module (filter unit) has about 20 000 fibres per module. The fibres are fixed in the top of the module and bottom of the module (casted PUR=polyurethane). Every module has about 50 m^2 filter area. The velocity range is 1-3 m^3/hr per module depending on the incoming water quality. Filtration type is “dead end”, but due to backwash and CIP (Clean-In Place) the overall recovery normally ends up at approximately 85 %. For every 100 l in feed there will be 85 l clean water and 15 l concentrate to be discharged. The backwash is normally done with the clean water from the system and has a periodicity of every 20 to 60 minutes. Chemical cleaning of the membranes is done once a day and once a month in general.

Figure 8 Left: filtration outside and Right: One filtermodule ZW1500

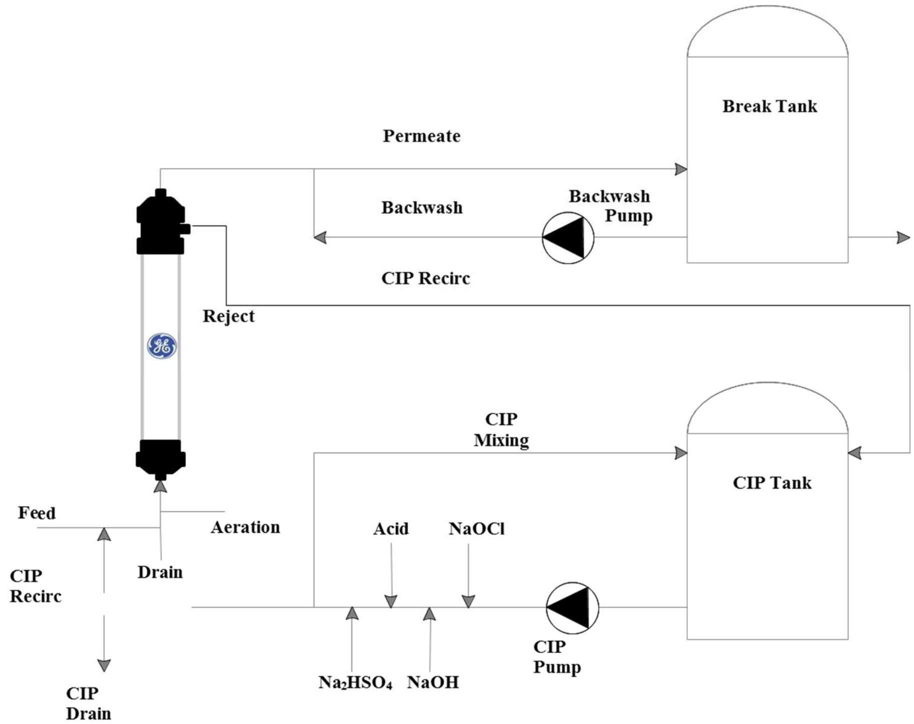


Figure 9 UF process description

Note that the installation at Rimbo included a bypass option so, for any reason, the flow could not reach demanded flow from the laundry the operators could switch to bypass.

Figure 10 Pictures from the installation. Left: UF unit arriving at Rimbo 25/11-2022, In the middle: Water treatment house outside, Right: UF installed at site ready to go.

4.3 Installation, testing and challenges when running

The complete UF-unit was tested in Ramson's workshop to verify all process parameters. A challenge regarding this was that the viscosity/amount of particles and the pumps possibility to lift the water was not the same. In the workshop the velocity could easily get up to 13 m^3/hr, but in real life the velocity could not get up to more than approximately 10 m^3/hr (lower limit for production). With a little luck this was managed during the whole pilot trial. The unit called "Bror 1" did not make any attempts to stop or make any troubles during the period.

The conclusion is that "process wise" UF is an excellent solution for the actual water. Recovery after every backwash and CIP was completely according to the book. The unit was connected to the internet and personnel from Ramson monitored the process during the complete pilot test. No errors or complaints came from "Bror 1". The actual pilot test was running between 25/11 to 19/12-2023. During the test Ramson did not detect a turbidity over 0.4 NTU (Nephelometric Turbidity Units) in the filtrate at any time. As a reference, drinking water limit is 0.5 NTU. The conclusion was that most of the particles were removed from the water.

Figure 11 Left: process unit during test before delivery, Right: water samples from left to right - raw/filtrate/reject

During the pilot trial the reject was pumped into a container and a sludge truck regularly transported the content to Norrtälje WWTP.

4.4 Suggestions for improvement

1. Looking at the filtrate water quality from UF and the fact that UF has a filtration grade of about 200 000 Dalton and that surfactants are about 350 Dalton: there is a large potential in recirculate the UF filtrate into the laundry. Considering that most processes overdose there is most likely a gain in reduction of dosing in the laundry. The water that Ramson treated was also "hot" so the energy profit by not having to heat raw water will also be an advantage. Recirculation reduces incoming already treated water.

2. Pretreatment before UF. Ramson's experience is that filtration is done in steps to prevent too much maintenance and failure per step. Pre-treatment is strongly suggested in this case. The solution is a belt filter "dead end" and non-pressurized, see Figure 12. The belt (Cloth) is disposable and treated as waste,

3. Input regarding optimization and minimizing reject:

    a) Belt (Cloth) filtration in first stage.
    b) Coagulation and sedimentation. (Perform a Jar-test)
    c) Overflow drain from b) recirculated to UF.

Figure 12 Left: Full scale cloth/fleece filter Right: Ramson pilot-scale cloth/fleece filter

4.5 Simple cost estimation for Ultrafiltration

Investment estimation

1. Complete UF unit 13 m^3/h installed in Rimbo: 260 000-300 000 EUR.
   Size: Will fit in 20 (m) x 4 (m)
2. Belt-filtration (Cloth): 80 000-100 000 EUR.

Estimated operational cost (OpEx):
1. Electricity: 32 A (cost is varying depending on electricity area so you need to calculate)
2. Chemicals: approximately 15 000 EUR/year.
3. Maintenance: Pumps, valves, gauges, modules etc: approximately 15 000 EUR/year.

Estimation leasing alternative

Leasing for UF includes equipment cost and prefiltration (Belt-filtration), chemicals and maintenance. Base scenario of 3 years and an approximate flow of 1 000 000 m^3: Estimated costs and savings at optimized conditions can almost become a zero-sum game of circa 2 Euro/m^3.

Following aspects will have big impact of the total cost and should be optimized:
- Energy (possible preheat incoming water)
- Water (recycling)
- Cleaning chemicals (recycling)
- Destruction of reject water (to be minimized, band filter…)
- Civil work costs (cost for housing constructions etc depending on the facility)

Cost of electricity will also have an impact.

5 “Hydro for laundries”

5.1 Description of “Hydro for laundries”

Hydro for laundries (HydRO) from Christyens is a system that reportedly recirculates the process water up to at least 80%. No system would be operating in either of the Nordic countries during the duration of the project and it was not feasable to test the system in a time-limited full-scale pilot. Therefore, Christeyns facilitated a visit for RISE and Textilia at CLOVA laundry in Wommelgem, Belgium during October 2022.

CLOVA is a healthcare laundry just like Textilia in Rimbo. They have two production units:
CLOVA 1: 140 tons/week: flat linen & workwear (nurses)
CLOVA 2: 15 tons/week: personal clothing from elderly people

HydRO was installed in 2017 and was expanded 2021 due to increase in volume. According to measurements by Christeyns, the freshwater consumption was reduced with ca 87 % after installing HydRO, see Table 2.

Table 2 Freshwater consumption before and after HydRO

CLOVA	Average freshwater consumption, l/kg
Before HydRO	6,4
After HydRO	0,81*

*rainwater not included

The process is a 2-step treatment system: (see Figure 13)
1 step: membrane bioreactor (MBR) = ultrafiltration combined with a biology
2 step: reversed osmosis

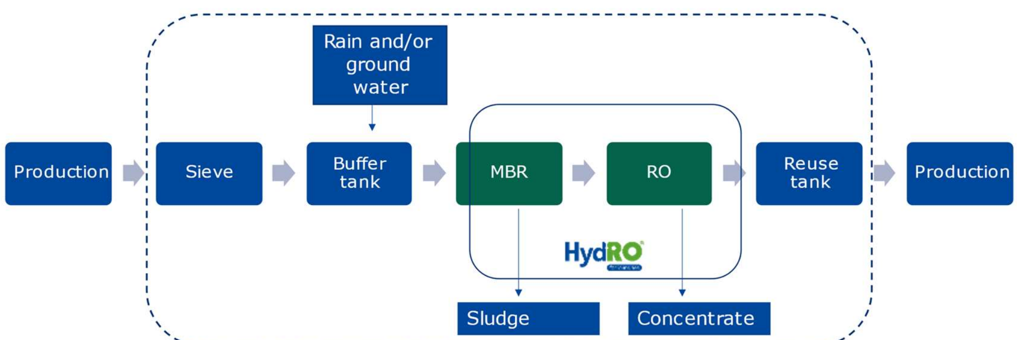


Figure 13 Schematic diagram of "Hydro for Laundries”

Figure 14 The HydRO -system outside the CLOVA laundry

From left to right in Figure 15: The concrete tank is the wastewater tank, the “open” container is the membrane bioreactor, the other container is the reverse osmosis and the black tank is the sludge tank. Inside the building there is also a freshwater tank.

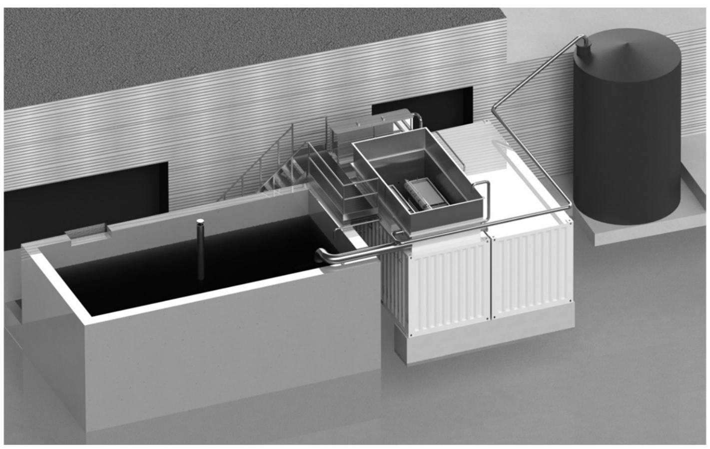


Figure 15 Schematic picture of the HydRO -system

Figure 16 Left bottle: 2. Filtrate water after membrane bioreactor step. Right bottle: 1. Dirty process water

5.2 Simple cost estimation for HydRO

Operational cost (OPEX)

Everything depends on the local situation: what is the cost of electricity, local sludge treatment, incoming freshwater cost, wastewater cost, does the laundry already have buffer tanks (clean and wastewater), availability of rainwater. This makes it hard to give a simple cost calculation.
One can say that the average cost to produce 1 m^3 of HydRO water is 0,5 EUR/m^3 to 1,5 EUR/m^3. Figure 17 shows an overview of the operational cost.

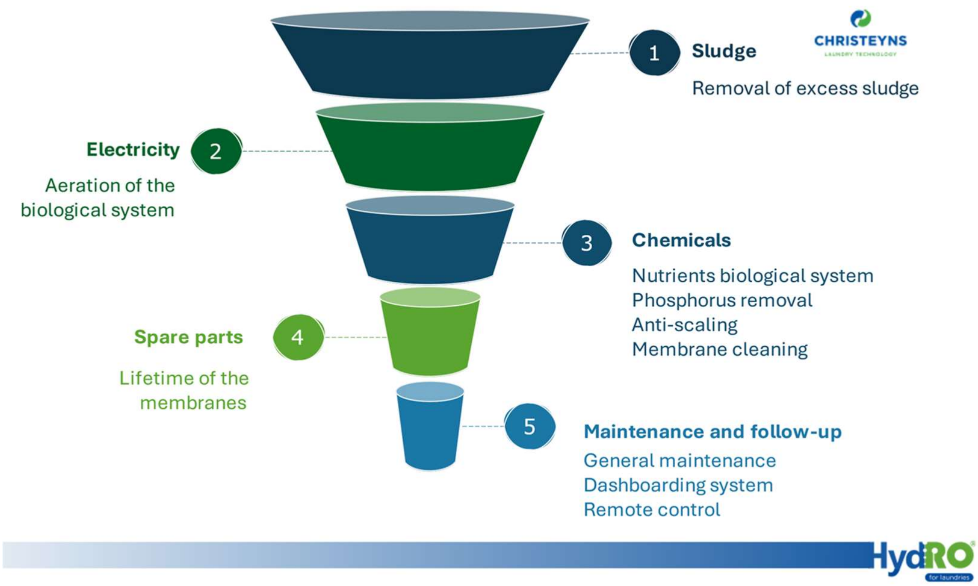


Figure 17 Overview of operational cost for HydRO

1. Sludge: depending on the incoming COD

2. Electrical consumption: RO = 1 kWh/m^3, MBR 2,5 – 3,5 kWh/m^3, depending on the incoming COD and wastewater volume.

3. Chemicals: RO = ca. 0,35 EUR/m^3 and MBR = ca. 0,05 -0,10 EUR/m^3

4. Membranes, lifetime MBR 8-10 years

Comments regarding capital expenditure (CapEx)
Depending on local situation, the need of civil works costs (for example building of the concrete tanks, foundation etc) variate a lot.

In general, a biological volume equivalent to one day's capacity and a sludge buffer tank is needed.

Depending on the local situation, there might be a need for extra buffer tanks for wastewater collection and cleanwater storage.

6 Simplifying preparation studying polyester in polycotton blends

The project included a small study to see if there could be a simple way to dye white polyester fibres to be able to assess the fibres quantitatively in a light microscope instead of a more sophisticated equipment such as FT-IR/SEM/Raman.
Neocarmin MS is a liquid dyestuff reportedly colouring cotton to blue colour and polyester to purple colour. Unfortunately, the contrast between the fibres and the white filter was still too weak for the microscope to reliably distinguish between the fibre fragments at the required level. This leads to excessive manual work which was supposed to be avoided. However, it could be stated that the filtration in general seems to work since there is a big difference between the total amount of fibres of the in- and outlet wastewater of the two filtration systems, see Figure 18.

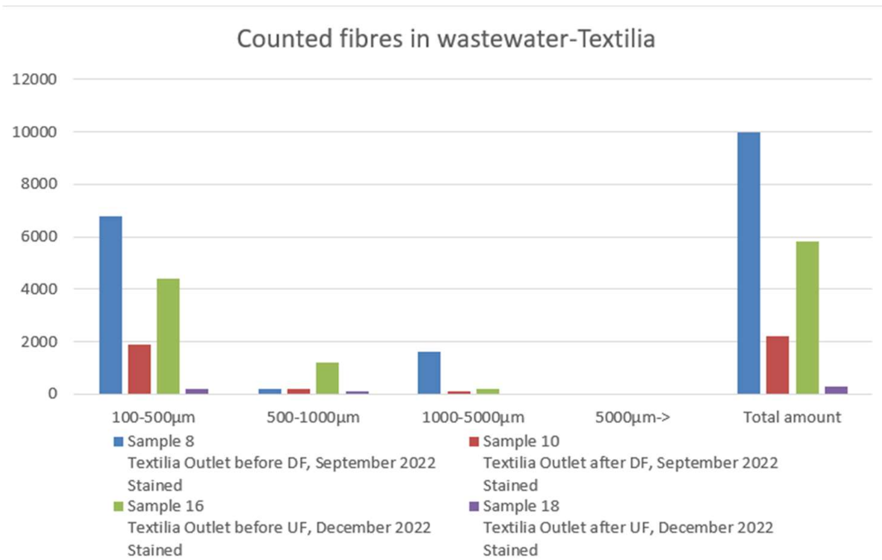


Figure 18 Amount of fibres per litre before and after DF (DynaDrum-filter) and UF (Ultrafiltration).

Nyli Metrology AB has developed a black filter to enhance the possibility to analyze white/light/ transparent fibres. But so far, it is still not black enough to provide a good enough contrast between light fibres and filter to significantly reduce the manual work.

RISE also tried to separate the polyester fraction from the cellulosic fraction by dissolving the latter with sulfuric acid. Dissolving cellulose with sulfuric acid is a well-known method when evaluating binary blends of polyester/cotton fabrics - and in this project the focus is on polyester. RISE have some earlier experience with this method and wanted to further explore this as a "fast-track" option when just looking at polyester, this time with higher requirements than “screening”. The idea was to use sulfuric acid to dissolve the cellulosic fraction (and hopefully al lot of the other solid matter), filter the wastewater, dry the remaining filtrate and weigh the sample with a microbalance.

First hydrogen peroxide was used to kill the bacteria in the sample and then sulfuric acid was used to dissolve the other fractions. The challenge was that wastewater samples are more complicated than a polycotton fabric. There are proteins, fatty substances and other solids that also needs to be removed. These solids proved not to be effectively removed with sulfuric acid, even when just focusing on polyester.

7 Results

The analyses were performed at Aalborg University in Denmark during the period January to May 2023.

7.1 Preparation of wastewater samples

The samples were analyzed for MPs in the size range of 10-5000 µm. The 10-500 µm particles were analyzed by µFT-IR hyperspectral image, while the MPs >500µm were analyzed by ATR-FTIR. See Appendix 2 for more details.

Size distribution image for wastewater

The larger the dots the higher the weight (Figure 19 and 20). More detailed information from the wastewater analyses, see Appendix 4.

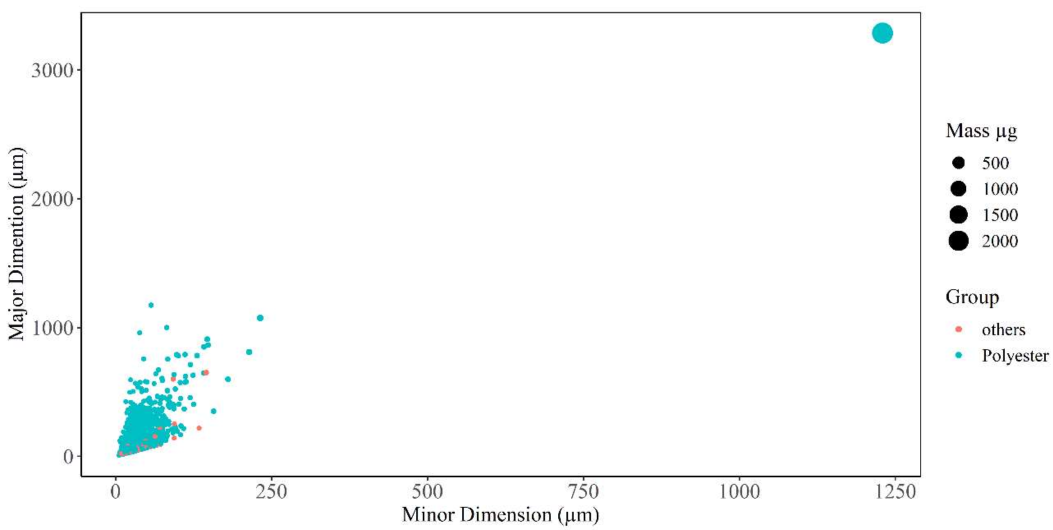


Figure 19 Bubble plot of minor vs major dimension of all detected MPs in waste- water sample

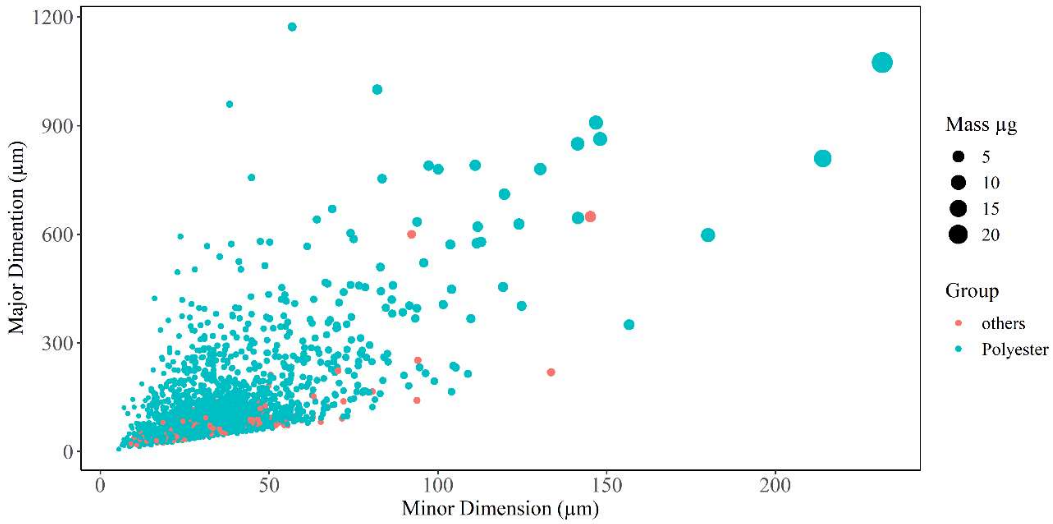


Figure 20 Bubble plot of minor vs major dimension of MPs (minor dimension) smaller than 300 µm in wastewater samples.

7.2 Analysis of microplastics in wastewater, abundance and mass

Both the abundance and the mass of the microplastics (i.e. fibre fragments) were calculated. Since the laundry is mainly contributing with polyester the other fibre fragments are counted together as "other fibres" in the tables below. More information from the wastewater analysis, see Appendix 4.

7.2.1 Abundance of microplastics in wastewater samples

For filtration with DynaDrum the reduction is between 68% - 78% for polyester compared to 65% -77% if other fibres are included, see Table 3. For UF-filtration there is no difference (see Table 4) and the reduction is very close to 100%.

The number of fibres before DynaDrum filtration in week 41 (see Table 3) is very high. The reduction of 78% and 77% respectively should therefore be considered with some caution. Especially since there are only four wastewater values from "before filtration" included in this study.

Table 3 Number of fibres per litre before/after filtration with DynaDrum

DynaDrum, counts L^{-1}	Polyester	Other fibres	Sum	Reduction of polyester	Reduction of all fibres
Week 40 - before filtration	2010	144	2154		
Week 40 - after filtration	642	100	742	68%	65%
Week 41 - before filtration	14039	373	14412		
Week 41 - after filtration	3026	335	3362	78%	77%

Table 4 Number of fibres per litre before/after filtration with UF

UF-filtration, counts L^{-1}	Polyester	Other fibres	Sum	Reduction of polyester	Reduction of all fibres
Week 49 - before filtration	5485	235	5721		
Week 49 - after filtration	29	14	42	99%	99%
Week 50 - before filtration	1667	333	2000		
Week 50 - after filtration	34	14	48	98%	98%

7.2.2 Mass of microplastics per litre in wastewater samples

Regarding the gravimetric analysis the reduction of MP mass with DynaDum is between 83%- 96%, see Table 5. The same caution as for the calculation of numbers for week 41 is also valid when calculating the mass, i.e. 96% reduction seems very high. UF show consistent results of reduction of MP mass at a level of <99,5% or more, see Table 6. A general caveat for the presented MP masses is that the masses are estimated from the 2-dimensional image of an MP. This is known to introduce quite significant uncertainty, especially for larger particles. In other words, a few large MPs in a sample can dominate the mass estimated of the sample.

Table 5 Mass of fibres per litre before/after filtration with DynaDrum

DynaDrum, µg L^{-1}	Polyester	Other fibres	Sum	Reduction of mass - polyester	Reduction of mass - all fibres
Week 40 - before filtration	285,00	5,08	290,09		
Week 40 - after filtration	37,33	11,20	48,54	87%	83%
Week 41 - before filtration	18258,47	6,11	18 264,58		
Week 41 - after filtration	608,36	19,8	628,16	96%	96%

Table 6 Mass of fibres per litre before/after filtration with UF

UF-filtration, µg L^{-1}	Polyester	Other fibres	Sum	Reduction of mass - polyester	Reduction of mass - all fibres
Week 49 - before filtration	1147,33	20,04	1 167,37		
Week 49 - after filtration	2,83	0,79	3,62	99,8%	99,7%
Week 50 - before filtration	419,79	41,79	461,58		
Week 50 - after filtration	1,68	0,39	2,07	99,6%	99,5%

7.2.3 Analyses of TSS and BOD

Samples from DynaDrum, UF and "Hydro for Laundries" at CLOVA were sent to SGS for analysis of TSS (Total Suspended Solids) and BOD (Biological Oxygen Demand). Since RISE and Textilia visited CLOVA for one day, no weekly composite sample could be collected. Instead, two samples from the day of the visit (before and after filtration) were collected. The samples were put in a fridge and shipped to Sweden in a cool bag the day after. At arrival in Sweden, the samples were stored frozen and shipped to SGS at a later occasion. Unfortunately, the samples from the DynaDrum-filter proved to be corrupted and were excluded from the study.

"Hydro for laundries" and Ultrafiltration both show very low content of TSS after filtration. The weekly composite samples collected before the filtration at Rimbo are also relatively low. They are likely to be influenced by sedimentation in the equalization tank, and possible also from an inlet flow from flushing the sandfilters. This could explain the relatively low TSS-values before filtration. Note that the reference TSS-values are also relatively low. The sample before filtration at CLOVA that was collected directly from the production, has a much higher TSS-value. It was also noted that the samples before and after filtration for UF did not visually look very different regarding turbidity which indicates low TSS-values.

The BOD value is not anticipated to be much affected if there is a lot of dissolved surfactants in the sample. A high content of surfactants was noted by Ramson when running the UF-pilot (see comment in section 4.4).

Table 7 Result TSS and BOD

Wastewater samples	TSS, mg L^{-1}	BOD, mg L^{-1}
CLOVA		
11th of Oct - before filtration	680	120
11th of Oct - after filtration	<2	<3
Ultrafiltration		
Week 49 - before filtration	34	280
Week 49 - after filtration	<2	250
Week 50 - before filtration	53	-
Week50 – after filtration	2,7	-
Reference at Rimbo		
Week 8 - no filtration	92	480
Week 20 - no filtration	79	260

RISE analysed the CLOVA samples in a light microscope with software designed to analyse fibres (Nikon Eclipse LV150, software ParticleView 4.2). Note that to be defined as a fibre the ratio diameter/length is always set to be 1:10 in this system. The latest definition is ratio 1:3 for synthetic fibres [2] which is used for the other analyses in this report performed by Aalborg University. As Figure 21 show, HydRO have a very high reduction rate. Reported as a percentage the reduction is ca 99.6% in the sample from the 11th of October 2022.

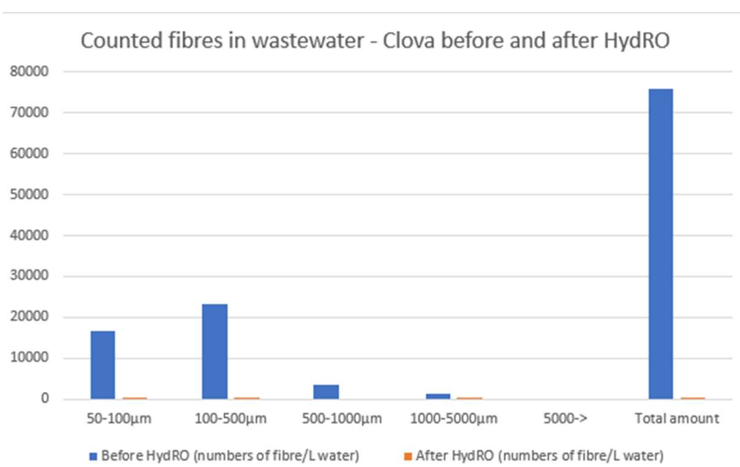


Figure 21 Number of fibres per litre before and after HydRO at CLOVA

7.2.4 Conclusions wastewater samples

The reduction of polyester and the reduction of "all fibres" have weekly almost the same value, i.e. does not significantly affect the percentages of reduction. The result show that a very high reduction of MPs can be achieved with Ultrafiltration, almost 100% of both the amount and the mass were retrieved.

Filtration with DynaDrum also have the capacity to catch a relatively large part of MPs. In this study DynaDrum captured between 68% - 78% of the amount and 87% - 96% of the mass of polyester (taking some caution with the result of 96%). However, the counts per litre show that the DynaDrum does let some MPs through even though the mass analysis show a high reduction percentage. Also note the very high number of polyester fibres in week 41. One theory is that there were a number of large and long fibres in the wastewater that week which influences the weight more than the number of fibres. One example can be mechanical degradation of larger cloths pieces or non-woven towels. Also note the general caveat for the presented MPs masses stated in section 7.2.1.

The TSS result from the HydRO-system showed a very low content of TSS with values below 2-3 mg/l after filtration. This also indicates a low content of MPs which was verified with light microscopy at RISE, see Figure 21. This system captured almost all the fibre fragments/MPs in the analysed sample.

Textilia laundry facility contributes with about 20% of the inlet organic load to Rimbo WWTP. Especially when looking at the UF-pilot, will reducing a large point source polluter of MPs almost to "nil" have an effect on the MP content in the sludge during the same period?

7.3 Analysis of microplastics in sludge samples

The preparation of the sludge samples followed a well-established method, see Appendix 2.

7.3.1 Size distribution of sludge samples

The larger the dots the higher the weight (Figure 22 and 23). The sludge samples show the same trend as the water samples, the majority of the MPs are in the lower dimensions.

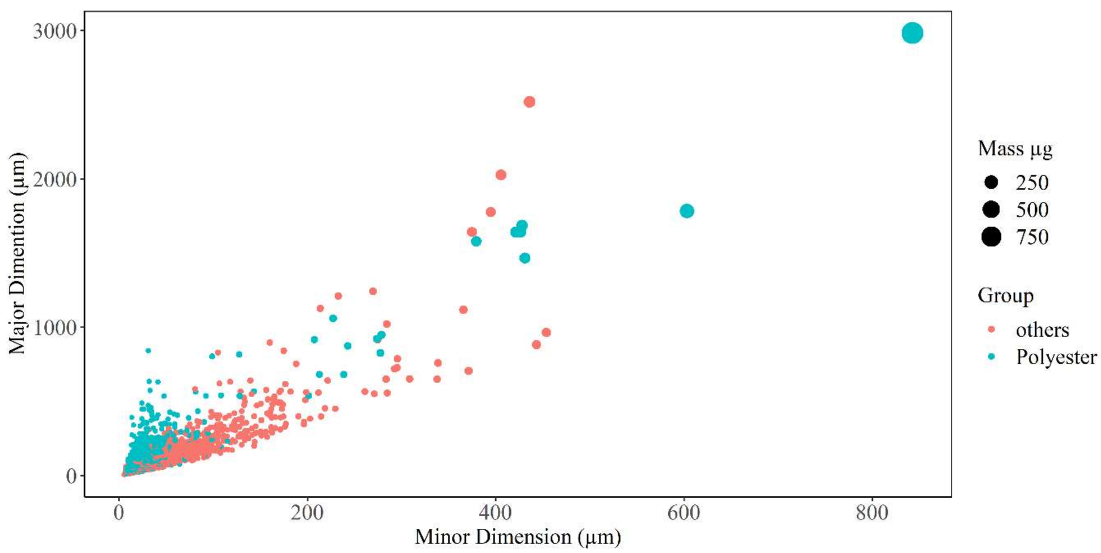


Figure 22 Bubble plot of minor vs major dimension of all detected MPs in sludge.

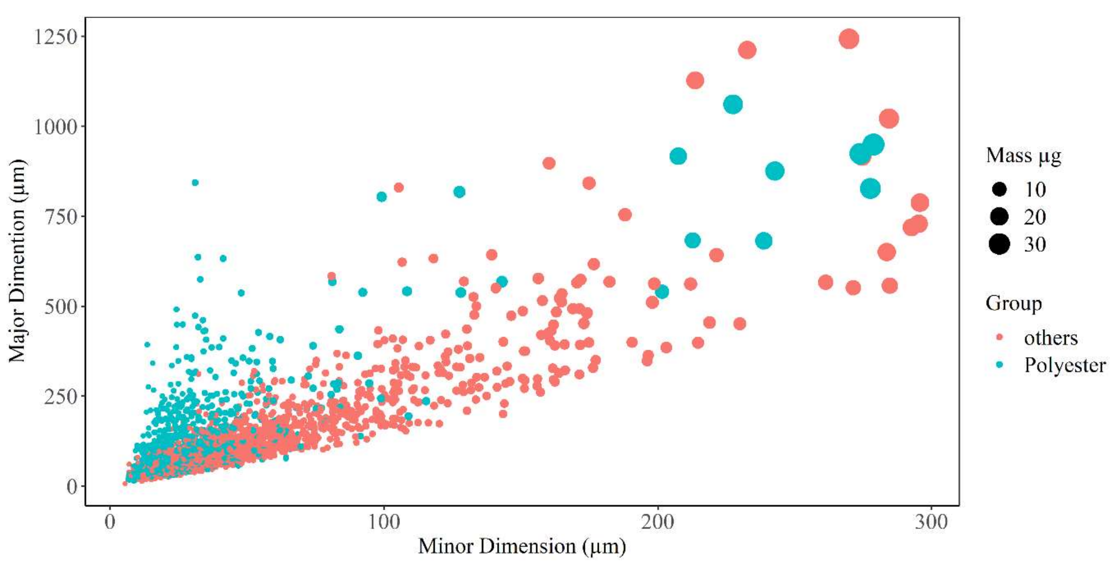


Figure 23 Bubble plot of minor vs major dimension of MPs (minor dimension) smaller than 300 µm in sludge

7.3.2 Dry mass of polyester in sludge samples

The result is highly fluctuating within the two samples from the same pilot and also between the two pilots and the references samples., see Table 8.
The UF pilot show the highest content of microplastics and the references, without any mitigating measures at all, show the lowest content. This was not anticipated. It is a fact that during week 49 and 50 the contribution from the laundry was reduced to almost

“nil”. It seems that removing a relatively large point source from the equation, in this case 20% of the inlet organic load, does not have an visible effect on microplastics content in the sludge. The other 80% of the inlet organic load coming from households, restaurants etc appears to take over completely. For more detailed information per fibre, see Appendix 5.

Table 8 µg/g dry weight for polyester in sludge

Polyester, µg/g dry weight	Week 24	Week 26
Reference	45	538
	Week 40	Week 41
DynaDrum	1 216	433
	Week 49	Week 50
UF	9 445	15 196

Aalborg University compared the content of polyester, polyethylene and polypropylene with measurements at other Swedish WWTPs, see Table 9. The strong overweight towards polyester in Rimbo WWTP sludge indicates that the discharge from the laundry has affected its polymer composition, i.e. the laundry has contributed significantly to the amount of MPs in Rimbo sludge.

Table 9 Percentage of fibres at four different WWTPs in Sweden

Fibre	Rimbo, Norrtälje	Sjölunda, Malmö	Gryaab, Göteborg	Käppala, Stockholm
Polyester	66%	40%	39%	35%
Polyethylene	20%	8%	46%	18%
Polypropylene	6%	11%	4,6%	5,8%

7.4 Final discussions and conclusions

Analysis of the wastewater show that UF-filtration can reduce the MPs in the outlet sewage close to 100%. This is also the case for the HydRO -system. Using a DynaDrum can reduce the MP emissions to relatively high level. The filter has a pore size of 40 µm (micron) which means that MP fibre fragments smaller than this diameter have the possibility to pass the filter. This influences the ability of the filter to retrieve smaller MP fibre fragments.

All three filtration systems need to have a solution for managing the reject. To evaluate different solutions regarding the reject was not included in this project. The chosen solution in this project was to store the reject in two containers and regularly transport it to another nearby WWTP by a sludge truck.

The hypothesis was that the laundry contributes enough to see a difference in content of MPs the sludge when installing an upstream filtration. But results from neither the DynaDrum -filter nor Ultrafiltration showed any reduction of the MPs in the sludge in this study. Although one cannot be completely sure since the laundry only contributes with approximately 20% of the inlet organic load to the WWTP. A reasonable explanation is that the other 80% from households (including washing), restaurants etc, contributes much more than anticipated when the pilots were running. Also, the references were not collected during the same period as when the pilots were running. Since the results are very fluctuating, even within the pilot trials, more samples are needed to get better statistics. This was not possible in this study due to limit of time.

Nevertheless, the result from the wastewater analyses shows that the upstream filtration itself works. The reduction of mass of total synthetic fibre fragment content (MPs) was at least ca 99,5% for Ultrafiltration and at least ca 83% for the DynaDrum-filter in this study.

A complementary comparison of sludge samples was performed. The sludge samples from Rimbo WWTP were compared to three other WWTPs in Sweden. This comparison showed that Rimbo WWTP has a higher concentration of polyester in the sludge compared to all the other three WWTPs. This indicates that the laundry does contribute significantly to the polyester content in the sludge.

The focus in this project is on upstream measures. This in order to catch the MPs as early as possible before they get even more fragmented. To get an overall reduction of MPs, not only large point sources need to reduce their contribution of MPs. It is equally important to handle and reduce other diffuse sources (households, stormwater etc) as well.

From a wastewater point of view, MPs are a relatively new pollutant to consider. Studies have been done primarily by the larger WWTPs and indicate that fibres are a significant part of the MPs that end up in the treatment plants with polyester being a top contributor [3]. It has been assumed that the primary source of polyester is laundry. Other factors, such as mechanical degradation of flushed personal care products, e.g. non-wowen wipes, as they pass through the systems of pumps and the mechanical pretreatment, could be a less explored source of polyester fibre. Lee et. al. [4] suggest that this is indeed likely. A higher load of polyester fibre than expected from household sources can help explain why we did not see any effects from the pilot filtration trials in the wastewater sludge.

The sludge analyses are very time consuming (approximately two months) and therefore also expensive. So naturally there is an ongoing quest to find a less time consuming and more cost-effective way to evaluate and monitor MPs in wastewater.
On candidate that is being discussed internationally is TSS. This is a standard test for, for example WWTPs. There are published articles, see example in the list of references [5] indicating that a correlation factor could be developed between TSS and MPs. The initiatives ZDCH - Zero Discharge of Hazardous Chemicals [6] - and TMC - The Microfibre Consortium [7] are investigating this further.

However, one should remember that MPs from polyester are fragments of low density – i.e. low weight. This means that a low TSS most probably also mean a low content of MPs, but it does not work the opposite way. A high TSS value does not automatically mean a high MP content. If a textile manufacturing plant produces different fabrics with varying fibre content during the week it will be very difficult to establish a correlation factor. For an industrial laundry this might be a little less difficult provided that the mix of fibres is fairly consistent.

Provided that a textile production facility uses Ultrafiltration, reverse osmosis or similar, the mass of the fibres after filtration is anticipated to be extremely low. This opens up for just counting the fibre fragments instead of weighing them. In this case "Image Analysis"-system of some kind could be very interesting for monitoring fibre fragments. Such equipment could also be used in on-line monitoring [8].

Capturing MPs upstream close to the source prevents them from further deterioration and getting even smaller. This of course is positive from an environmental aspect since the smaller the MPs gets - the harder they are to catch.

7.4.1 Future work

The discharge of MP from the laundry will vary from day to day. At the same time, MPs are particles which can linger for a long time in the sewer pipes, leading to occasional flash-flows. Monitoring how a treatment at a laundry affects the treatment plant should hence preferably be made as long time series, for example analyzing sludge over one year without treatment, then monitoring it for one year with treatment. Another approach, or probably a complementary approach, would be to collect the discharge from the treatment at the laundry over a long period of time, and quantify the total amount of plastics retained. Finally, the µFTIR imaging approach used to quantify MP number and estimate mass, should be supplemented with pyrolysis GC-MS, which yields an accurate mass quantification – but which cannot tell the number of particles or whether they are fibres or not.

Another path is to further evaluate if TSS (provided a constant mix of fibre content) or on-line image analysis can be a way to monitor MPs in wastewater for industrial laundries as mentioned in the above discussion. Note that this requires an UF filtration or equivalent in operation at site.

The European Environmental Agency has listed possible measures where "*Pre-washing and filtering at industrial level*" is one, see Figure 24.

Figure 24 Possible mitigation action to prevent release of MPs along a textile products lifecycle, report from the European Environment Agency [9]

This suggests that both industrial laundries and WWTPs could be looking at new mandatory requirements in a not-too-distant future. If (when) this becomes reality the textile service sector needs to be prepared.

If the Swedish textile service sector is to invest in MP mitigation measures, they will contribute significantly less to the inlet sewage load of the WWTPs. What kind of incentives should be in place to support this kind of mitigation measures? How will future procurement requirements be affected?

A non-expected finding is the seemingly large impact from households, restaurants etc. It would be interesting to investigate this effect at other WWTPs. Future mitigation requirements for households is also an interesting topic.

From the WWTP point of view, future work on MP content in separated sewage systems (greywater and blackwater) can help to further expand knowledge of the origin of MPs in sewage. It would also be interesting to analyze more sludge samples at Rimbo during a longer period to get information about the variation of composition of the MPs fractions.

8 Questionnarie to Swedish laundries regarding microplastics

A questionnaire was sent out to the members of the Swedish Textile Service Association during December 2022 -January 2023. The aim of the survey was to find out how the discussions are going regarding MPs within the Swedish textile service sector, give an overview of the amount of textiles with synthetic content and how well prepared the textile service sector is for possible future requirements of reduction of MPs in the wastewater.

The answers will, together with the result, contribute as a part of the basis to the Swedish Environmental Agency's work to reduce MP emissions to water. The questionnaire got 42 replies, predominantly from larger laundries. Sweden's two large textile service companies are included which together have answered for 18 facilities (43 % of the respondents). Also, note that most of the questions can be multi answered.

7.1 Compilation of answers

Which categories of textiles do your company work with?

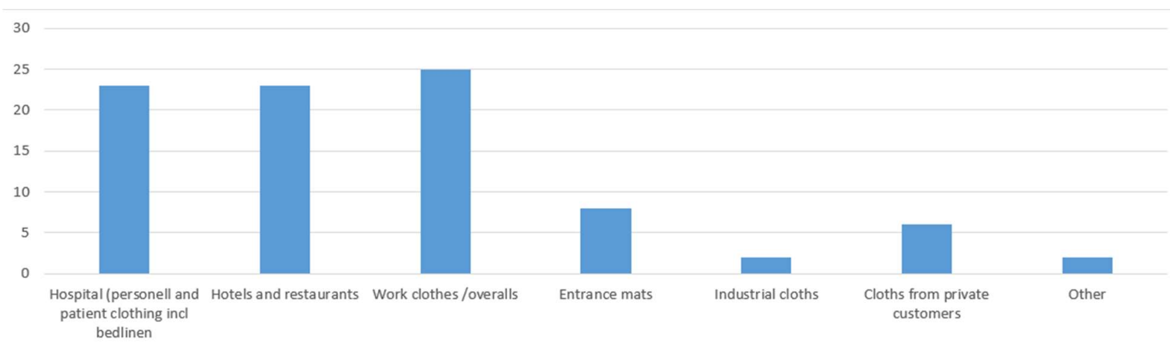


Figure 25 Textiles divided into different categories, Y-axis: number of answering facilities with multiple answers possible

The dominating categories are hospitals, hotels & restaurants whereas entrances mats, clothes from private customers are not so frequent.

<u>Which is the estimated share of synthetic fibres in your textiles?</u>

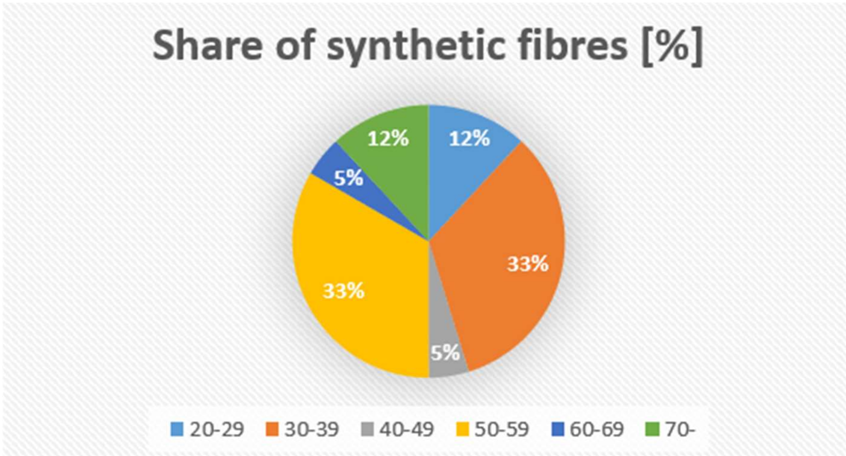


Figure 26 Share of synthetic textiles

Compiling the self-estimates from the 42 respondents, ca 2 244,8 tons are washed each week. The synthetic share is ca 43% or 959,9 tons per week. The synthetic share comes predominantly from blended fabrics of polyester and cotton.

<u>With what frequency does your company analyze the wastewater?</u>

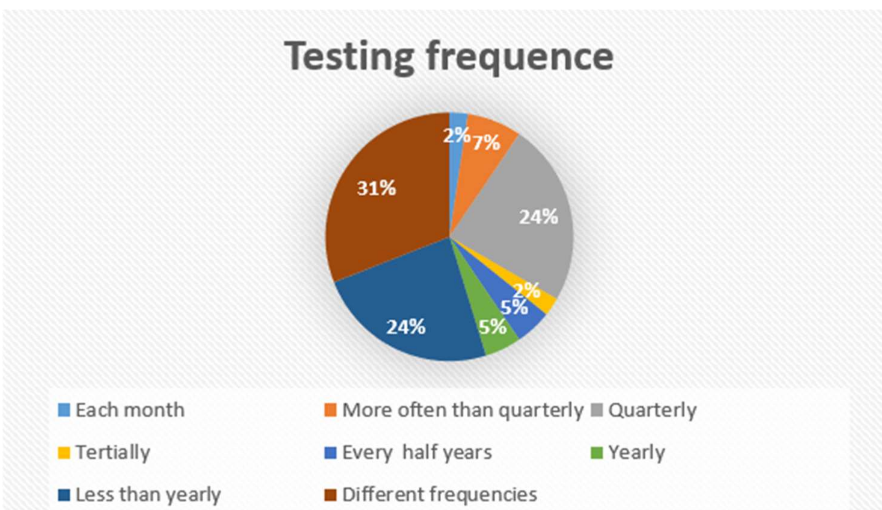


Figure 27 Testing frequency

Which parameters are normally being monitored?

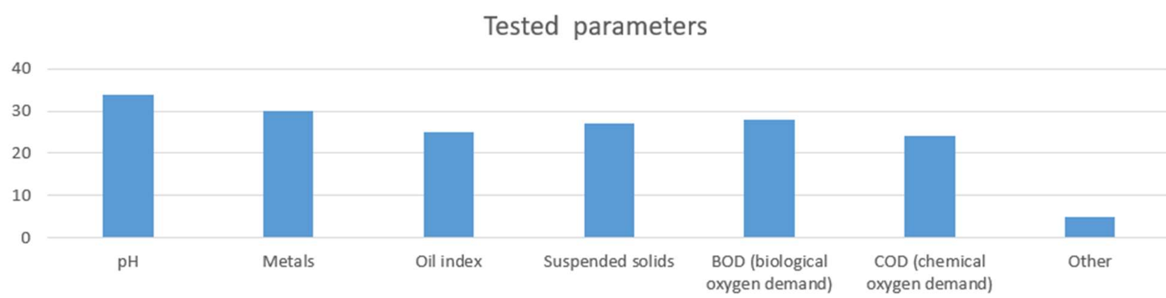


Figure 28 Tested parameters. Y-axis: number of answering facilities with multiple answers possible.

PH and metals are the most common parameters, closely followed BoD, suspended solids and CoD, with oil index being a little less frequent.

Approximately 44% of the laundries have a sedimentation step, whereas 28% have a biological purification step and 28% have another unspecified purification step. No one claims to have installed the purification step out of concern regarding microplastics and most of these filtration/purification steps have been operating for several years.

Where are discussions/questions regarding microplastics coming from?

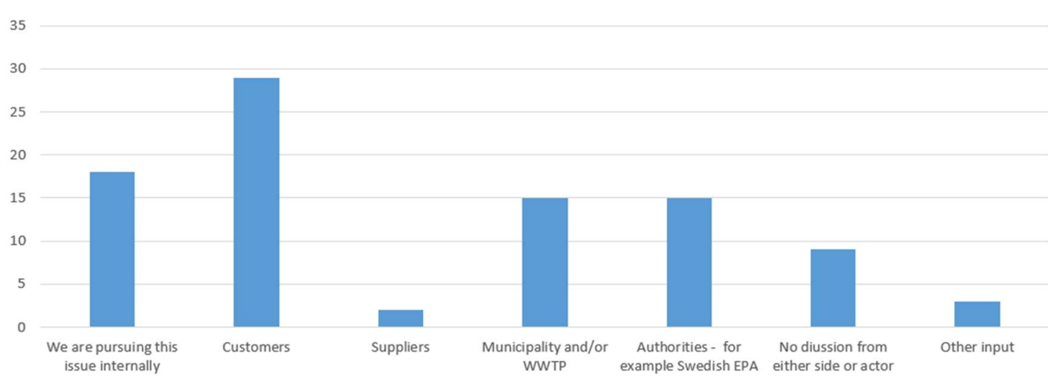


Figure 29 Discussion regarding microplastics. Y-axis: number of answering facilities with multiple answers possible.

The microplastics issue seems so far not to be a concern from the suppliers but more from customers and the laundries themselves. Some input also comes from the municipality and authorities. The answers indicate that larger laundries discuss the microplastic issue more than the smaller laundries.

Examples of free text answers includes:

<u>From customers:</u>
- What impact do microplastics have on the environment?
- How do you work to reduce microplastics emissions?
- Can you retrieve the microplastics from your wastewater?

<u>From laundries:</u>
- How can we reduce the microplastics emissions?
- What can be done / what should be done? There are no clear guidelines
- When will new requirements be implemented and how will this affect our sector?
- Currently no discussion at our company
- We look upon this as a potential significant environmental aspect that need to be addressed as such and investigate status, conditions for possible mitigation measures.

<u>Have your company initiated discussions with suppliers?</u>

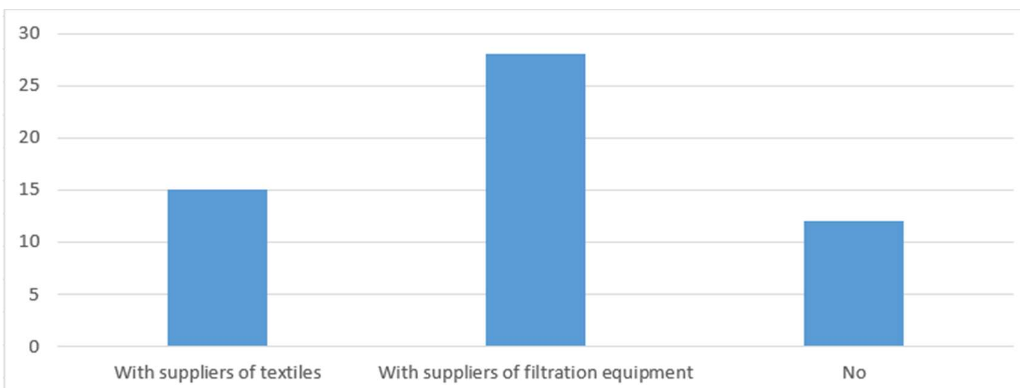


Figure 30 Initiated discussion with suppliers. Y-axis: number of answering facilities with multiple answers possible.

Many of the laundries appear to have initiated discussions with especially suppliers of filtration equipment. However, in this case the result can be a little deceiving since two of the larger laundry companies have several locations in Sweden.

What active mitigation measures have your company already taken?

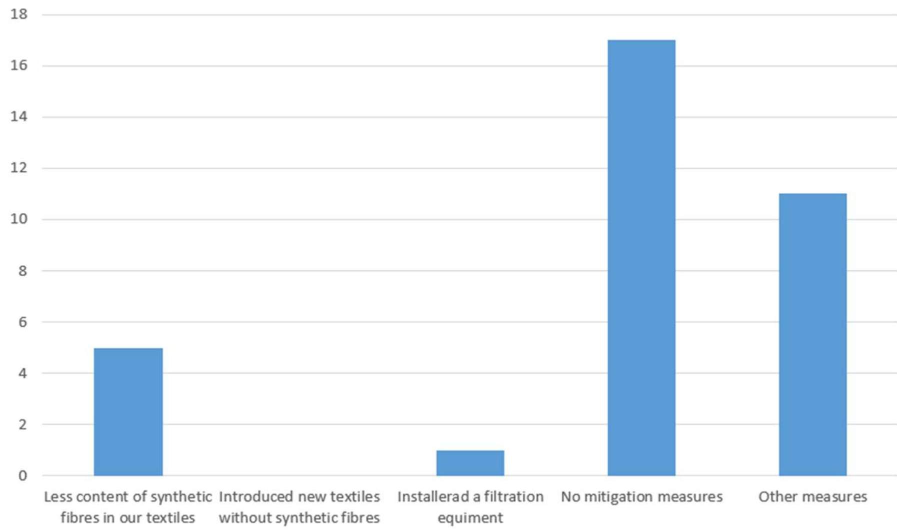


Figure 31 Mitigation actions. Y-axis: number of answering facilities with multiple answers possible.

Other measures include:
- we are following the development
- we are investigating filtration options and purification of the process water

What is the planning horizon for investments to mitigate microplastics?

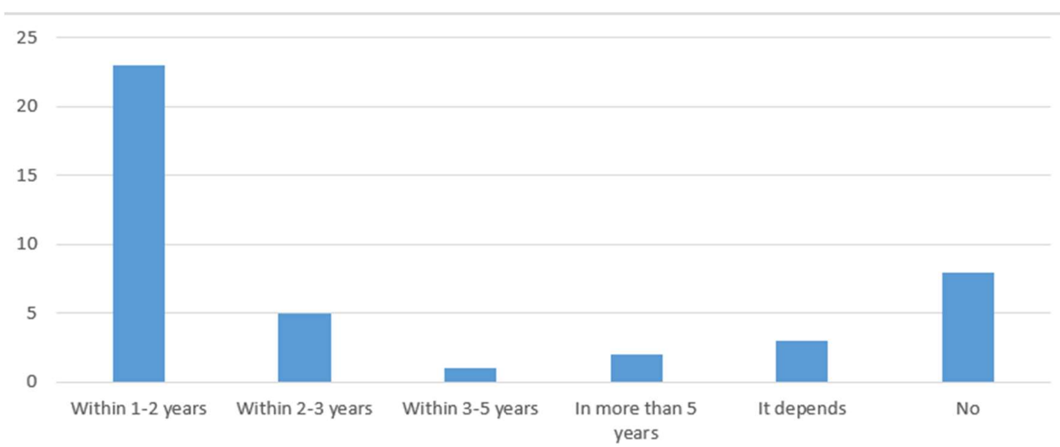


Figure 32 Investment horizon. Y-axis: number of answering facilities with multiple answers possible.

The result show that the majority of the respondents are in the planning phase of an investment within 1-3 years. Looking closer into the answers it can be concluded that planning of investments is predominantly coming from the two larger laundry companies.

7.2 Summary questionnarie

-The majority of input and questions regarding microplastics have so far come from the customers of the laundry (B2B-customers). Internal discussions within the laundries as well as questions from suppliers and authorities are getting more frequent.

- Discussions with suppliers of textiles and filtration equipment has been initiated

- Little active mitigation measures at the laundries have been taken so far

- Some laundries are waiting for more information before taking any action.

- There is a lack of guidelines and what to expect from possible new requirements

- Especially the two larger industrial laundries have a planning horizon of 1-3 years for investing in MP mitigation measures. The smaller laundry companies have a longer planning horizon or no plan for mitigation measures.

9 References

Ref 1. www.diva-portal.org/smash/get/diva2:1633776/FULLTEXT01.pdf

Ref 2 www.naturvardsverket.se/amnesomraden/plast/om-plast/mikroplast

Ref 3. www.diva-portal.org/smash/get/diva2:1578388/FULLTEXT01.pdf

Ref 4.
www.researchgate.net/publication/351082855_Discharge_of_microplastics_fibres_from_wet_wipes_in_aquatic_and_solid_environments_under_different_release_conditions

Ref 5. www.sciencedirect.com/science/article/pii/S0043135420303973

Ref 6. www.apparelcoalition.org/collaboration-impact-zdhc/

Ref 7. www.microfibreconsortium.com

Ref 8.
www.researchgate.net/publication/362838168_Measuring_and_Controlling_Microparticles_in_Textile_Wastewater

Ref 9. www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/plastic-in-textiles-potentials-for-circularity-and-reduced-environmental-and-climate-impacts

Note – references regarding sample preparation of wastewater and sludge samples, see Appendix 2.

10 Appendix

1. Sample collecting at Textilia industrial laundry and Rimbo WWTP
2. Preparation of wastewater samples
3. Preparation of sludge samples
4. Results from wastewater analyses incl shape and size distribution
5. Results from sludge analyses per fibre incl size and shape distribution

Appendix 1

Sample collecting at Textilia industrial laundry and Rimbo WWTP

Reference samples

Samples at Textilia were collected in the process-line outlet

Sampling date	Outlet flow (previous day)	Sample set textilia	Sample set in	sample set out	Sludge sample
07-jun	1249	1			
08-jun	1326	1	1		
09-jun	1284	1	1		
10-jun	1260	1	1	1	
11-jun	1242		1	1	
12-jun	1225		1	1	
13-jun	1224		1	1	1
14-jun	1212		1	1	
15-jun	1445			1	
16-jun	1836			1	
17-jun	1195				
18-jun	1150				
19-jun	1142				
20-jun	1136	2	2	2	
21-jun	1136	2	2	2	
22-jun	1134	2	2	2	
23-jun	1124	2	2	2	
24-jun	1118		2	2	
25-jun	1113		2	2	
26-jun	1190		2	2	
27-jun	1200				2

DynaDrum

X= no sample collected

As the samples over weekends were collected from Friday morning to Monday morning, these samples had a higher chance of failure as the sampler wasn't checked on daily

Sampling date	Outlet flow Rimbo wwtp (previous day)	Sample set Textilia	Sample set in	Sample set out	Sludge sample
27-sep	1248	1	1		
28-sep	1558	1	1		
29-sep	1159	1	1	1	
30-sep	854	1	1	1	
01-okt	1129		x	x	
02-okt	1062		x	x	
03-okt	859		x	x	
04-okt	1306	2	2	1	
05-okt	955	2	2	1	1
06-okt	1249	2	2	2	
07-okt	1163	2	2	2	
08-okt	1150		2	2	
09-okt	999		2	2	
10-okt	655		2	2	
11-okt	845	3	3	2	
12-okt	1078	3	3	2	
13-okt	1158	3	3	3	
14-okt	887	3	3	3	
15-okt	880		x	x	
16-okt	1264		x	x	
17-okt	822		x	x	
18-okt	1314			3	2

Ultrafiltration

X= no sample collected

Sampling date	Outlet flow Rimbo wwtp (previous day)	Sample set Textilia	Sample set in	sample set out	Sludge sample
07-dec	1383	1	1		
08-dec	1524	1	1		
09-dec	1344	1	1	1	
10-dec	1418	x	1	1	
11-dec	1337	x	1	1	
12-dec	1285	x	2	x	1
13-dec	890	2	2	1	
14-dec	1169	2	x	1	
15-dec	1389	2	x	2	
16-dec	1170	x	2	2	
17-dec	995	x	2	2	
18-dec	1371	x	2	2	2
19-dec	1262	3	3	x	
20-dec	1016	3	3	2	
21-dec	1256	3	x	x	
22-dec	1550			3	
23-dec	2024			3	

Appendix 2

Preparation of wastewater samples

Wastewater samples were mixed, and from 0.78 L to 3 L subsamples (Table 2) were selected to proceed with similar enzyme oxidation sample preparation process as the sludge samples in Appendix 3. In the last step, the samples were evaporated into a 10 mL vial, and the ethanol evaporated in an evaporation bath (TurboVap® LV, Biotage) at 50 °C. Finally, the particles were suspended into 3 mL of ultra-pure HPLC quality 50% ethanol.

Table 1 Wastewater sample information

Sample	Identification	Volume (L)
W1	After Drumfilter 3-7/10	1.8
W2	Before Drumfilter 11-14/10	0.85
W3	After Drumfilter 11-14/10	1.81
W4	Before Drumfilter 3-7/10	0.78
W5	BEFORE UF 7-9/12	0.86
W6	AFTER UF 7-9/12	2.95
W7	BEFORE UF 12-16/12	0.99
W8	AFTER UF 12-16/12	3

Analytic techniques for MPs with ATR-FTIR and FPA-µFTIR

The extracted particles >500 µm were handpicked and imaged using a stereomicro-scope (ZEISS, SteREO Discovery.V8) equipped with an Axiocam 105 color camera with a maximum magnification of 8 ×. ZenCore (Zen2Core SP1 from ZEISS) software coupled to the microscope was used to measure particle dimensions, including area, minimum, and maximum Feret diameter. The particles' IR spectra were obtained with an Attenuated Total Reflection: ATR-FTIR (Agilent Cary 630 FTIR with a diamond ATR). Upon obtaining the background, the sample spectrum of the particle was recorded by 64 co-added scans in the spectral range of 650–4000 cm^{-1}. OMNIC software (Thermo Fisher Scientific Inc., 8.2.0.387 version 1) and its library were used to identify the material of the recorded IR spectra.

Particles between 10 and 500 µm were analyzed using FPA-µFTIR: Agilent Cary 620 FTIR microscope equipped with a 128 × 128 pixel FPA (Mercury Cadmium Telluride detector) and coupled to an Agilent 670 IR spectroscope. The particles suspended in 50% ethanol were homogenized with a vortex, and sample aliquots were taken with a glass pipette of 25 µL, 50/100 µL, and 200 µL. The sub-sample was deposited on a 13 × 2 mm zinc selenide window (Crystran, UK) held in a compression cell (Pike Technologies, USA), leaving a 10 mm diameter free area. The windows were left to dry for some hours on a heating plate at 50 °C.

If needed, the process was repeated until the window was adequately covered by particles. The volume deposited on the window for each scanning of sludge and slurry was 100 µL. The deposited volumes for as-received products were 25 µL, concentrate 100–200 µL, solid residue 200 µL, distillate 600 µL, and bio-crude 50 µL.

Three windows were scanned for each sample. Details of the technology are described in Simon et al., (2018) and (Kirstein et al., 2021). The background was acquired by 120 coadded scans, while the sample was obtained by 30 co-added scans at the wave-number range 3750–850 cm^{-1}. The scan was done in trans-mission mode with a 15 × Cassegrain IR objective, producing a pixel resolution of 5.5 µm.

The resulting chemical images were analyzed with siMPle, which is an automated soft-ware program that provides particle dimensions, area, volume, and mass estimates of MPs (Primpke et al., 2017). To this end, the MPs were mapped by matching each pixel of the scan to a custom-built reference database, containing more than 110 spectra of different materials by a Pearson's correlation (Liu et al., 2019). Only particles consisting of at least two pixels were included as MPs.

Appendix 3

<u>Preparation of sludge samples</u>

About 500 g of sewage sludge was homogenized, and 20 g of duplicate sub-samples equivalent to 5 g dry matter (each) were taken (Table 1). The samples were pre-oxidized in 1 L beakers by gradually mixing 200 mL of 50% hydrogen peroxide (H_2O_2) and 250 mL of Milli-Q into the sample. The sample was left for 48 h and then filtered through a 10 µm stainless steel filter. The particles from the filter were detached by ultra-sonication into 500 mL sodium dodecyl sulfate solution (SDS, 5% w/vol). The sample was incubated for 48 h at 50 °C by continuously mixing with a glass-coated magnet. The filtered particles were transferred into 300 mL of acetate buffer (pH 4.8), then 500 µL of cellulase (Cellulase enzyme blend®, Sigma-Aldrich) and 500 µL of cellulolytic enzyme mixture (Viscozyme®L, Sigma-Aldrich) were added.

The mixture was incubated at 50 °C for 48 h. The filtered particles were transferred to 300 mL of tris buffer (pH 8.2) where 500 µL of protease solution (Protease from Bacillus sp.®, Sigma-Aldrich) was added and incubated at 50 °C for 48 h. The solution was filtered and the particles were transferred into 200 mL of Milli-Q water. A Fenton oxidation was conducted by adding 145 mL of 50% H_2O_2, 65 mL of 0.1M NaOH, and 62 mL of 0.1M $FeSO_4$ while maintaining a temperature of 15–30 °C.

After this step, the larger MPs (major dimension >500 µm) were separated from the smaller MPs (major dimension between 500 and 10 µm) using a 500 µm mesh sized sieve and a 10 µm stainless steel filter. The larger particles were removed from the sieve by backflushing with particle-free water, which were then stored in an aluminum tray. The water was evaporated in an oven at 50–60 °C. The cleaned and dried particles were stored for later analysis. The smaller particles were transferred into a 250 mL pear-shaped separation funnel containing a Zinc chloride ($ZnCl_2$) solution of density 1.7-1.8 g cm^{-3}. The particles were mixed using compressed air bubbling from the bottom of the funnel for 30 min. The mixture was left to settle for 24 h. Three-fourth of the bottom part was removed: the process was repeated up to 3 times. The top floating particles were filtered using a 10 µm steel filter and washed with Milli-Q water to remove $ZnCl_2$. The filtered particles were removed using an ultra-sonicating bath and transferred into ultra-pure HPLC quality 50% ethanol. The particles were moved to 20 mL vials, and the ethanol evaporated in an evaporation bath (TurboVap® LV, Biotage) at 50 °C. Finally, the particles were suspended into 10 mL of ultra-pure HPLC quality 50% ethanol (Chand et al., 2022).

Table 2 Sludge sample information

Sample	Label on sample	Water, %	Sample in work, g wet/dry
S1	Rimbo Sludge Drumfilter 5/10	72,74	18,40/5,01
S2	Rimbo Sludge UF 16/12	73,58	19,06/5,04
S3	Rimbo zero-reference 1-13/6	83,78	30,62/4,97
S4	Rimbo Sludge Drumfilter 18/10	72,10	17,88/4,99
S5	Rimbo SludgeUF 12/12	73,84	19,57/5,12
S6	Rimbo zero-reference 2-27/6	70,74	17,61/5,15

References

Chand, R., Kohansal, K., Toor, S., Pedersen, T. H., & Vollertsen, J. (2022). Microplastics degradation through hydrothermal liquefaction of wastewater treatment sludge. *Journal of Cleaner Production*, *335*, 130383. https://doi.org/10.1016/J.JCLEPRO.2022.130383

Kirstein, I. V., Hensel, F., Gomiero, A., Iordachescu, L., Vianello, A., Wittgren, H. B., & Vollertsen, J. (2021). Drinking plastics? – Quantification and qualification of microplastics in drinking water distribution systems by µFTIR and Py-GCMS. *Water Research*, *188*, 116519. https://doi.org/10.1016/J.WATRES.2020.116519

Liu, F., Olesen, K. B., Borregaard, A. R., & Vollertsen, J. (2019). Microplastics in urban and highway stormwater retention ponds. *Science of The Total Environment*, *671*, 992–1000. https://doi.org/10.1016/J.SCITOTENV.2019.03.416

Primpke, S., Lorenz, C., Rascher-Friesenhausen, R., & Gerdts, G. (2017). An automated approach for microplastics analysis using focal plane array (FPA) FTIR microscopy and image analysis. *Analytical Methods*, *9*(9), 1499–1511. https://doi.org/10.1039/C6AY02476A

Simon, M., van Alst, N., & Vollertsen, J. (2018). Quantification of microplastic mass and removal rates at wastewater treatment plants applying Focal Plane Array (FPA)-based Fourier Transform Infrared (FT-IR) imaging. *Water Research*, *142*, 1–9. https://doi.org/10.1016/J.WATRES.2018.05.019

Appendix 4

Results from wastewater analyses incl shape and size distribution

Table 1 Sample information

Identification on the bottles	# bottles	Identification on the lid	Sample
After filtration 3-7/10	2	44:1 45:1	W1
Before drumfilter 11-14/10	1	46:1	W2
After filtration 11-14/10	2	47:1 48:1	W3
Before drumfilter 3-7/10	1	49:1	W4
Before UF 7-9/12	1	53	W5
After UF 7-9/12	3	54 55 56	W6
Before UF 12-16/12	1	63	W7
After UF 12-16/12	4	64 65 66 67	W8
	15		

Table 2 MP abundance in wastewater (counts L^{-1})

Sample	others	polyester	sum
W1	100	642	742
W2	335	3026	3362
W3	373	14039	14412
W4	144	2010	2154
W5	235	5485	5721
W6	14	29	42
W7	333	1667	2000
W8	14	34	48

Table 3 Mass concentration of MPs in wastewater (µg L^{-1})

Sample	others	polyester	sum
W1	11.20	37.33	48.54
W2	19.80	608.36	628.17
W3	6.11	18,258.47	18,264.58
W4	5.08	285.00	290.09
W5	20.04	1,147.33	1,167.37
W6	0.79	2.83	3.62
W7	41.79	419.79	461.58
W8	0.39	1.68	2.07

Table 4 MP shape distribution

Sample	total		polyester	
	fragment	fiber	fragment	fiber
W1	61.24%	38.76%	59.09%	40.91%
W2	51.97%	48.03%	48.40%	51.60%
W3	85.91%	14.09%	85.83%	14.17%
W4	66.96%	33.04%	65.07%	34.93%
W5	54.57%	45.43%	53.10%	46.90%
W6	44.00%	56.00%	29.41%	70.59%
W7	53.03%	46.97%	45.91%	54.09%
W8	62.50%	37.50%	52.94%	47.06%
Sum	60.02%	39.98%	54.97%	45.03%

*if the ratio between major and minor dimension larger than 3, then the MP is identified as fiber, else it is fragment.

Table 5 Size distribution of polyester in wastewater

Sample	polyester										
	11-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	>1000
W1	66.23%	27.92%	3.25%	1.95%	0.00%	0.00%	0.00%	0.00%	0.00%	0.65%	0.00%
W2	47.81%	34.99%	8.45%	4.66%	1.75%	0.87%	0.87%	0.29%	0.29%	0.00%	0.00%
W3	92.44%	6.43%	0.89%	0.12%	0.00%	0.06%	0.00%	0.00%	0.00%	0.00%	0.06%
W4	54.55%	31.58%	9.57%	2.87%	0.48%	0.00%	0.00%	0.96%	0.00%	0.00%	0.00%
W5	53.74%	27.66%	10.17%	3.50%	2.07%	1.43%	0.32%	0.32%	0.16%	0.32%	0.32%
W6	41.18%	35.29%	23.53%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
W7	49.09%	26.82%	8.18%	7.73%	3.18%	2.73%	0.91%	0.91%	0.45%	0.00%	0.00%
W8	52.94%	41.18%	5.88%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

*All this based on major dimension of MPs, 10-100 means MP≥11&MP<100.

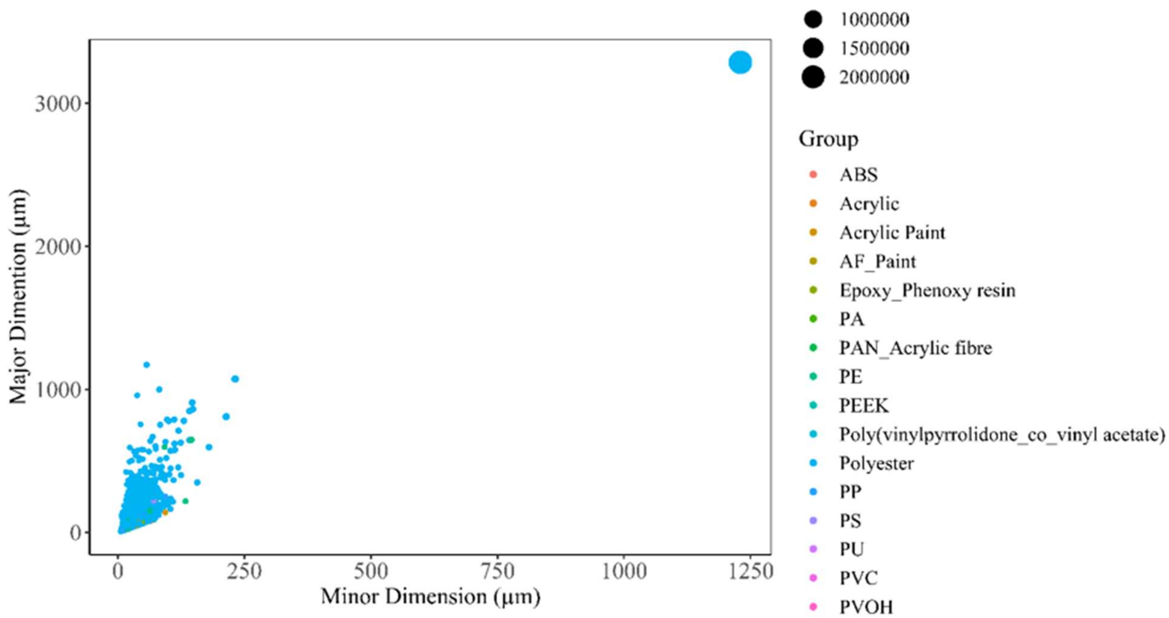


Figure 1 Size distribution of all MPs detected in wastewater.

Appendix 5

<u>Results sludge analyses per fibre incl shape and size distribution</u>

1. Summary of abundance and mass concentration of microplastics (MPs) in sludge: Raw data files are archived at RISE.

Table 1 Abundance of microplastics in sludge (count/g drye)

Sample	Acrylic	Alkyd	Epoxy_Phenoxy resin	PA	PC	PE	PEEK	polyester	PP	PS	PU	PVC	PVOH	Ship Paint_DANA	summary
S1	109.7804	0	19.96007984	59.88024	0	1756.487	0	1247.505	159.6806	39.92016	39.92016	0	0	0	3433.134
S2	287.6984	29.7619	99.20634921	99.20635	0	3422.619	0	2757.937	128.9683	19.84127	59.52381	0	19.84126984	9.920635	6934.524
S3	90.54326	20.12072	20.12072435	20.12072	0	4899.396	0	1217.304	181.0865	10.06036	80.4829	10.06036	10.06036217	0	6559.356
S4	120.2405	0	0	40.08016	0	3106.212	0	1923.848	100.2004	20.04008	140.2806	10.02004	0	0	5460.922
S5	205.0781	9.765625	48.828125	29.29688	9.765625	3447.266	0	3183.594	136.7188	39.0625	39.0625	29.29688	0	0	7177.734
S6	184.466	9.708738	9.708737864	67.96117	0	2203.883	0	1621.359	116.5049	19.41748	19.41748	9.708738	9.708737864	0	4271.845

Table 2 Mass concentration of microplastics in sludge (mg/g drye)

Sample	Acrylic	Alkyd	Epoxy_Phenoxy resin	PA	PC	PE	PEEK	polyester	PP	PS	PU	PVC	PVOH	Ship Paint_DANA	summary
S1	361799.6	0	3259.598004	872.3015	0	633123.1	0	1216203	1460794	14378.74	500.2822	0	0	0	3.690931
S2	379183.8	47914.1	1194.104464	2431.917	0	1743271	0	9445361	2463.524	10.95714	930.8076	0	379.8571429	1772.706	11.62491
S3	5500.101	1260.526	176.8518109	237.385	0	3191686	0	45483.41	16300.4	18.75724	811.3477	146.8003	335.2488934	0	3.261957
S4	1217215	0	0	1432.129	0	696405.3	0	433570.5	5254.611	699.4356	5330.752	253.5505	0	0	2.360161
S5	130188.4	192525.5	2121.416406	173.2783	128.0143	598092.4	0	15196391	2476.407	523.2031	472.5551	2721.509	0	0	16.12581
S6	1075897	196.435	88.39902913	1822.706	0	1047759	0	537933.9	820450.3	385.7552	333.4212	189.1738	344.8816505	0	3.485402

All the low score particle was checked manually and removed from the result.

2. Shape summary (Excel sheet 2). Raw data files are archived at RISE

Table 3 Shape summary

Sample	fiber	fragment	fiber(%)	fragment(%)
S1	128	216	37.2093	62.79069767
S2	204	496	29.14286	70.85714286
S3	184	468	28.22086	71.7791411
S4	121	424	22.20183	77.79816514
S5	252	484	34.23913	65.76086957
S6	125	315	28.40909	71.59090909

The data is calculated based on the siMPle data. Ratio of major dimension and minor dimension is used as indicator. Fiber is defined if the ratio large than 3, while fragment is defined if the ratio less than 3. The raw data is listed in Excel sheet 3 to sheet 9, archived at RISE.

3. Size distribution

The raw data (Major dimension and minor dimension) is listed in Excel sheet 4 to sheet 10. The summary result is shown in Excel sheet 3. Raw data files are archived at RISE.

Table 4 Major dimension distribution (siMPle)

Sample	1-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	>1000
S1	186	102	29	12	6	1	2	2	2	0	2
S2	458	156	42	19	4	2	5	2	2	3	7
S3	375	164	59	26	14	8	0	2	2	0	2
S4	357	135	35	9	4	2	1	0	0	1	1
S5	493	162	43	15	7	5	3	0	2	1	5
S6	258	111	34	17	4	9	1	0	1	0	5

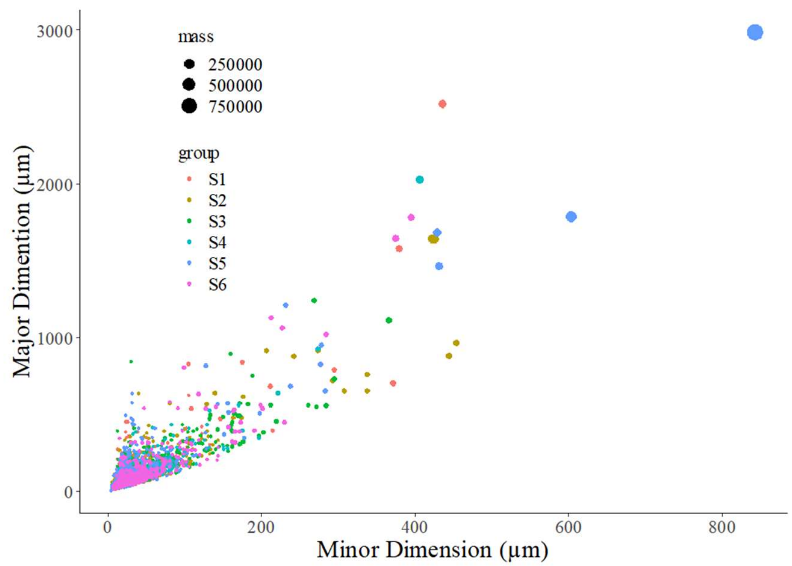


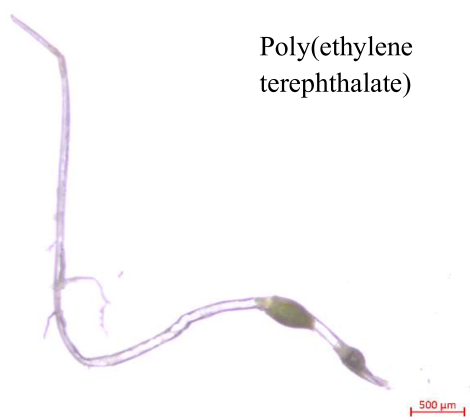
Figure 1 Size distribution based on siMPle data.

- The small particles are analyzed by FTIR, followed by siMPle. The large particles (> 500 µm) are collected after size fraction, and analyzed by ATR, the result is showed below.

4. Big particles
    - The major and minor dimension of the large particles are measured by the microscope.
    - The mass of fragment MPs was calculated from the volume of the particle assuming an ellipsoid shape and the density of its material.
    - The mass of fiber MPs was calculated from the volume of the particle assuming an ellipsoid shape and the density of its material.

Sample 1

Type	Poly(ethylene terephthalate)-fiber
Major Dimension	12019.827 µm
Minor Dimension	90.521 µm
Mass	20.387 µg



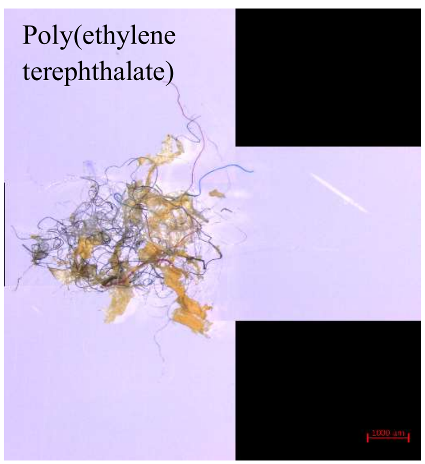
Type	Poly(ethylene terephthalate)-fiber
Major Dimension	6636.5 µm
Minor Dimension	103.4 µm
Mass	14.687 µg

Type	Poly(vinyl stearate)
Major Dimension	1846.748 µm
Minor Dimension	1266.91 µm
Mass	1559.781 µg

This is the fiber cluster, we didn't do the calculation.

Type	Poly(vinyl stearate)
Major Dimension	2857.94 µm
Minor Dimension	1230.243 µm
Mass	2276.143 µg

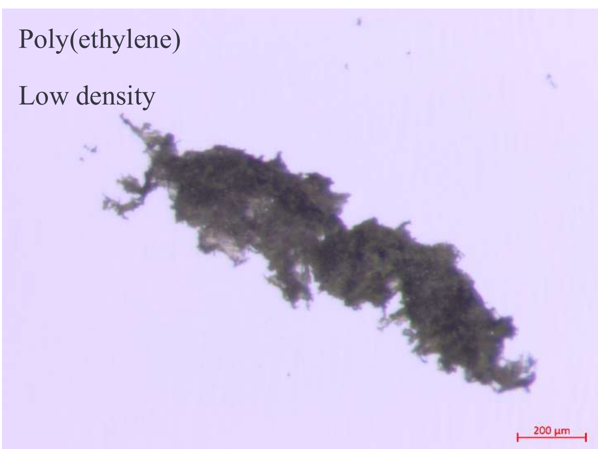
Sample 2



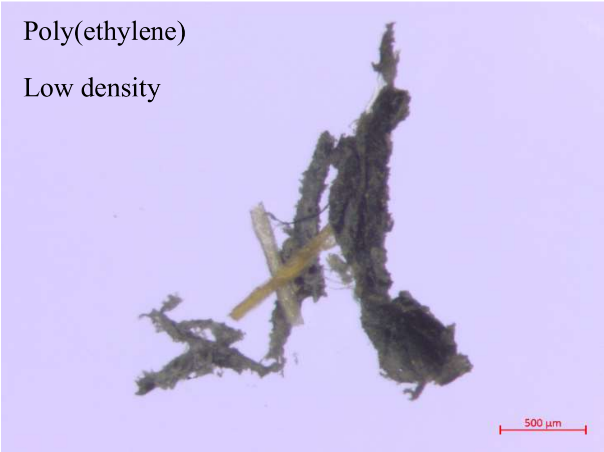
This is a fiber cluster, no calculation was performed.

Type	Poly(benzyl methacrylate)
Major Dimension	1434.846 µm
Minor Dimension	738.605 µm
Mass	411.902 µg

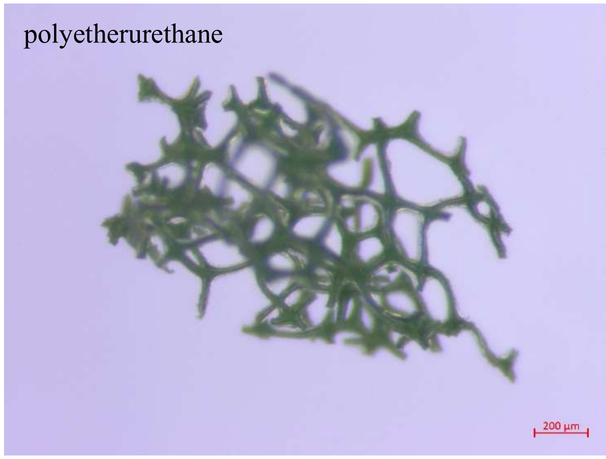
Sample 3



Type	Poly(ethylene)
Major Dimension	1278.5 µm
Minor Dimension	339.98 µm
Mass	76.207 µg



Type	Poly(ethylene)
Major Dimension	2149.888 µm
Minor Dimension	343.885 µm
Mass	131.109 µg



This is not fiber or fragment, no calculation was performed.

Type	Poly(ethylene)
Major Dimension	1967.404 µm
Minor Dimension	184.753 µm
Mass	34.631 µg

Sample 4

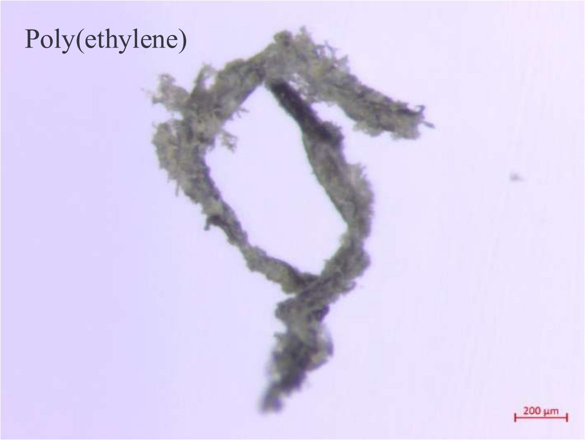
Type	Poly(vinyl stearate)
Major Dimension	1745.812 µm
Minor Dimension	1667.442 µm
Mass	2554.251 µg

Type	Poly(vinyl stearate)
Major Dimension	3383.775 µm
Minor Dimension	728.762 µm
Mass	945.671 µg

Sample 5

Type	Poly(ethylene)
Major Dimension	1622.062 µm
Minor Dimension	190.414 µm
Mass	30.328 µg

Sample 6



Type	Poly(ethylene)
Major Dimension	1436.206 µm
Minor Dimension	162.802 µm
Mass	19.630 µg

Type	Poly(vinyl acetate:ethylene 3:1)-fiber
Major Dimension	3195.663 µm
Minor Dimension	37.993 µm
Mass	2.478 µg

Type	Poly(vinyl acetate:ethylene) 9:1
Major Dimension	2328.433 µm
Minor Dimension	1039.839 µm
Mass	1550.045 µg

Through our international collaboration programmes with academia, industry, and the public sector, we ensure the competitiveness of the Swedish business community on an international level and contribute to a sustainable society. Our 2,800 employees support and promote all manner of innovative processes, and our roughly 100 testbeds and demonstration facilities are instrumental in developing the future-proofing of products, technologies, and services. RISE Research Institutes of Sweden is fully owned by the Swedish state.

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