10.6.2022

The MiPlaFi 2.0

Washing clothes with a clear conscience

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ENTRY TO THE STOCKHOLM JUNIOR WATER PRIZE 2022, GERMANY

Summary

The project deals with the question of how microplastics can be filtered out of the wastewater from washing machines.

In the first phase, it was investigated whether microplastics detach and are detected when clothes are washed. Two microplastic filters (MiPlaFi) were developed outside the washing machine, which filter microplastics from the wastewater. The results of the first phase were presented at the Jugend Forscht competition 2020.

In the second, current phase, the project was revised. Here, the collected knowledge, ideas, optimisation and improvement suggestions from the first phase are bundled. The aim is to develop a new device so that it can be installed directly in the washing machine and the consumer only has to empty it. This means that the washing machine does not need to be retrofitted and the microplastic produced is removed from the cycle directly before it enters the environment. This prevents it from spreading in the water.

The new, improved filter unit was designed and manufactured in a CAD programme and then permanently installed in the washing machine.

The end user now only has to empty the microplastic filter when it is full, similar to the lint filter. The natural water cycle should thus be relieved globally in the long term.

Table of content

Table of abbreviations and acronyms

1. MiPlaFi – microplasticfilter
2. Fig. – figure
3. i.e. – it est, for example

Acknowledgements

Institution: Youth Research Centre Schwarzwald-Schönbuch e.V.

<u>Second phase</u>

Persons: Professor Doktor Klein, Uwe: Scientific Director of the JFZ (Discussed and debated the process of chemical treatment with me); Quintus, Marcel: Drawing the outlet channel in SolidWorks; Renz, Barbara: Managing Director of the JFZ (organising the sponsors); Weippert, Heinz: Supervisor (assisting with the installation of the filters, tips on construction).

Companies: Friedrich Boysen GmbH und Co. KG (financing and printing of the filter); CoMaZo GmbH + Co.KG (sponsoring the new linen).

<u>First phase:</u>

Persons: Mäurer, Manfred: Chemistry teacher (Discussed and debated with us the process of chemical preparation); Schrade, Markus: Supervisor (Support in planning, tips on construction, soldered on the power supplies of the pumps, supervisor during chemistry experiments); Weigand, Frank: School management (Support in financing the plastic filter).

Companies: Friedrich Boysen GmbH und Co. KG (financing and printing of the metal filter); 3Faktur | 3D Druck Service & Rapid Prototyping (plastic printing of the filter).

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I would like to thank all supporters!

1. Introduction

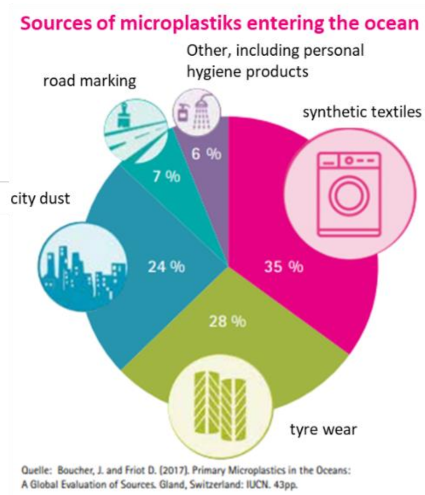


Figure 1 - shows source of origin of microplastics and their proportions; adapted and translated from[2].

The basic idea of the project started with the determination of the microplastic content in the river Nagold at different locations in the water and sediment. The occurrence and entry of microplastics into the environment were investigated to identify the influence of industry, infrastructure and population density. This research showed that the washing machine releases the largest proportion of microplastics (35%) into our environment every day[1,2].

Microplastics are plastic particles smaller than five mm[3]. They are now detectable in almost all areas of our environment, even in our food[4]. But how do microplastics get into our washing machines? PET bottles and other recyclable plastics are melted down and processed into microchips. These, in turn, become sewing threads, which are used to make our clothes. During the washing process, the plastic detaches from our clothes in the form of microplastics. It passes unhindered into the wastewater of washing machines. From there, it is released into the global water cycle via the sewage system[2]. A large proportion of microplastics also accumulates in the sludge of wastewater treatment plants. The sludge is often used to fertilise our fields, and the microplastics thus end up in our food[5].

A quick and efficient way to biodegrade plastics, especially microplastics, is still researched in science[6]. In the meantime, some approaches are intended to prevent further entry of microplastics through the washing of textiles. The company GUPPYFRIEND developed washing bags[7]. Here, the laundry is washed in the laundry bag during the washing process. Due to the special structure of the fabric, the microplastics cannot get into the wastewater. However, their use is not compulsory, leading to rare usage. Microplastic filters are also available for upgrading the washing machine[8]. The filter must be obtained and installed by the user. Since this is done voluntarily, only environmentally interested users will introduce this system into their households. In addition, technical know-how or a service technician is necessary. Moreover, it is challenging to upgrade wastewater treatment plants. Studies are conducted on the bacterial degradation of microplastics[6], which could be used in such a wastewater treatment plant setting.

Based on these findings, I aimed to develop a filter construction that can be installed directly into the washing machine during its construction. In this way, the filtration would be independent of location, environmental awareness, craftsmanship, space at the consumer's premises and the filtration possibilities of a wastewater treatment plant.

The project can be divided into two phases: The first phase took place from 2018 to 2020 and was carried out as a Jugend forscht project at school (Christophorus - Gymnasium Altensteig) with my colleague Hannah-Marie Zakes. With our idea, we won the regional competition. We were forwarded to the state competition, which was cancelled due to the corona pandemic. From then on, we were not allowed to resume our work due to the Corona regulations until the Abitur 2021. The focus of the first project was on the detection of microplastics. Tap water samples were compared with washing machine wastewater samples and evaluated, and two initial filter prototypes were developed. The second phase began after the Abitur in July 2021. I resumed the project. My partner started a voluntary ecological year in Innsbruck at the same time and was unfortunately no longer able to participate. In the first step, I installed the first prototype into the washing machine. In the second step, the entire project was reconsidered and relaunched. In the meantime, the project has been discussed with a patent attorney, and patent proceedings have been initiated.

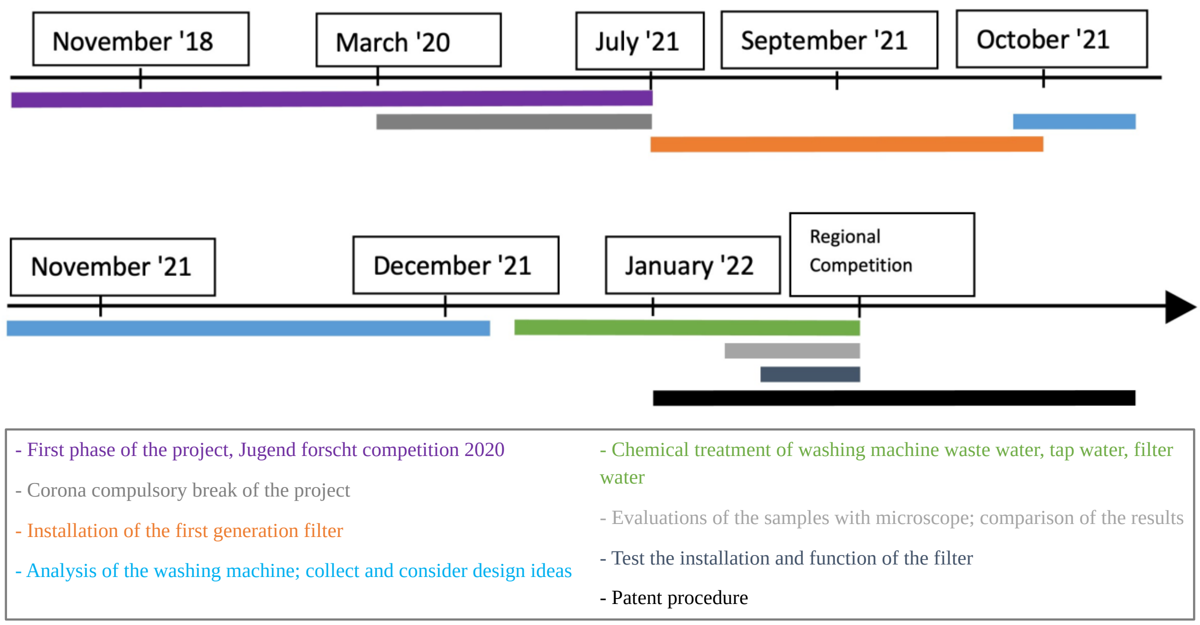


Figure 2 – show the timeline of the project with the labelling

2. Chemical detection of microplastics

2.1 Material, approach, and methods

In the first step, the chemical processing of microplastics should verify the research results. Therefore, a protocol of the US Department of Commerce was used[9]. The water sample was dried at 90°C for 24 hours. Then it was mixed with 20mL iron(II) sulphate solution and 20mL hydrogen peroxide 30%. Afterwards, it was heated to 75°C for 30 min. It should be possible to skim off the microplastic from the sample via density separation with a saline solution. However, it turned out that PET (polyethylene terephthalate) has a higher density than a saturated sodium chloride solution and was therefore not captured. Also, the chemical process for preparing the sample could not be fully understood and raised some questions.

Thus, I researched new methods[10/11] in the project's second phase to allow a better evaluation. I also asked several textile companies for unwashed laundry. With this laundry, I ensured that the same amount of microplastic was released during the washing process with and without a filter unit. I washed the same number of garments under the same condition and with the same type of fibre. The new chemical treatment process to verify microplastics is based on the Fenton reaction. It is like the process used in the first elaboration. This process has been scientifically tested. In the first step, one litre of the water sample is evaporated at 70°C using the rotary evaporator. Then 10 mL of Fenton reagent (20g $FeSO_4$ (ferrous sulphate) are dissolved in 1L of demineralised water and adjusted to a pH=3 with H_2SO_4 (sulphuric acid)). Then 20mL of 30% H_2O_2 (hydrogen peroxide) is added, and the reaction starts. In the next 10 minutes, 5mL 30% H_2O_2 is added per minute. The hydrogen peroxide is split into two radicals. The Fe^{2+} ions are oxidised to Fe^{3+} ions in the acidic environment to keep them stable. This forms a hydroxide radical and a hydroxide ion: $\boldsymbol{Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + H\text{-}O\cdot + HO^-}$. The radical ($H\text{-}O\cdot$) now attacks the carbon chains: $\boldsymbol{H\text{-}O\cdot + R\text{-}H \rightarrow R\cdot + H_2O}$ and decomposes them into H_2O (water) and CO_2 (carbon dioxide), e.g., $\boldsymbol{C_2H_5OH + 6H_2O_2 \rightarrow 2CO_2 + 9H_2O}$. The microplastic remains due to the long-linked carbon chains. To ensure that the reaction occurs properly, the sample is briefly heated to 90°C to release the total activation energy. After cooling down for 10 minutes, 4mL 98% H_2SO_4 are added. The precipitated Fe^{3+} ions are reduced again to soluble Fe^{2+} ions: $\boldsymbol{Fe^{3+} + e^- \rightarrow Fe^{2+}}$. For a stable suspension and good microscope evaluation, 10mL of the 0.1% surfactant TWEEN 20 is added.

The microplastic evaluations were carried out with a VH-Z100R microscope from Keyence with a 100·100x magnification. The microscope's digital programme was used for the evaluation. The programme was unable to detect any particles in the micrometre range. The lint filter from Miele filters out all particles larger than 10mm, and the one from Bosch particles larger than 25mm. In addition, the water sample was filtered through a 5mm sieve, as particles are only considered microplastics if they are smaller than 5mm. In the first part of the project, we recorded all particles and created comparative tables. This approach took several weeks. It was now dispensed in the second phase. The particle diameters and sizes were determined and compared on a test basis.

2.2 Results

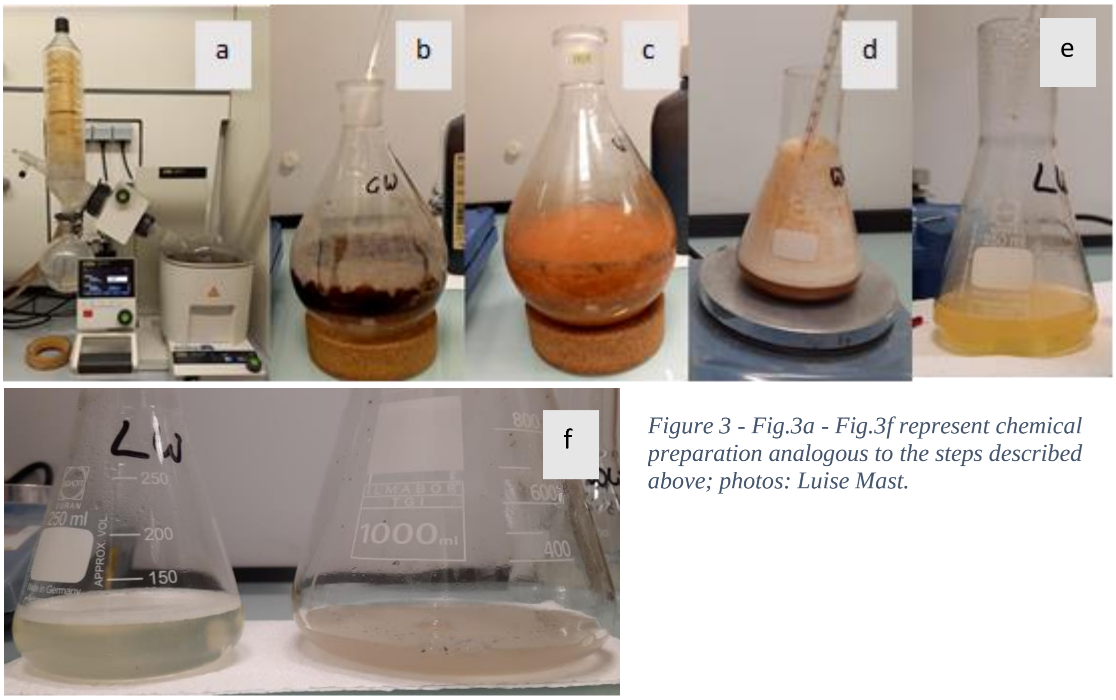


Figure 3 - Fig.3a - Fig.3f represent chemical preparation analogous to the steps described above; photos: Luise Mast.

Microscope evaluation:

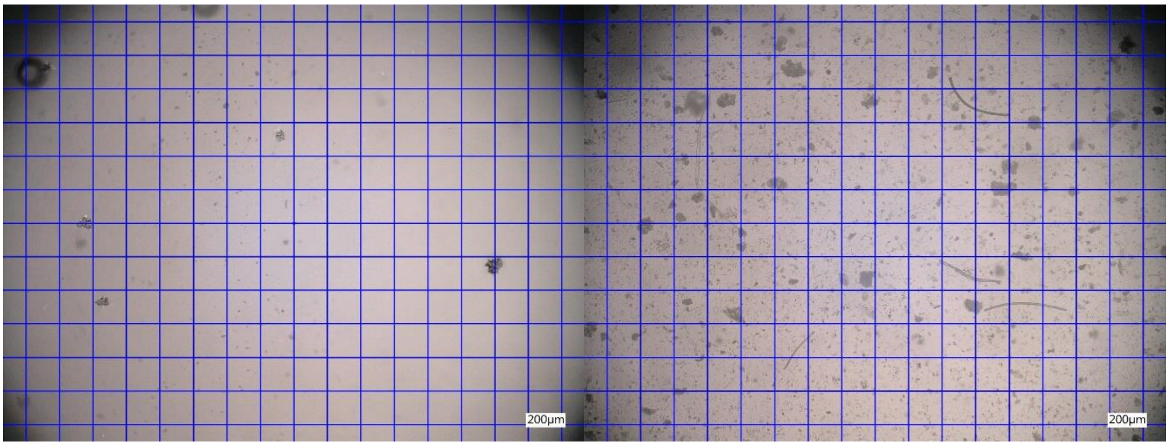


Figure 4 - Fig.4a (left) shows tap water, Fig.4b (right) shows washing machine wastewater; Photo: Microscope; Luise Mast.

Comparing the tap water samples with wash water samples shows a clear difference. The microplastic content has increased considerably. The chemical process and evaluation were carried out without the help of third parties.

3. Microplastic filter

3.1 Material, procedure and methods

The individual components of the microplastic filter are based on my ideas (without the help of third parties). All SolidWorks (CAD software) knowledge was acquired and applied solely through self-study without the help of third parties.

In the first phase of the project, an external filter unit was installed in the washing machine. The focus of the installation was on the wastewater hose. The wastewater should be cleaned before entering the sewage system and the global water cycle. Initial thoughts and assumptions were collected to construct a filter unit:

1. The filter and/or its case need to absorb the entire amount of wastewater of one pumping process. Concerns were that the wastewater could not be pumped out quickly enough through the filter material and would accumulate. Therefore, the individual wastewater volumes of pumping processes were collected and evaluated. It resulted in a filter volume of 7.5L.
2. The filter and/or its case should be removable to access the filter material. For this, a lid and a collection container are needed.
   2.1 To ensure that the filter material is evenly wetted, the wash water should be directed onto the filter material via a perforated plate in the lid.
3. The filter material needs a support structure. I decided to use a cone-shaped support structure. Thus, the microplastic that gets stuck on the material is rinsed downwards.
4. The microplastic should be collected in a separate container, which can be emptied regularly. The collection container was placed in the centre of the cone-shaped support structure.

Figure 5 - shows first prototypes made of plastic; Photo: Luise Mast.

5. An additional pump had to be placed behind the lye pump and the external microplastic filter unit. This pump allowed the wastewater to be sucked through the microplastic filter.

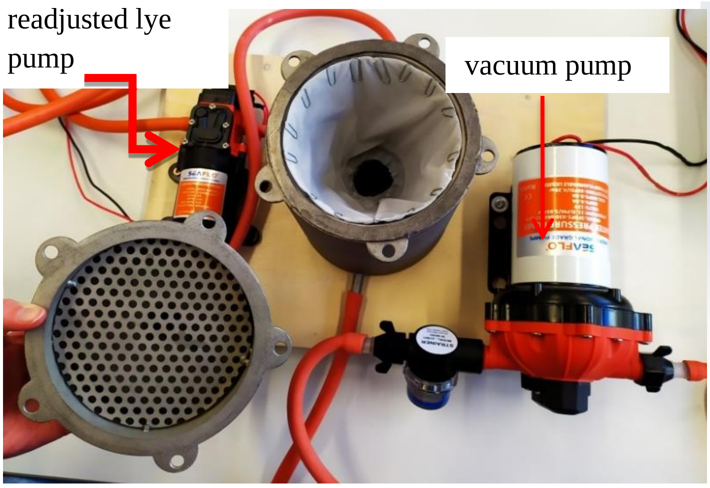


Figure 6 - shows second metal prototype during testing; photo: Luise Mast.

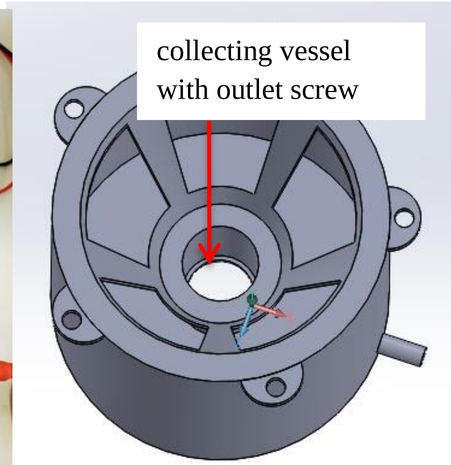
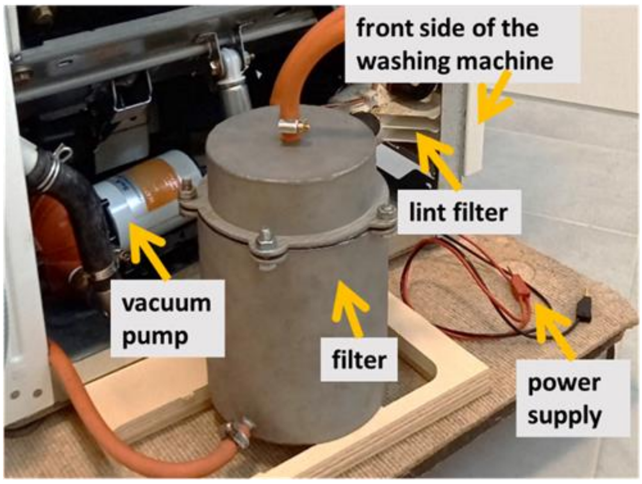


Figure 7 - shows second prototype metal filter case; drawing: SolidWorks; Luise Mast.

Two prototypes were produced with 3D printing. The first was produced from plastic according to the described design. The second was produced from metal and sponsored by Boysen GmbH & Co KG in Altensteig. Some compromises had to be made in this production. The cup is replaced by a partition wall with an outlet screw and can no longer be removed. The first prototype also taught us that a strong vacuum pump makes a large volumed filter case unnecessary. It pumps out quickly enough so that there is no significant water accumulation. Therefore, the volume of the second prototype was reduced to 2.5L. The filter was tested externally with two pumps. Due to a forced Corona break, the installation into the washing machine could not be accomplished. At this point, the second phase began. In the first step, the filter was installed with reducers in the wastewater hose. The electrical integration turned out to be very difficult. It needed a microcontroller, relay, sensor and external power supply to switch the vacuum pump in parallel with the washing machines lye pump. The sensor is attached around the cable of the lye pump. If current flows through it, the sensor detects this and transmits the values



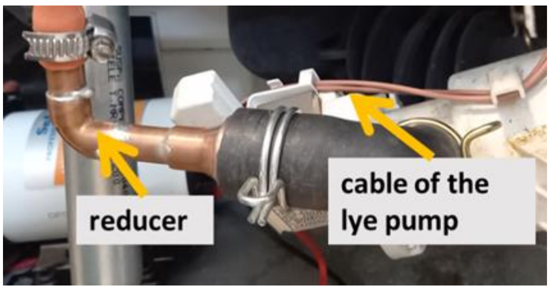


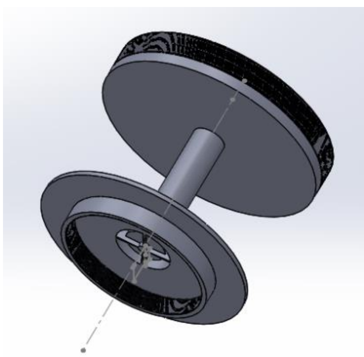
Figure 8 - Fig. 8a (left) - shows installed prototype, Fig.8b (right) shows installation in the wastewater hose.

to the Arduino. If the measured values exceed a limit, the Arduino controls the pump via a relay. Since the power supply for the vacuum pump is provided by an external power supply unit, the installation was not completed. My supervisor Heinz Weippert supported me in this process.

In the next step, I focused on the complete integration of the filter into the washing machine. To maintain the current design of the washing machine, the microplastic needs to be filtered after the lint filter and before the lye pump. By this, large particles are first filtered out by the lint filter and then smaller microplastic particles by the microplastic filter. This consideration led to the direct arrangement of the microplastic filter with the lint filter. This design allows the existing opening on the front of the washing machine to be used for emptying the lint filter and the microplastic filter unit, thus enabling a user-friendly and already familiar emptying mechanism of the filters. This arrangement also eliminates the need for a second pump. Additionally, the electrical integration is simplified, and constant control of the filter is guaranteed. The washing machine has a sensor that detects when the pump-down time is too long and interrupts the washing process. This functionality is now also used to detect a full microplastic filter. No additional sensor is needed.

Construction:

1. **The lint filter:** There are two standard lint filters from Miele and Bosch-Siemens on the market. The lint filter from Miele is installed as standard in all washing machines. The Bosch-Siemens lint filter varies slightly depending on the washing machine model. However, the design remains the same. They do not have a connection surface for the microplastic filter unit. A connection piece with internal threads has been fitted to the flat bottom surface.



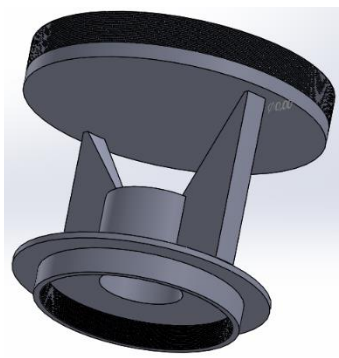


Figure 9 - Fig.9a (left) - shows current lint filter Miele, Fig. 9b (middle) shows new lint filter for Miele and Fig.9c (right) shows new lint filter for Bosch; photo/drawings: Luise Mast.

2. **The microplastic filter:** The microplastic filter should have two parts to guarantee a clear separation between microplastic and wastewater. The first part is a support basket, and the

second is a filter net. Both have a cylindrical shape. The bottom and casing of the support basket consist of a perforated plate. It is open at the top to guarantee unhindered water flow into the filter net. Thus, the filter net can be inserted together with the support basket. The filter net is attached to the upper edge of the support basket with a tension ring. The upper opening holds an external thread, which can be screwed onto the connection piece of the lint filter. A flat seal is fitted between the microplastic filter and the lint filter to guarantee the wastewater's flow through the filter.

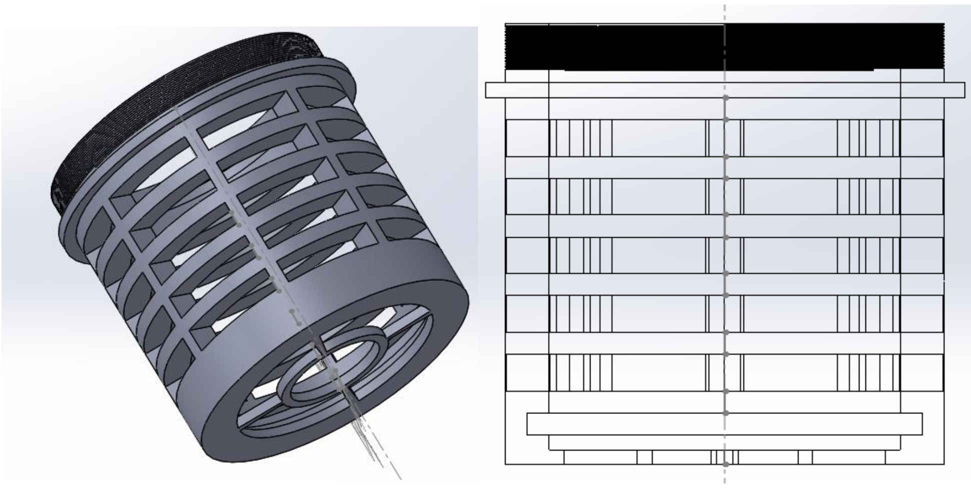


Figure 10 - shows the microplastic filter in Fig.9a-9b; drawings: SolidWorks, Luise Mast.

3. **The lint filter case:** The lint filter case had to be extended due to the arrangement of the microplastic filter. All other dimensions remained the same. Since a vacuum pump replaced the lye pump, it can no longer be attached directly to the lint filter case via a bayonet fitting.

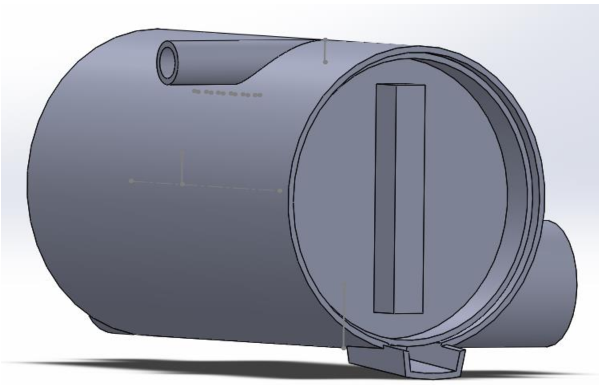
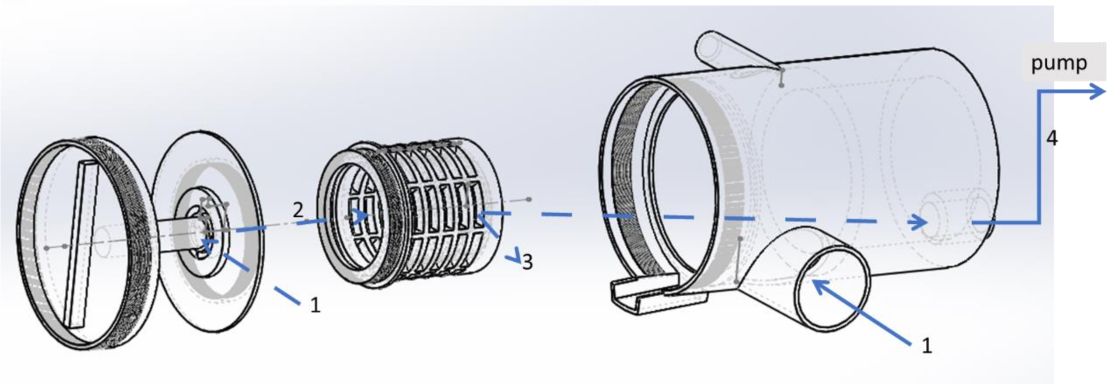


Figure 11 - shows the lint filter housing from the outside; drawing: SolidWorks, Luise Mast.

Figure 12 - shows exploded view of the lint filter housing. The sequence of numbers is to represent the wastewater path; drawing: SolidWorks, Luise Mast.



4. Thus, a short connecting piece has been mounted. A short hose was attached to the piece feeding the wastewater directly into the pump.
5. **The vacuum pump**: A more powerful vacuum pump replaced the previous lye pump to enable the pumping of the wastewater through the fine-pored filter net. As the new pump operates with 12V direct voltage, a power supply unit is required. The power supply unit converts the 230V alternating voltage into 12V direct voltage. We can regulate the amount of wastewater via the adjustable direct voltage. The connection for the power supply unit is taken after the on/off switch via so-called wire-tap connectors. The cable from the lye pump is used to control a relay that switches the 12V circuit for the vacuum pump. My supervisor Heinz Weippert supported me during the electrical integration and installation of the filter into the washing machine with the electrical integration.

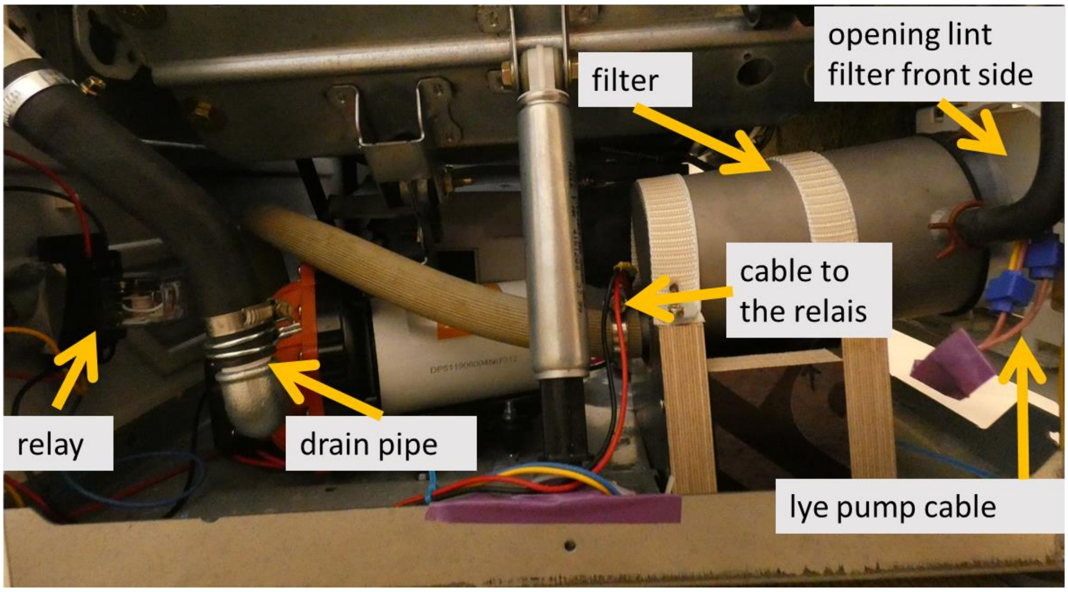


Figure 13 - shows the washing machine (left side of the housing) with the filter housing installed.

When the wash water is pumped out during the washing process, the cable of the lye pump is activated. The signal is intercepted and passed on to the relay. This relay controls the replaced lye pump, i.e. the vacuum pump. The additionally installed power supply unit powers the pump with electricity. The wastewater is cleaned and pumped out.

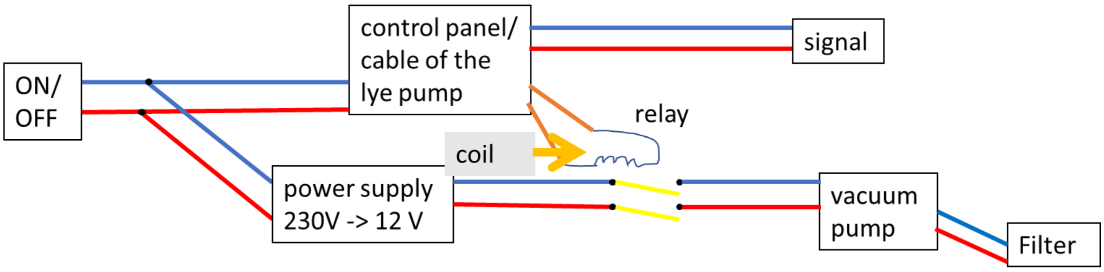


Figure 14 - shows the circuit diagram of the vacuum pump with new filter unit; drawing: Luise Mast.

If the lint or microplastic filter is full, the washing machine detects this automatically. A sensor measures the duration of the pumping process. If it takes longer than usual, it sends a signal. In this case, the washing machine blocks after the washing process, and the user must remove and clean the lint and the microplastic filters.

Figure 15 - shows the built-in power supply unit, view: right side of the washing machine, edge to the rear wall; photo: Luise Mast.

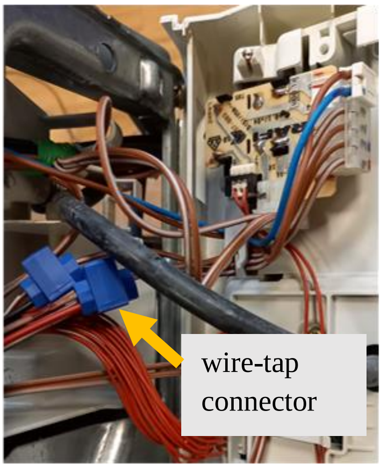


Figure 16 - shows the tapping of the cables with on/off cables with wire-tap connectors; photo: Luise Mast.

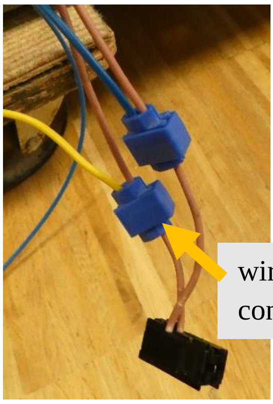


Figure 17 - shows the tapping of the layer pump cable signal with current thieves; photo: Luise Mast.

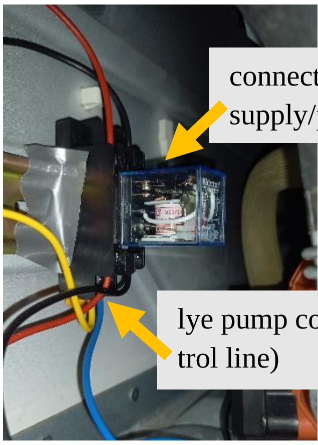


Figure 18 - shows installed relay; Photo: Luise Mast.

3.2 Results

The filter was planned to be made from metal using 3D printing, but this was impossible due to its complexity. The structure was discussed with engineers and 3D printing staff from Boysen, and a few changes were made:

1) Since making a screw thread in the customized version is too complicated, three screws are attached to the respective positions instead. For this purpose, the dimension between the case and the lint filter was changed. The lint filter is no longer screwed into the case but attached in front of it. The three screws are used to fix it to the housing.
2) The outlet channel was omitted during production, as the new arrangement of the lint filter would no longer allow for a seal. This channel is to be fitted after the production.

3) The pipe sockets are no longer attached tangentially but radially. In this way, the connecting pieces can be welded on.

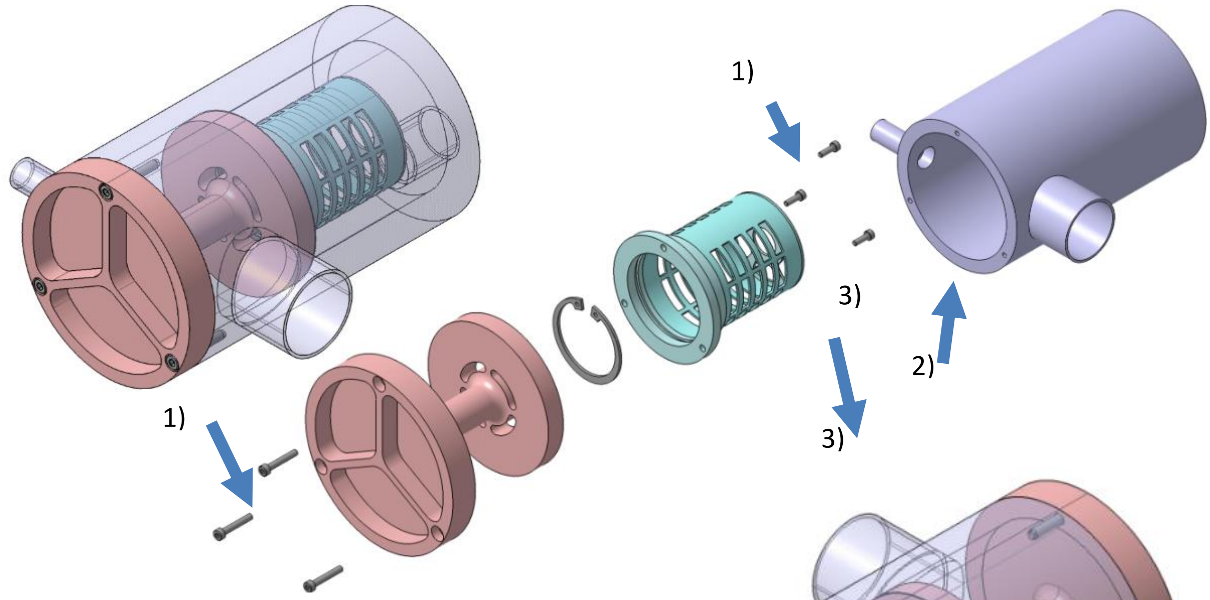
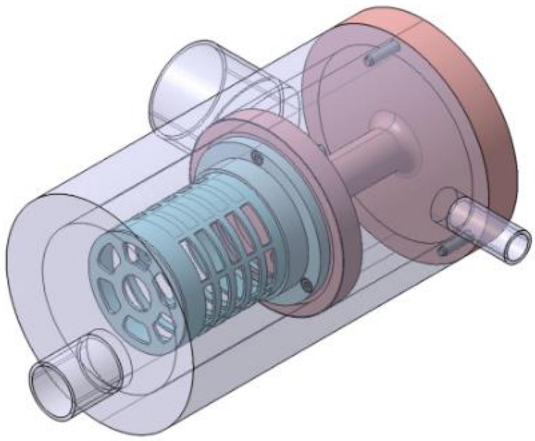


Figure 19 (above) - shows the filter unit for production; drawing and photo: Florian Ziegler.

Figure 20 (right) - shows filter unit from behind; drawing and photo: Florian Ziegler



As a Miele washing machine was used for the trial, the lint filter was produced by Miele. With the help of laser technology and partly 3D printing, the filter is made of aluminium, stainless steel and other metals. Completion took place on February 9, 2022.

Figure 21 - shows the lint filter from the side, yellow circles indicate screw connections; Photo: Luise Mast.

Manufacturing:

Lint filter:

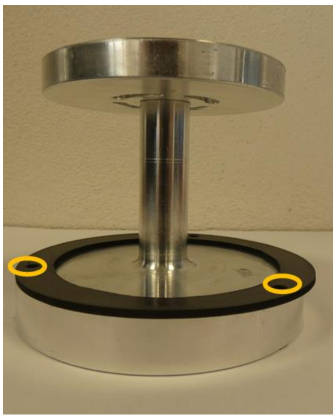
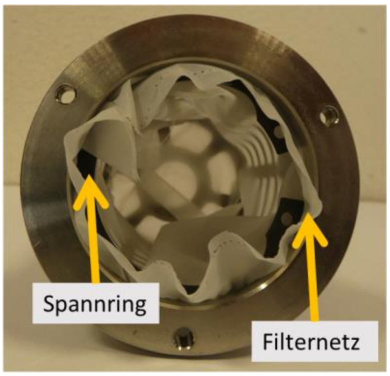


Figure 22 (left) - shows the lint filter installed in the housing from the front, yellow circles indicate screw connections; Photo: Luise Mast.

Figure 23 (right) - shows the lint filter from the side, yellow circles indicate screw connections; Photo: Luise Mast.

Microplastic filter:



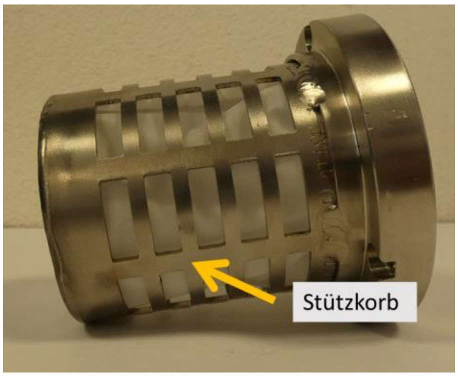


Figure 24 (left) - shows the microplastic filter with filter net from the front/top; Photo: Luise Mast.

Figure 25 (right) - shows the microplastic filter with net from the side; Photo: Luise Mast.

Housing:

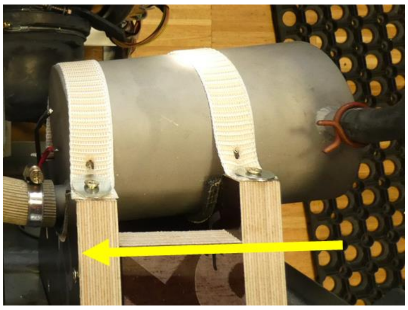


Figure 26 (left) - shows the housing installed from the front; photo: Luise Mast.

Figure 27 (right) - shows the casing installed from the left side, yellow arrow is to represent direction of extension; photo: Luise Mast.

Complete filter unit:

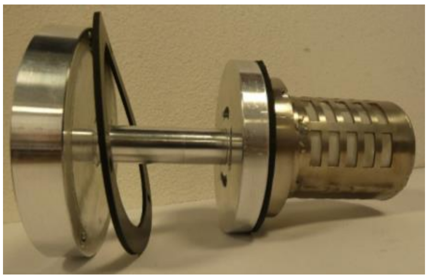


Figure 28 - shows the complete filter unit assembled (lint filter with microplastic filter); Photo: Luise Mast.

Evaluation:

Figure 29 - shows filter net after use; Photo: Luise Mast.

The filter net of the microplastic filter was very dirty after washing, showing that microplastics were caught. The microscope evaluation also confirmed this finding: Only two microplastic particles could be detected in the filtered wastewater sample under the microscope. A user-friendly clamping ring was bent so that the filter can be operated and emptied without additional tools in the future.

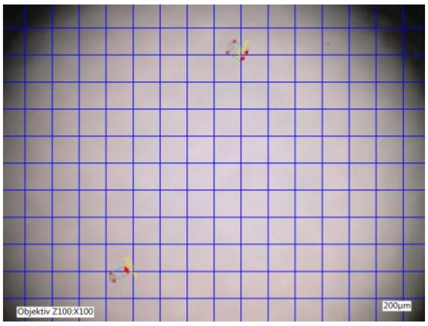


Figure 30 - shows the microscopic evaluation of a filtered wastewater sample with two microplastic particles (marked); Photo: Luise Mast.

Figure 31 - shows new tension ring; photo: Luise Mast.

4. Summary

4.1 Discussion of results

The fundamentals had to be laid in the first phase of the project. In the beginning, we were still very inexperienced. We first had to learn how to find and use scientific papers on chemical processing. A big challenge was the English language, which was insufficient to understand and compare scientific papers at that time. To examine the prepared samples, we needed a special microscope that could be connected to a camera and laptop. The school had a microscope with a camera, but the driver CD for the analysis programme was missing. After several weeks we found a test version with which we could activate the driver of the CD. In parallel, we had to find out how and where to install a filter in the washing machine. Our basic technical knowledge and experience of manufacturing possibilities and methods were initially limited, so the basic construction ideas were not practical and were discarded several times. After the first feasible design – the first prototype – was available, the next challenge came up: the technical drawing. We wanted to produce the design with 3D printing. Therefore, it had to be implemented in a technical drawing programme. First, we tried the programme TinkerCAD. However, it quickly became apparent that a professional programme was necessary for the construction. Therefore, we used the CAD software SolidWorks. It took several weeks until we were able to use the programme. We also looked for a suitable filter material and finally used the laundry bags from GUPPYFRIEND.

The second prototype was completed three days before the Jugend forscht regional competition in 2020. Thus, it was not possible to install it before the competition. After winning the regional competition, we were highly motivated and anticipated installing the filter before the state competition. This step could no longer be completed, as the first Corona lockdown started two weeks later and we were not allowed to meet for the installation. After the great disappointment caused by the cancellation of the state competition, we wanted to submit the project again to the Jugend forscht competition in 2021. After the summer holidays, we were able to resume our work. Two weeks later, the Corona regulations were again tightened, and all activity meetings at school were prohibited until further notice. We no longer had the opportunity to resume the project until the Abitur in 2021 and had to withdraw the project from the Jugend forscht competition.

After graduating high school, I wanted to install the filter and finish the project. The change of location to the youth research center (JFZ) in Nagold and new supervisors opened new doors for me. The installation was complicated but brought much motivation. I decided to rethink the project and resume it. Thus, the break also had several advantages. I was now older and had more knowledge and experience. There was no time pressure to finish the project as quickly as possible. I could build on the fundamentals of the first phase and reapply the knowledge I had gained. The change of supervisor also brought a new perspective to the project, and new questions were discussed. A big challenge was that I was working alone on the project. I could no longer have discussions with my partner, and it was more challenging to keep track of things. I started to focus on the nature of the washing machines and had a straightforward task compared to the first phase. The first prototypes showed several possibilities for improvements. I took these on board and was able to look for specific solutions with a focus on a complete integration into the washing machine:

1) The size: Both prototypes were too big to be integrated into a washing machine. I looked for free space in the washing machine and focused on the space behind the lint filter.
2) Additional pump: The additional pump was discarded, and a powerful vacuum pump was installed behind the filter case instead of the washing machine's previous lye pump.
3) Electrical installation: By replacing the lye pump, a power supply unit is now needed. This unit could be incorporated without a microcontroller and sensor. The connection of the lye pump is now used for this unit.
4) Clean separation between microplastics and wastewater: Due to the construction of a support basket and a filter net, the microplastics remain without wastewater. When the filter net is full, it can be removed and replaced. It is no longer present as contaminated wastewater, which can be removed via a drain plug and must be disposed of as hazardous waste.
5) Sensor: The detection of a full microplastic filter is guaranteed via the sensor measuring the pumping time of the washing machine. In this case, the washing machine blocks after the washing process. This function did not exist in the first two prototypes.
6) Replaceable filter material: The filter material is no longer fixed in the filter with silicone but can be easily removed and replaced via a clamping ring.

Due to the late completion of the filter (one week before the regional competition), it became very stressful. It still had to be installed and tested. In addition, the samples had to be chemically prepared and examined. Due to the prolonged shutdown of the washing machine, many deposits accumulated, which came loose during the first wash cycle and clogged the machine, including the filter. A contaminated chemical was used in the chemical treatment, and the test could not be evaluated. Despite these delays, everything was completed, and I successfully participated in the national competition.

4.2 Summary and outlook

In retrospect, I am satisfied with the project's status, as a functional solution is available. The first part of the project was still far from this goal. Now, the focus of the project needs to shift to possibilities for mass production. The presented filter unit is a custom-made production. As a result, some accommodations had to be made in production, which now needs to be resolved. The prototype was currently manufactured in individual parts. However, this could be done in mass production by injection moulding with a stable plastic. The screw connection of the filter unit has to be adapted in a user-friendly way. It needs to be operable without tools or aids so that no difficulties arise for the user. The drainage channel, which has now been omitted, needs to be reattached. Otherwise, water could get inside the washing machine when the filter unit is emptied. Furthermore, the lye pump should be replaced by a vacuum pump with 230V alternating current voltage so that no additional power supply unit with relay control would be necessary. Depending on the number of washing cycles and the various washing programmes, the filling level of the filter network needs to be observed and evaluated.

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