Clean Waters final report

PDP 2023

1 Contents

2 Introduction

The PDP 2023 course was a challenging yet rewarding experience for our team. We started with great enthusiasm and ambitious goals for the project, but as we encountered various difficulties along the way, we had to adjust our expectations and persevere through the obstacles.

We faced a range of challenges, from technical limitations and time constraints to unexpected setbacks with our original sponsor. However, with the support of our dedicated project managers and the connections of the course staff, we were able to secure a new sponsor and develop a new topic that built on our initial interests in microplastics.

Our focus eventually narrowed down to microplastic sample processing, which presented us with a complex set of subsystems to tackle within a limited timeframe. Despite these challenges, our team maintained a positive outlook and remained committed to delivering a high-quality product.

Throughout the course, we gained valuable experience in project management, teamwork, problem-solving, and communication. These skills will undoubtedly serve us well in our future endeavors, and we are proud of the final product we developed. We invite you to read on to learn more about our journey and the successes we achieved along the way.

3 Who We Are

3.1 Team Introduction.

Our team is a diverse group of 10 members who come from different academic backgrounds and educational institutions. Six of our team members are pursuing master's degrees at Aalto University, a prestigious institution known for its research-intensive programs and focus on innovation. The remaining three members of our team are studying at HAMK University, which is renowned for its practical approach to education and emphasis on hands-on learning.

Figure 1: Team Poster

3.2 Background - Why Microplastics?

Should we be concerned about the widespread presence of microplastics in our environment and their impact on wildlife and human health? Do we want to make a difference and contribute to a cleaner and healthier world? Then it's time to invest in the development of new technological solutions that can help us address this serious pollutant.

Figure 2: Microplastics

Microplastics are tiny plastic particles that are less than 5 millimeters in length and can persist in the environment for hundreds of years. They have been found everywhere, from the most remote places such as the Arctic and Antarctic regions to our oceans, rivers, lakes, soil, and even the air we breathe. Microplastics are ingested by marine life, which can have devastating consequences on their health and survival. Moreover, microplastics can enter the human body through food, water, and air, and there is evidence to suggest that they may have adverse health effects, including inflammation, immune system dysfunction, and cancer.

Unfortunately, there is currently insufficient data on the effects and sources of microplastics to enforce new laws that ban their use. The heterogeneity of methodologies used to study microplastics also jeopardizes the comparison between studies. That's why we need to invest in the development of new technologies and standardized methods to monitor, extract, purify, and identify microplastics in a reliable and efficient manner.

We must act now to tackle the growing problem of microplastics. Approximately 26 million tons of plastic out of the total 300 million tons produced annually find their way into the ocean, resulting in a staggering 5.25 trillion plastic pieces floating in our seas and oceans. This number is projected to rise significantly in the coming years, making the situation even more alarming.

Investing in the development of new technological solutions to tackle microplastics is not only the right thing to do, but it's also good for business. Companies that develop innovative solutions to tackle microplastic pollution will be at the forefront of a growing market that demands sustainable and eco-friendly products. Join us in the fight against microplastic pollution and be part of a cleaner, healthier, and more sustainable future.

4 Our path to the final project topic

In this section, we will discuss the journey we took to arrive at our final SYKE project topic. Our experience is divided into several parts, each of which highlights important stages in the process.

4.1 Sponsor Selection and the Start of Our Journey

The first significant milestone in the course was the distribution of sponsors among the teams. The team forming process was smooth and straightforward, and most teams were satisfied with the sponsors they received. However, some conflicts are unavoidable, and we happened to be part of one of the only two teams that selected the same sponsor during the first round. As a result, apart from three sponsors, every other sponsor was immediately taken, and we had to go to a vote with our pick. Unfortunately, we lost the vote by a couple of votes and had to concede on the sponsor.

This created a rather difficult situation for us, as we weren't originally planning on going after either of the remaining sponsors and hadn't put much thought into them. Moreover, we were still a freshly made team, which meant we were still working on effective communication and decision-making, which was further complicated because we weren't yet fully comfortable around each other. Lastly, we only had like 30 minutes to make the decision, and we couldn't keep the course personnel waiting only because of us. However, we managed to choose one of the sponsors based on the quality of their presentation and the general feel that we got from them during the very short meetings we had. This is how we ended up having ECSens as our sponsor.

4.2 Our Original Sponsor: ECSens

ECSens is a small spin-off company created within the University of Twente. In early 2023, it had only eight permanent employees, and their main and only product is a high-tech nano-sensor and the system around it that can count individual virus and bacterial particles in liquid biopsies. The sensor works by pushing the liquid biopsies through nanoscale tubes and counting the electrical signals generated when the viral and bacterial particles interact with the antibodies inside the tubing. These signals are then counted to give the user the precise number of measured particles within the biopsy. Each antibody type can interact with a single type of particle, and there is no theoretical limit on how many tubes can be put parallel to each other or how many different antibodies can be put in series inside one tube. This theoretically allows the user to measure tens of thousands of different bacteria and viruses using only a single test.

We started our collaboration with ECSens positively. Our team was enthusiastic about the product and the potential impact it could have. We quickly arranged a meeting to discuss our ideas and how we could help. The initial communication with ECSens was promising, and we were excited to work on a project with such a promising technology.

4.3 Our Relationship with ECSens Breaks Down

We have decided to part ways with ECSens due to some challenges we faced during our collaboration. Although we put in efforts to establish a clear direction and make progress, the lack of communication and a clear project scope made it challenging to set concrete project goals. As time went on, the situation became more difficult, and we were not seeing the expected results. Despite these challenges, we appreciate the opportunity to have worked with ECSens and wish them all the best in their future endeavors.

4.4 The Search for a New Sponsor: SYKE

A couple of weeks of general research, we were able to create our first plan for the system that would be built around the sensor. This initial plan was to build a floating water beacon type of system that could be followed using a GPS and that would continuously take measurements. However, this type of system was an enormous uptake, something which we recognized. Therefore, after a couple of more weeks of more research this plan ceased because one of our group's members was able to find an already existing system called FerryBox that could be used as a platform for our project. This would allow us to reduce the scope of our project, which in turn might help us increase the system's overall quality and increase our chances of delivering something functional and usable.

Now the FerryBox that we found is something called a through-flow system that can be attached to larger boats such as cargo ships or ferries. It essentially just pumps subsurface water from outside the boat, removes the big sediments and air from the pumped water, before finally draining the water back outside the boat. Its main purpose is to serve as just a platform on which researchers can create their own water measuring and sampling systems without having to worry about how they will supply the water as they can just use the water supplied by FerryBox. And to make things ever simpler, the FerryBox contains a central computer that is used to control everything and log all the data. All this reduces the researcher's workload and just generally makes it easier for especially smaller groups to get into the field of water research. And since the water management is done by only one system, it requires only a minimal amount of maintenance by the host ship and even this can be removed as long as they let researchers board the ship when it is docked.

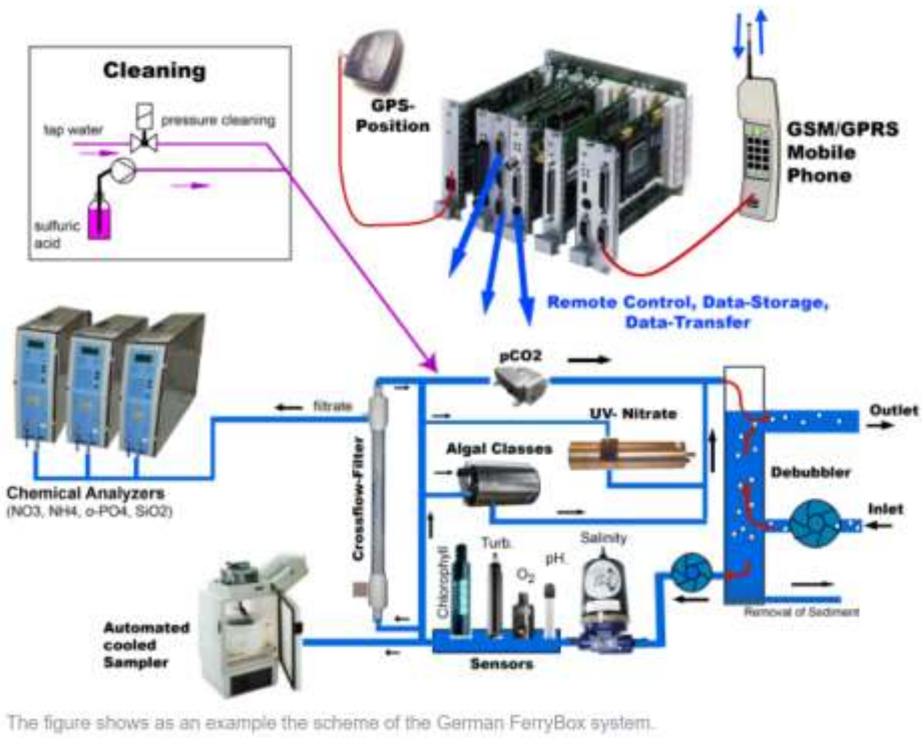


Figure 3Ferry box system

Now how would all of this affect us. The main thing was that it would make our project simpler because we could use the readymade functionality of the FerryBox. Additionally, our system wouldn't need to be as robust as we would be relocating our system from the harsh outside environment into relative safety inside the ship. The secondary thing was that, since our system would now be an extension to an already existing system, it would be much more likely that it would be helpful for someone after the course ends.

Unfortunately, during this whole time, our sponsor's representative hadn't been that receptive to our ideas. While he hadn't been outright against anything, he hadn't given us any encouragement or useful feedback either. Their main point of contention was that their sensor wouldn't work for outside water as it would contain too much non-relevant matter which would clog it even if we filtered out all the bigger matter. We discussed this problem within the team extensively, but we couldn't find any reasonable solution that we could use to solve this. We also explored possibilities of trying to measure something else, but we quickly realized that anything we could try to use apart from human/animal bodily fluids would most likely have the exact same problem. Therefore, it wasn't possible for us to solve it which meant that we had to just assume that it would work or there would exist a system/method that could prevent the clogging.

4.5 What Went Wrong with our sponsor?

After analyzing the situation with ECsens, our team had a series of constructive meetings to assess what went wrong. Although it is difficult to be completely objective as one of the parties involved, we took responsibility for our part in the breakdown. We identified that about 20% of the blame could be attributed to our team, primarily due to communication issues and unclear planning. If we had communicated more effectively and planned better, we might have been able to avoid some of the problems and maintain a positive relationship with ECsens.

Approximately 50% of the blame cannot be assigned to anyone in particular. We acknowledge that cultural differences may have played a role in our perception of ECsens' representative, and their membership in EU ATTACT may have affected their level of motivation to participate fully in the course. Additionally, their system was highly specialized, limiting the scope of what we could do with it. However, some of the blame can still be attributed to ECsens for their inflexibility and lack of effort in understanding our team's objectives. Although we acknowledge that the hectic period of their product launch may have affected their level of participation, we believe that they could have been more transparent about their challenges, allowing us to work around them and maintain a positive relationship.

Finally, we attribute the remaining 30% of the blame to ECsens for their lack of professionalism and transparency in the project. They appeared to have little interest in working with our team and made little effort to prepare for the course or understand our objectives. Had they been more transparent and willing to work with us, we could have addressed the problems and salvaged the relationship. Nonetheless, we appreciate the opportunity to work with ECsens and remain optimistic about future collaborations with them or other partners.

4.6 Exploring Our Options

After the Christmas break, our team faced some challenges that ultimately turned into valuable learning experiences. We had several topics to discuss, which we spread across multiple meetings to ensure that everyone had sufficient time to reflect before making decisions. However, the confusion and motivation loss caused by the ECSens breakdown had a significant impact on our already damaged motivation levels. As a result, some team members put forth less effort than before, which slowed down progress.

Despite these difficulties, we persevered and eventually started to make decisions more quickly. However, because we were behind schedule and needed to find a new topic, we had to explore multiple paths simultaneously, which slowed down progress even further. We quickly realized that we couldn't spend months brainstorming and researching multiple paths, so we chose the most promising ones: the use of satellite data, FerryBox, and SYKE.

While the idea of using satellite data seemed promising at first, we soon realized that it would require a significant amount of data processing. This would involve custom-made algorithms and complex mathematical models, which our team didn't have the expertise to develop. Moreover, even if we were able to create an algorithm, building a system around it would take too much time, given our schedule.

Our next idea, the FerryBox, was our final plan for ECSens, and we had already put a significant amount of effort into it. However, we found out that the people responsible for the FerryBox had already been researching ways to add microplastics sampling to it. This meant that anything we did would most likely be redundant, which wasn't very motivating for us.

Fortunately, our team managers had been in contact with SYKE, and this collaboration proved to be fruitful. We didn't have any specific plans when we approached SYKE, but they had several ideas about microplastics that they would like us to work on. We were most drawn to their biggest microplastic analysis bottleneck: the sample processing process. This process required multiple small steps and long wait times, which were not only time-consuming but also created a prime environment for human error. We realized that this process was an excellent target for automation, which matched our team's skills and would be helpful if we could build it.

In conclusion, our team faced several challenges, but we ultimately learned valuable lessons from them. We realized that we couldn't spend too much time researching and brainstorming and that we needed to choose our ideas carefully. We also learned that setbacks and failures can lead to new and more promising opportunities.

4.7 Refining Our Topic With SYKE

There doesn’t exist any single standard way to process microplastic samples. This is because microplastic detection is still an emerging field that has just begun to gain significant traction in the last decade or so. This means that new methods for detection and removal of unwanted matter are emerging constantly, and no one knows what exactly what the best method is to do either of those things. Therefore, it is uncommon that different research groups would happen to use exactly the same processing method.

Figure 4: Syke logo

In the case of SYKE, the extremely simplified version of their process is comprised of the following. Firstly, if the sample is taken from sediments, they use sodium iodide to density separate most of the unwanted matter from the sample. After this, the sample is filtered and divided into two portions, one that contains all particles bigger than 500µm and one that contains everything smaller than that. Then different processes are used on the two portions to separate the microplastics from the rest of the matter. This is done because particles bigger than 500µm can be removed by hand, while a much lengthier chemical process must be done for smaller particles. After the microplastics have been isolated, they still have to be stained using a dyeing agent called Nile red. This is done because the microplastics are small and possibly even transparent, which makes them hard to analyze. Only after all of these steps, can the samples finally be analyzed using different Fourier-Transfrom Infrared Spectroscopy (FTIR) techniques. These techniques use the different absorption and emission rates that materials have for different electromagnetic wavelengths, to get detailed information about things such as chemical composition.

As mentioned previously, this was a very simplified version of the process because otherwise this part of the report would be too long and boring. Just to give you an example, the detailed instructions document used by SYKE, that only covers the removal of unwanted matter from the particles smaller than 500μm that was mentioned in the last paragraph, is 12 pages long. It should be noted that that step is the longest one in the whole process, but it should also make it clear that it isn't even remotely feasible for us to create a system that could automate the whole process used by SYKE. Therefore, we had to find the section of the process that would reduce the workload of the researchers the most, while also being feasible for us to build.

This turned out to be a rather difficult task because of four reasons. Firstly, we had to minimize the amount of microplastics/sample lost during the process. This meant that every part of the system would have to be of extremely high quality for the process to minimize these losses. Secondly, we had to also minimize the amount of microplastic contaminations our system would introduce to the sample. Because of this, we were very limited in the types of components and materials we could use. Thirdly, while the process contains a lot of steps, most of them are very small and simple to do for a human such as thoroughly rinsing a filter with distilled water. Therefore, any automation we tried to do could very easily just create more work for the user thus making our solution useless. And finally, a lot of the steps require motion for them to be done efficiently, like the previously mentioned filter rinsing. However, the types of mechanical motions required in the process aren't even close to the realm of the skills our team has. Therefore, even if we managed to build something, our solutions would easily have been inefficient, too big, and ultimately just not worth the effort for the end user. All of this meant that there wasn't any good section in the process that we could try to fully automate.

This forced us to concede and to assume that the user will make at least some preparations for our system. With this assumption we were finally able to find a section that we could try to automate. The section we ended up choosing was a part of the chemical treatment process done to sample particles smaller than 500μm. In this section, the system would essentially just need to able insert correct amount of a chemical to the sample, then agitate the solution to expedite the chemical reactions and finally remove the chemical completely from the sample. This same process would then be repeated for a total of five times with different chemicals. The used chemicals and the workflow of the chosen section can be seen on the image below which is taken from SYKE brief. But as mentioned previously we had to make the assumption that the user will, for example, prepare all of the chemicals for the system. This meant that the user would still have to do things such as create the chemical solutions with the correct pH level and enzyme powders and then filter the solutions to remove any undissolved powder.

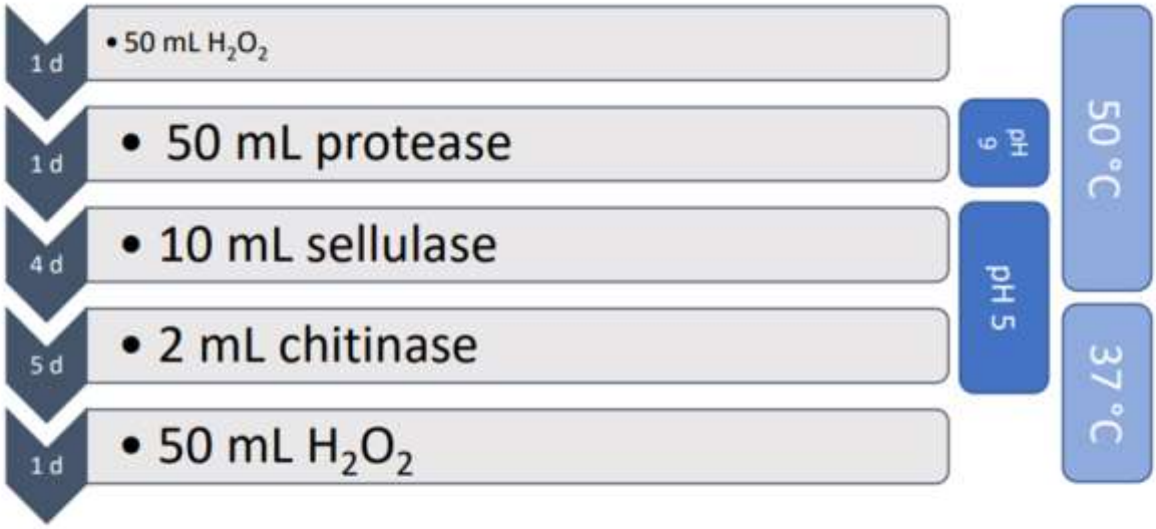


Figure 5: Process flow at SYKE

5 Design of Our System

5.1 General Description

Studying microplastics in the environment generally requires three phases: collecting samples, processing the samples to isolate microplastics, and analyzing the collected microplastics. The scope of this project covers certain steps in the second phase. Therefore, it is important to first understand the manual process flow, some drawbacks during the manual process, then, the defined extent to which this project will include.

In SYKE's laboratory, the target samples usually come in the form of sediment or liquid. Based on the type of samples, they will be treated with different steps. However, the final goal is to extract microplastic pieces from other substances or contaminants. Sediment samples will go through a density separation process to remove most of the irrelevant elements in the sample whose density is heavier than plastics. The separated samples are then partitioned with a 1 mm mesh filter. The part that is larger than 1 mm can be immediately analyzed and "big size" microplastics (> 1 mm) are easily found with a stereo microscope. The other part will go through the main processing phase to dissolve impurities and organisms potentially affecting the analysis. A liquid sample would be directly treated to the partition step.

After that, the following series of steps treat the sample sequentially to isolate microplastics and they apply to both types of samples. These steps are summarized in Figure 6. The partitioned sample (< 1 mm) will be divided into subsamples if necessary. First, all the chemicals used in the process are prepared with accurate concentrations and pH values. The enzymes come from manufacturers. All solutions use MQ water as a solvent to avoid impurities and the equipment should be cleaned thoroughly before and after making solutions. Then, the chemicals will be filtered in order to obtain the desired size below 0.7 μm. First, the sample is mixed or submerged in 100 ml of SDS in a flask. The flask is put in an incubator with a temperature of 50°C and a speed of 45 RPM for one day. Then, the flask will be removed, and the solution will pour through a 0.7 μm GFF filter (Figure 7). The flask should be rinsed thoroughly with MQ water to assure that all microplastic is transferred to the filter. This step will be repeated after every step and the same filter is used throughout the whole process. Next, the sample is treated with 20 ml of protease enzyme and 100 ml of TRIS HCl buffer. The incubator's temperature remains at 40°C and the incubating time lasts for one day. The next step uses 20 ml of cellulase and 100 ml of NaOAc. The temperature reduces to 40°C and the incubating time lasts for three days. This step can be optional for liquid samples and depends on the quality of the sample. Similarly, the sample is treated with hydroxide, chitinase and NaOAc, and hydroxide, respectively. The corresponding incubating temperature is 37°C and the waiting time is one day after each step. Lastly, the leftover on the filter is microplastic, usually stored in ethanol 70% until analysis.

While the incubating times have already been optimized with a suitable amount of enzymes and buffers, we can still notice that there are a lot of repeating manual procedures. According to a survey, SYKE's lab technician mentioned that they have to spend about 30 minutes between each step, filtering old solutions, rinsing the equipment, and proceeding to the next step. That is one of the problems which we wish to solve in this project, reducing the labor work and dead time between each step in the process. Moreover, during the sample processing, technicians interact with the samples and handle various equipment made from plastics, which may contaminate samples with extra microplastic. Hence, the results might become less accurate. Throughout the development of our system, we try to process samples in a closed environment and make use of non-plastic materials to avoid unnecessary contamination. Yet, it is still feasible to include plastic parts in places that do not directly contact with the sample flow.

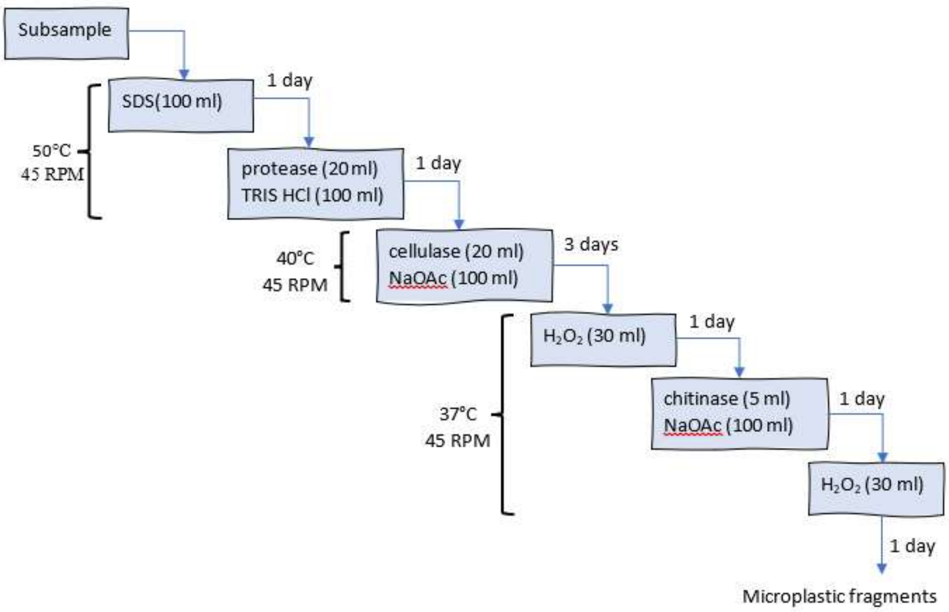


Figure 6 Process flow of extracting microplastics

Figure 7 Manual work after every step

Due to the limited time of this project, it is crucial to define and set the scope to certain steps that require the most optimization and make sure the goal will be achievable. We first focus on a device that can successfully replicate the process flow described in Figure 6. Presuming that samples have been separated and divided into subsamples, the system will cover all the chemical treatments and output ready samples for the next analysis phase. Similarly, all the previous phases such as buffer preparation or density separation should be done by technicians as normal. Since we start at this step, sediment samples have already been filtered to less than 1 mm in size. Therefore, we assume to work with liquid samples because, at this stage, both types of samples will be handled in a similar manner. In addition, the device is expected to only contain one sample at a time. By doing this, we can study and understand the basic concepts of the whole process. From there, it is possible to scale the device into processing raw sediment samples or handling multiple samples at the same time. Further developments will be discussed toward the end of this report.

5.2 Process

5.2.1 Automated process flow in detail

A closed-system processing sample needs to replicate the procedure described above. Our team came up with the idea of making a tank holding a 0.7 μm GFF filter through which the fluid can flow (Figure 8). While inorganic and other matter is dissolved by enzymes and disposed, microplastics will be held back by the filter. The filter remains in place between the tank and a connecting pipe, and these two parts are held together by a clamp. The chemicals are dispensed from above. Because the chemicals are expected to be prepared beforehand and there is some waiting time between every chemical distribution, we need a place to store chemicals, awaiting the corresponding step. For that, some kind of chemical container must be included in or near the device. Then, chemicals are delivered in order to the sample through a pipe system to the sample tank. A controller will monitor this process, assuring that the correct chemical is dispensed at the right time and in an accurate amount. The tank has the shape of a funnel, helping the flow of chemicals gather around the sample.

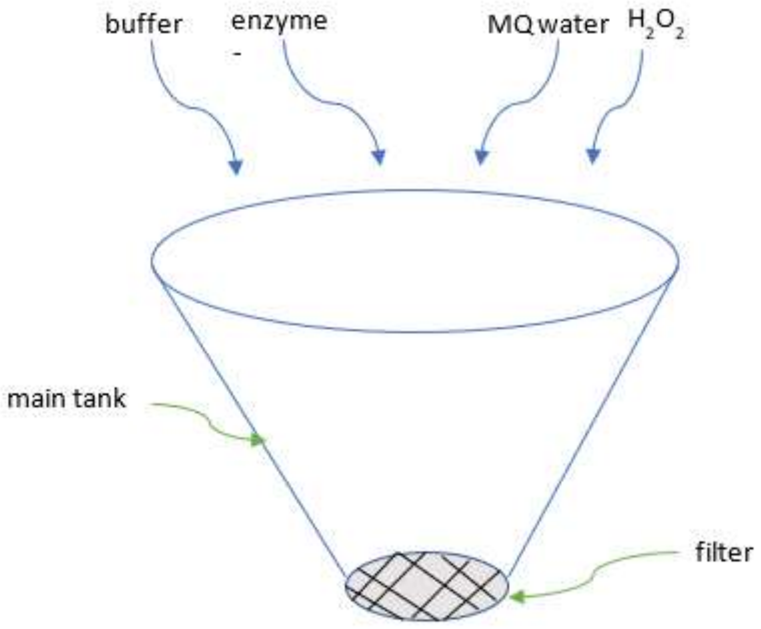


Figure 8 Top part of the funnel where chemicals are mixed with a sample and a standardized filter retain microplastics.

After an enzyme is introduced to the sample, some certain time must pass before moving to the next enzyme. The implementation of this action is sketched in Figure 9. The lower part of the funnel connects to a solenoid valve to stop the liquid. Once the required period finishes, the controller opens the valve and disposes the liquid. The filter acts as a barrier preventing microplastics from passing through, only allowing chemicals and dissolved matter to flow down to an exhausting pipe. After the liquid is disposed, a step is done and the system pumps in MQ water to clean the tank and pipes, and it moves to the next chemicals. The whole procedure loops until the sample is treated with all the necessary enzymes.

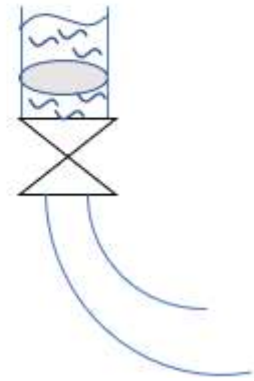


Figure 9 Bottom part of the funnel has a solenoid valve connecting to a tube

Another important aspect of the process is the incubator. It creates a suitable environment for the enzyme and helps to accelerate the dissolving time. One of the targets of the system is creating a closed environment to minimize outer contamination, thus, we are trying to simulate the incubating step with built-in equipment. The sample will stay in the funnel throughout the process, reducing the need for another machine and, at the same time, avoiding interaction with the outer environment. An incubator used in SYKE's lab basically breaks down into two main functions, providing heat and moving the sample container in a circular motion. Based on this idea, we include a cartage heater near the funnel and an orbital shaker under the funnel that can rotate in a controlled manner. This feature will be discussed later in a separate section.

5.2.2 Final Design of the Process flow

Combining all the above concepts, we have a system that replicates the manual process flow in a more efficient way. The system will have a separate control subsystem to replace manual work and for higher accuracy. The overall process is sketched in Figure 10.

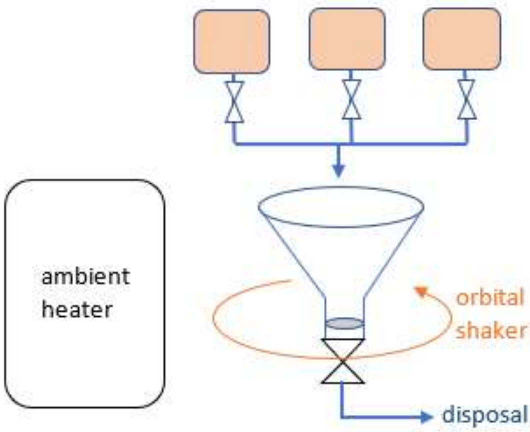


Figure 10 Sketch of the automated process

The next step in this project is to implement all ideas into a tangible product. The next sections will be dedicated to the design of mechanical components and a control system. Material selection and component selection will also be discussed.

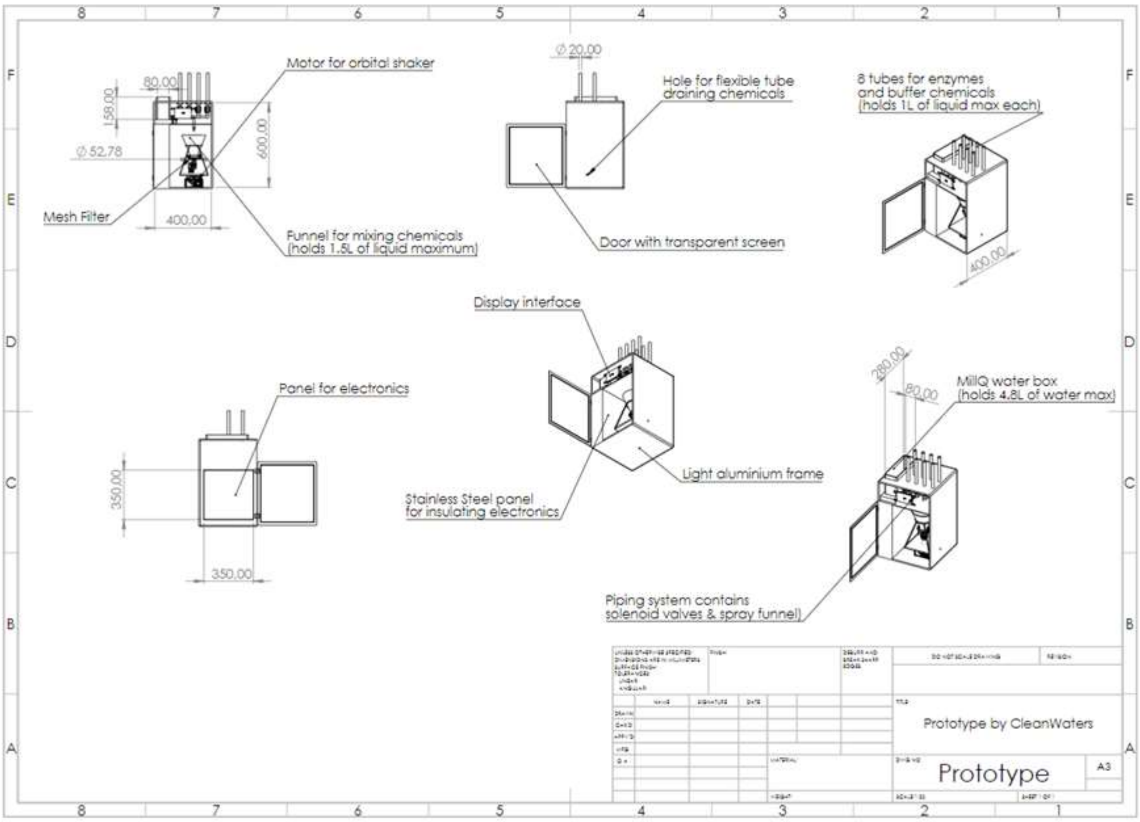
5.3 Mechanical design

The frame of our prototype is made up of 8 mm aluminium sheets on the bottom, back, right, and left sides. We initially wanted 10 mm thick aluminium sheets for better heat insulation, but the supplier Nakorauta only offer sheet aluminium up to 8 mm thickness.

For the assembly, we considered two options: welding of the sheets together at the edges or attaching them together with fasteners. The choice of frame material would have been dependent on the choice of assembly since stainless steel would makes sense or welding and aluminium for fastener assembly otherwise. Ultimately, we decided to go with aluminium since it is significantly lighter than the stainless-steel counterpart.

Initial Designs

In the initial designs, the size of the container is 600 mm by 400 mm by 400 mm as described in the mechanical drawings below. The width of the container is then increased to 500 mm to accommodate the room for the route of the orbital shaker.



A funnel for mixing enzymes and acid buffer solution is placed in the middle of the aluminium container. The material for the funnel is cut from acid resistant stainless-steel plate AISI 316 and bent into shape using a metal bender. The edges are then sealed by welding them together. The funnel holds 1.5 litre of liquid maximum, but it should only need up to 800 mm under normal operating conditions. The bottom of the funnel has a diameter of 47 mm which is identical with the diameter of the mesh filter which will be put in place. The top diameter is 167 mm with a height of 150 mm.

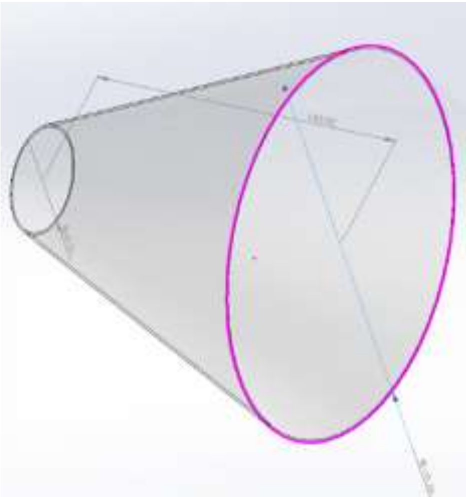


Figure 11: Funnel design

The funnel is hold in place on top of the metal plate attached to the orbital shaker by a ring holder made of galvanized iron tubes. The iron ring wraps around the middle of the steel funnel giving it a stable support while in motion. The iron ring is supported by 4 legs also made of galvanized iron pipes erected on top of the steel plate. The stand is designed to support the weight of the funnel as well as the steel clamps and the metallic solenoid valve. The valve will be connected to a flexible metal pipe which will then be drained through a hole from the right side of the panel.

Figure 12: Funnel mounted on the shaker mechanism

The door of the container is designed to be a thick aluminium sheet cut in the middle for a transparent plexiglass layer. The border of the door made of aluminium sheet will be connected to the main frame with two door hinges. A door latch made of steel or iron will be on the opposite side to ensure sealed containment.

The left chamber of the container is designed to be space reserved for all the electronics and wires. The wall of the chamber will be insulated with insulating materials such as foams. The dimensions of the chamber are designed to be 100 mm by 400 mm with a height of 450 mm.

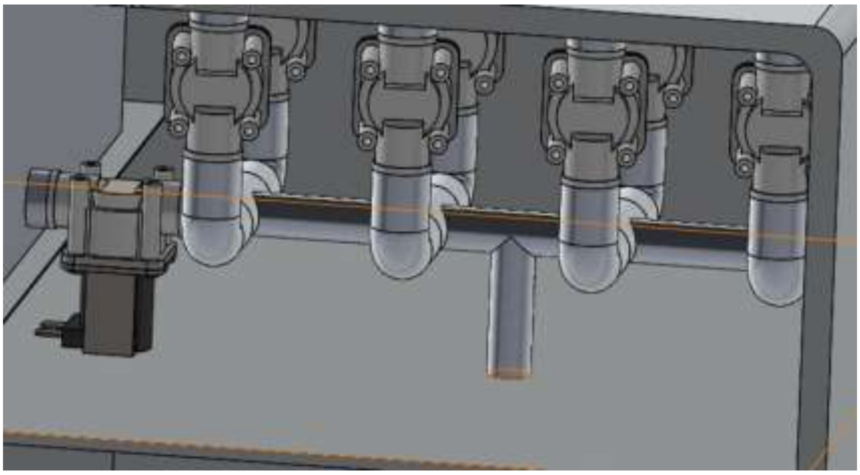


Figure 13: Piping

The top part of the container is reserved for general piping and sprinkling system. The height of the piping containment is 150 mm with 400 mm by 400 mm in size. The material of the piping system is made up of stainless-steel pipes connected by ½ inch and ¼ inch fittings. A water tank for milli-Q water is on the top left side of the container holding up to 4.8 litres of liquid in volume. The size of the water tank is 280 mm by 80 mm with 158 mm in depth.

Finally, the pipes on top of the container are designed to hold chemicals such as enzymes and acid. Each pipe with a diameter of 20 mm and height of 400 mm holding up to 1 litre of liquid each. The pipes are connected to the valves with ½ inch fittings and controlled by PLC.

Design Practicalities

When assembling the aluminium sheets with fasteners, the main issue we had is sealing. The sheets don't fit all the way and leaving gaps, not sealing together to control temperature. To solve this issue, we bought and installed some insulating silicon tapes similar to the kind commonly used on the rim of the fridges. These are installed all along the rims and the gaps to contain the thermal insulation.

Another issue with sealing is the sealing of the water tank for milliQ. The initial container is designed with aluminium and can't be sealed by welded together. Alternative methods such as hot gluing, lead soldering and super gluing were tried and tested but without success. Finally, we gave up the idea of marine aluminium being the material for water tank and replaced with stainless steel which might rust in a few years. The steel sheet is then welded together to seal it contain watertight.

A change in electric chamber was also made late in the prototype phase since the PLC box we order was a bit larger than the chamber we designed. In the final prototype, we will be placing the PLC outside the box with the wire connected to valves through holes drilled on the side. An extra ventilation fan was also installed in the place for better circulation of the airflow.

5.3.1 Tubing & Fittings

We chose to get the tubing and fitting material from Swagelok because of their faster delivery, better pricing, and easier assembly than other suppliers.

1. Swagelok SS Tube Fitting, Female Connector, 1/4 in. Tube OD x 1/2 in. Female NPTSS-400-7-8
    - Product code: SS-400-7-8
    - Quantity 2x

- Location: water pump inlet & outlet

Figure 14: Swagelok SS Tube Fitting

2. SS Swagelok Tube Fitting, Male Connector, 1/4 in. Tube OD x 1/4 in. Male NPT
    - Product code: SS-400-7-8
    - Quantity: 16
    - Location: inlet & outlet of chemical dispensing Solenoid valves\

Figure 15:Swagelok SS Tube Fitting

3. 316L SS Convoluted (FM) Hose, 1/2 in., 316L SS Braid, 1/2 in. Tube Fitting x 1/2 in. Male NPT, 18 in.
    - Product code: SS-FM8SL8PM8-18
    - Length: 45.7 cm
    - Location: Outlet of draining valve
    - A flexible tube was chosen because of it is location on the shaker moving mechanism.

Figure 16:Swagelok SS Tube Fitting

4. SS Swagelok Tube Fitting, Union Elbow, 1/4 in. Tube OD
    - Product code: SS-400-9
    - Quantity: 1
    - Location: Outlet of the chemical dispensing valves

Figure 17:Swagelok SS Tube Fitting

5. SS Swagelok Tube Fitting, Union Cross, 1/4 in. Tube OD
    - Product code: SS-400-4
    - Quantity: 3
    - Location: Outlet of the chemical dispensing valves

Figure 18:Swagelok SS Tube Fitting

6. SS Swagelok Tube Fitting, Male Elbow, 1/2 in. Tube OD x 1/2 in. Male NPT

- Product code: SS-810-2-8
- Quantity: 1
- Location: Outlet of the draining valve

Figure 19:Swagelok SS Tube Fitting

7. Seamless Tubing Stainless Steel
    - Product code: SS-810-2-8
    - Quantity: 6m
    - Location: Used for chemical dispensing area, funnel support and as wiring cover

Figure 20: 1/4" Stainless steel pipe

5.3.2 Filtering, and clamping mechanism

A funnel shaped design made from steel for the main chemical container was chosen some advantages of the design was that it was easier for the microplastic particles to be flushed down to the filter. Moreover, a tight filtering mechanism was chosen to make it easier for the researchers to add or remove the filters from KF supplier which are explained in detail below.

Figure 21:Exploded view of the clamp and filtering flanges

Filtering
We chose this centering flange with sintered stainless-steel filter.
Size: DN 40
Filler material: stainless steel
Pores width : 20 µm
Order code: KF40MCRV-303

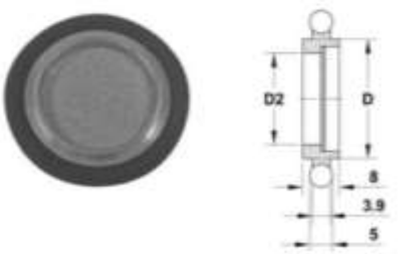


Figure 22: sintered stainless-steel filter.

Clamping
DN: 40
Order Code: TU40K20-44.5-316

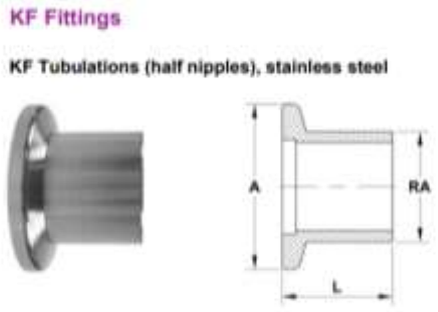


Figure 23: KF flanges

KF to NPT adapters drain

DN: 40/ Order code KF40NPT12-316/ GZ: ½” / Material: stainless steel

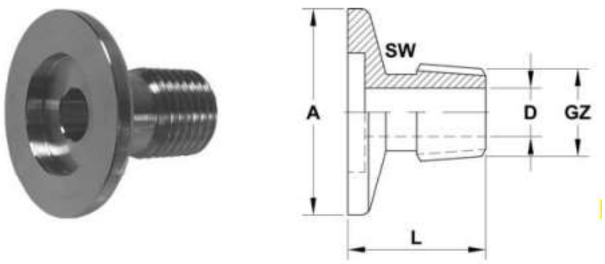


Figure 24: KF to NPT adapters

KF clamp rings

DN:40

Material: aluminum

Order code: KF40C

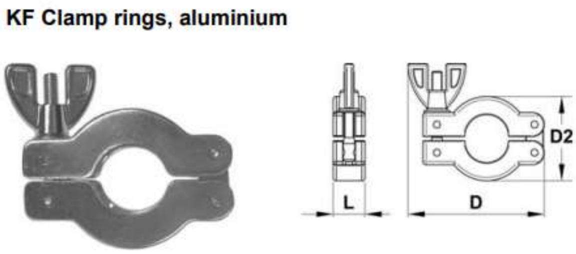


Figure 25: KF Clamp rings

5.4 Shaker mechanism

As our project is to automate the manual sample processing of SYKE, we had to mimic one of their key processes of incubation. The incubation consists of 2 processes: shaking and heating. In this chapter we will focus on the former one.

At first, we had two totally different shaking mechanism ideas. The first idea was simple but did not provide orbital shaking, which is commonly seen in incubators. Hence, we decided to go with our second idea, which was to build our own orbital shaker (OS), such as the ones used in chemical laboratories [Figure X]. The idea behind building one rather than buying one, was to be able to control it via PLC and customize it based on our requirements.

Figure 26: Example of an orbital shaker commonly used in chemical laboratories.

The goal was to recreate the orbital motion such as a common OS has, to do so we started to look for solutions on the internet. Fortunately, we found a DIY ("Do It by Yourself") project where a small OS was built [Figure 26], we got inspiration from it.

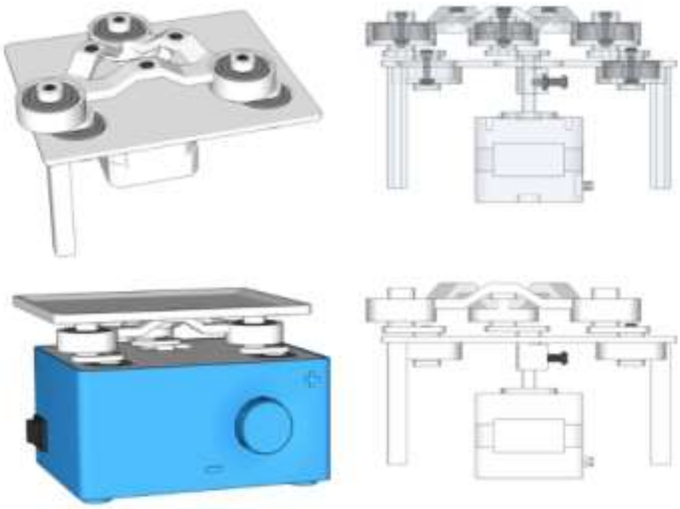


Figure 27:DIY orbital shaker

After we got a general idea on how to build the shaking mechanism then we needed to find a solution on how to place a vessel on top of it, so the motion can be transferred to it and to the solution it may contain during the incubation reaction. The solution we found was to attach the vessel to the OS using 4 pillars, as [Figure 27] shows.

Figure 28:Screenshoot of the 3D design.

Initially, we had the idea to leave a hole in the middle of the OS, so the hose attached on the bottom of the vessel could have gone through all it. The idea behind this was to use gravity to help the liquid to get out of the funnel. Later, we figured out that this could potentially make the shaker jam, and then opted to put the outlet hose through the side wall.

Another thing that we needed to consider was the weight that the OS would hold on to the top. To do so, we considered the weight of the vessel, the valve, and the hose, estimating an absolute maximum weight of around 3 kg. In addition, we knew that the desired shaking speed would be around 45 rpm, as it was in SYKE's incubator. With these characteristics we managed to find a DC motor that was powerful enough to fulfill those requirements (Figure 29). After acquiring the motor, we could finally start CAD modeling the shaker around it.

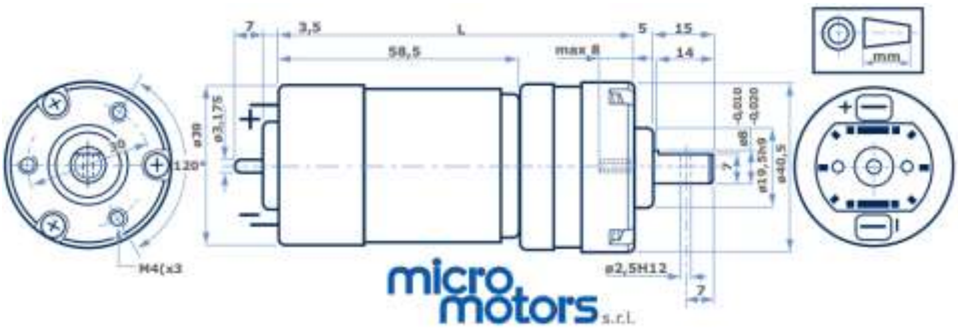


Figure 29: DC motor used, which has a gearbox to increase the torque of it (192-91-12V).

The first problem that occurred was that our orbital shaker was not stable with the 3-bearing model as shown in the DIY project. As of this, we added a fourth bearing to our iteration to make the shaker stable. Also, we did not have enough space to put the motor vertically as it was too long. Because of this we had to iterate and design our box so that the motor was placed horizontally, and the direction of the turning force was changed using bevel gears and a shaft. This then led to our second problem, that was how the shaft is supported. The problem was tackled by designing it so that the shaft is held by two bearings, one on top and one on the bottom. After we 3D printed all parts, we noticed that there had been minor design errors regarding the dimensions of our printed parts, which caused us small problems. These problems were rather easy to tackle by making the necessary changes to our CAD models and 3D print the parts again [Figure X]. In addition, some other components were laser cutted, such as the box that would keep the motor in place and secure some of the electronics needed to make it work. The result is shown in [Figure 30]

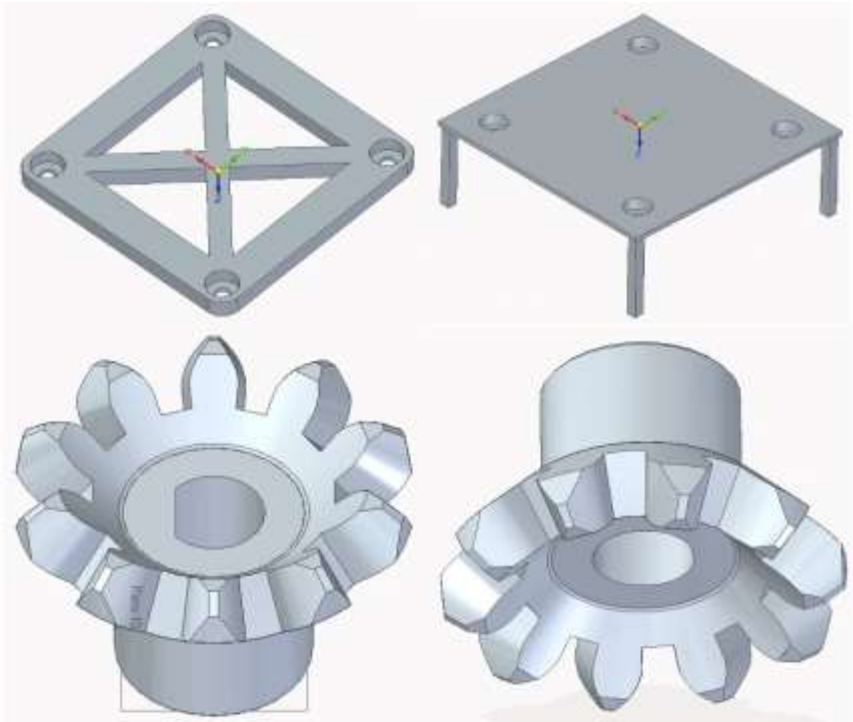


Figure 30: Models of the 3D printed components.

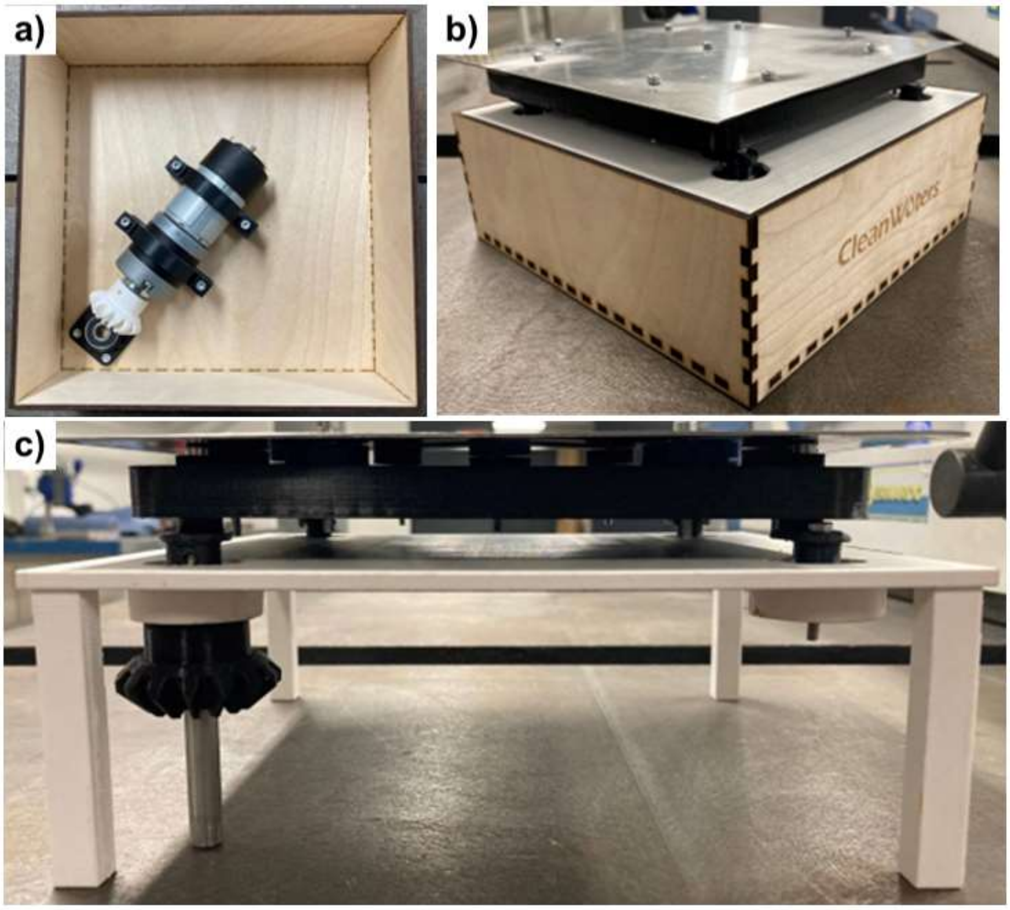


Figure 31:Orbital shaker constructed, view a) from the top (without the rotation set), b) from the side (completely assembled), and c) from the side of the rotation set.

The logic behind the shaking mechanism is fairly simple. When looking at [Figure X a] when the motor rotates it will rotate the white bevel gear. This will then rotate the black bevel gear attached to the shaft which can be seen in [Figure X c]. The rotation of the shaft will then start turning the black rotation set seen in [Figure X b,c]. Because of really clever engineering the rotation of the rotation set will then shake the vessel attached to the metal part on top of it.

Afterwards, when the OS was completely assembled, it was tested using different loads in order to be sure that the design would hold the maximum weight estimated. When this was assured, we continued to the next step: place the vessel, with all the piping, on top of the OS.

The last stage is to create a vessel holder that will be attached to the metal plate on top of the shaker. At the time of writing, this has not yet been completed, but it will be completed within the last week. The most crucial aspects to consider while developing the holder are stability and durability.

5.4.1 Electronics

Solenoid Valves:

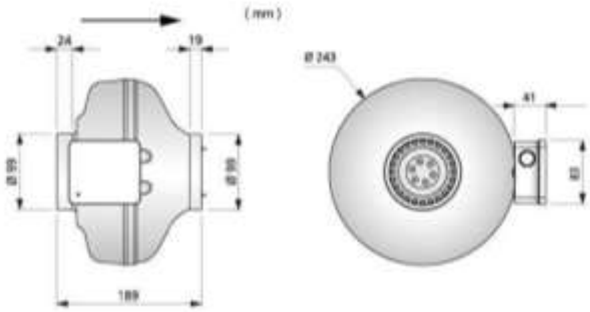
For simple applications it is often enough to select a valve based on the thread size and orifice diameter. The valve is suitable for pressures of 0 - 10 bar (0 - 145 psi) and a maximum temperature of 130° C (266° F). The valve has a Kv-value of 1.02 m3/h, which translates to a flow rate of 17 l/min at a differential pressure of 1 bar

Size & Material: 1/4" (7 Pcs), 1/2" (1 Pcs) stainless steel
Material: FKM & EPDM
Power Supply : 24V DC
Quantity: 8 Pcs
Location: Chemical dispensing (Top compartment), Drain (lower compartment)

Figure 32Solenoid valves

Fans:

Fan1: Used inside for circulating the heat air.
Power supply: DC Fan, 24 V
Size: Circular, 150 mm, 38 mm
Fan2: Used for air exhaust from the heating compartment.
Power supply: 240V



Water Pump: For pumping miliq water into the funnel we used a motor to have a high pressure dispensing into the funnel to cleanse the funnel thoroughly. The pump is lacking speed control feature, but it was suitable for our application since it was made of stainless steel and had ½ inch connections.

Thermometer: This temperature sensor is used for measuring temperature inside the heating compartment.
Type: RTD, PT100, 4 Wire
Range: 0-250°C,
Size: 6 mm Diameter x 200 mm

Figure 33: PT100

Heater: Cartridge Heater, this heater type was initially bought to heat the water sample directly, however later we decided to use it as air heater for the heating part, which could still serve its purpose.

Power 100W, 45 W/in²
Material: Stainless Steel
Power Supply: 240V
Dimensions: 6.35 X 76 mm
Temperature: 677 °C

Figure 34: cartiage heater

PID Controller: To accurately control the heating compartment temperature this PID controller was used with below specs:
Model: ATR-244-12ABC
Inputs & outputs: 1 analogue input + 2 relays 5 A + 2 SSR + 2 D.I. + 1 analogue output V/mA
Power supply: 24..230 V AC / DC

Figure 35 PID controller

5.5 Control System

5.5.1 Research and Requirements

Out of all of the system parts, the control system was the most straightforward one. This is because unlike other parts of the system, the control system didn’t have any special requirements or conditions that it needed to able to handle. The only potential thing that was considered was the potential heat transfer from the incubator through the metal wall which could raise the ambient temperature around the electronics. It was however decided that we can assume there to be some sort of insulation to prevent this in which case the heat transfer would be very minor. Therefore, we could add a couple of ventilation holes, or a small fan, and assume that the ambient temperature around electronics would be close to the room temperature. This meant that we didn’t have to do any special research before starting the design process.

Similarly, to the research, it was very simple to define the main requirements. These were the ability to serve as human machine interface (HMI), supply power to other components, and to control all other electrical components. These main requirements of course were divided into several sub requirements, such as HMI displaying the current process step and the remaining time. However, these sub requirements won’t be listed here as this isn’t a design document and the reader most likely can have a general idea what sort of requirements they are.

After the requirements were defined, it was also discussed whether we want to do any user experience research. For our purposes it would mostly have been regarding the HMI layout and potential interfacing devices such as buttons or keyboard. However, as we were limited on time it was decided that we would favor a very simple interface in which case we wouldn’t have to care or plan around user experience.

Before we could start to design our control system, we still had one problem we had to discuss about. This was the fact that other parts of the system were also being designed at the same time. This meant that we didn’t really know things such as how many devices the control system would need to manage, and what kind of sensors would there be. Therefore, we decided to try to oversize our system and try to make it as modular as possible in case we needed to add or switch something later. The two main things this affected were that our power supplies needed to be more powerful than normal, and we needed to have spare output and input signal ports.

5.5.2 Raspberry Pi vs Programmable Logic Controller

Before starting the system design, we had to choose what kind computer we would use as our main platform. This was a major decision as it would define what kind of components we could use and how we would have to do our development. The choices were almost immediately narrowed down to Raspberry Pi (RPi) or Programmable Logic Controller (PLC). Both of these had their own strengths and weaknesses.

The RPis' had two significant advantages over PLC, the first of which is its popularity. The popularity meant that there would exist enormous amounts of hobbyists and more professional learning resources and existing components such as peripherals. This would almost ensure that we could execute any type of design we wanted. It also meant that, if needed, any team member with even a little programming background could assist in the development. The second advantage was its versatility/modularity as the RPi was designed to be a general-purpose device. This would have allowed us quickly and easily make design changes on the go as we could use more commonly available components. This would have also made it easier to find all the necessary components.

This versatility, however, came with a major drawback, all the development would be more laborious. This is because since the RPi isn't designed for any specific purpose/task, we would have to do significantly more work to make it suitable to handle all our needs. This then in turn would make the development more complex and introduce a lot of potential problems that we would have to account for or fix. One example of these problems is that RPi has a moderate risk of SD card corruption if it shuts down abruptly or improperly. We also didn't have any members who had pure programming background which made this task look significantly more intimidating and riskier.

Compared to RPi, PLCs are computers designed solely for industrial automation, which is the type of thing our system is trying to do. This meant that there already exist all the necessary components and features we might require and which we could just directly buy, instead of building our own solutions with the RPi. Additionally, PLCs have existing software frameworks which are built specifically for automation purposes. This all would make the design and development significantly simpler, and we could avoid most of the problems we might have with RPi.

This specialization, however, came with its own problems. Firstly, we would be significantly more restricted with our designs and components. This wasn't that big of a problem because PLCs are designed for these sorts of tasks and therefore, they should already have all the necessary components and features available. However, this had the risk of potentially long delivery times which could be catastrophic if we notice a mistake close to the final gala. The second thing was that PLCs use their own niche programming languages which make the programming related to automation simpler and faster. However, these languages and how they are used differ greatly from the more typical general purpose programming languages and therefore skills are not directly transferable between the two. This means that people new to PLC would have to start learning from the absolute basics, which would take a significant amount of time. And since we didn’t have a lot of time left, we didn't have the option of letting team members try to learn them. Luckily, we had one person who already had this knowledge and could do all the PLC programming. This, however, also meant that we would be putting all of the burden on that one person which was very risky.

As both RPi and PLC had their own risks, we couldn’t make a clear decision between them. Objectively speaking PLC was clearly the superior choice, but the fact that only one team member knew how to work with them was too risky because it made our project have a single point of failure. Ultimately, we decided to go with PLC because its advantages were just too big and the team member with previous knowledge of them was confident, he would succeed. However, to cover our bases, we decided to also start creating the designs for RPi implementation in case the PLC failed. The plan was to continue this way until we reached the point with the PLC where we were relatively confident it would succeed.

5.5.3 Final Design of the System

The final system used for the PLC setup can be found below. The c6015-0020 was chosen because it was one of the most reliable and used industrial PLCs that Beckhoff has to offer in addition of having a small profile and being in stock. The digital and analog terminals are generic components and therefore do not have any specific model. In the final system we are using 15 digital output, 0 digital input, 0 analog output, and 1 analog input channels. The extra/unused channels were bought on purpose so that we wouldn’t have to order them separately in case the design of other parts of the system were changed or we missed something.

- 1x 2 core C6015-0020 industrial PC
- 2x 8-channel digital input terminal
- 2x 8-channel digital output terminal

- 1x 8-channel analog input terminal
- 1x 8-channel analog output terminal

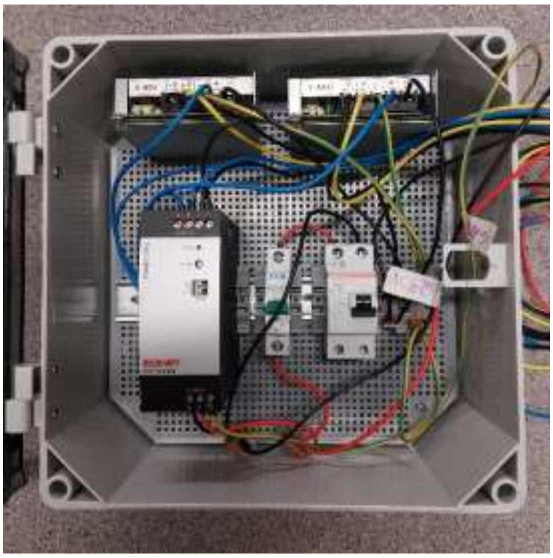


Figure 36 Assembled PLC

The PLC would then manage the system in the following manner. The digital outputs, apart from one, are connected directly to relays on the coil side while the switch side of the relay was connected to inputs of devices such as solenoids and motors and our systems power supplies. This way the PLC could easily control whether the devices were on or off by simply keeping a digital output high and letting the respective relay conduct. While this specific implementation lacks the support for more precise control of such devices through for example pulse width modulation, we chose this method because of its simplicity, and we had no need to for example control motor speeds. However just in case this feature was needed, we had an analog output terminal which could be used to accurately control many standard industrial actuators and motors. The single separated digital output terminal is connected to our PID temperature controller, and it can be used to change between the preprogrammed temperature limits in the PID. And finally, if any component such as sensor needed to communicate the PLC, we had the digital and analog input terminals. However out of these terminals only one analog input is used so that the PID controller can tell PLC when to cut the power to the heating element.

All of these previous components are then powered using two 12V and one 24V power supplies in addition to also directly using the 240V mains power. We didn't choose any specific power supply models as the only thing we cared about was whether they could supply enough current.

Originally the plan was to buy smaller 12V power supplies to make testing easier and then buy a single strong 12V power supply once all the components were chosen. However, in the end we chose to not pointlessly order a new 12V power supply partly due to our limited time and we just used the two smaller ones. And lastly since these power supplies had to be connected to multiple different devices, we used terminal blocks with bridges to serve as our power buses.

And finally, to make our system safer to use, we added multiple different safety devices and measures. Firstly, we mounted a proper main power switch before any other component through which you can easily and quickly shutdown the power to the whole system. After the switch we used proper circuit breaker to protect our components and users from short circuits. Additionally, as circuit breaker is only suitable to protect against high currents, we also added a residual current device next to it to protect our users from potential ground faults. And finally, we grounded our power supplies and our systems metal walls using the safety ground present in the main power cable. With all of these features, the user should have more than reasonable amount of protection from any electrical accident.

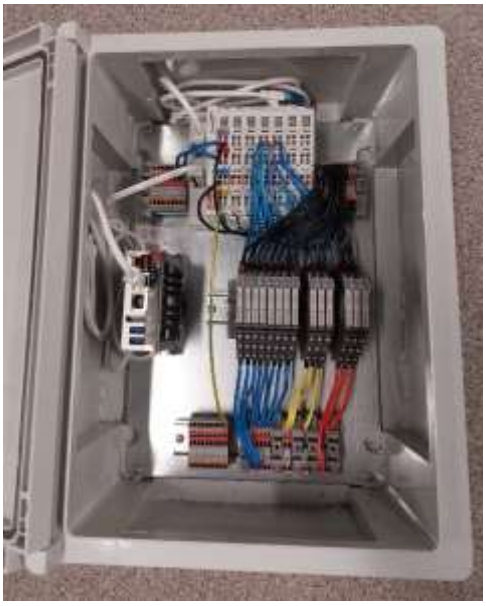


Figure 37: Assembled PLC Junction box

Originally all of these electronics were supposed to go inside a specifically reserved compartment inside our system. However, we realized that the compartment was too small for all the electronics and wires. There was a possibility to enlarge this compartment slightly but it would have been only just big enough for the largest electronic component. However, it would have been unnecessarily difficult to work with the very limited amount of space and wiring would have been extremely messy. Therefore, a decision was made to mount the electronics using two separate electrical boxes mounted on our system's walls. The reason for using two boxes was that a single large box would have been almost the same size as our systems wall, which we believed to look unprofessional. Additionally, by using separate boxes we were easily able to order a box with a see-through door which makes it easy for users to check whether circuit breakers are blown. Below on the left you can see the box that contains all the power supplies and circuit breakers. The box on the right picture contains all of the other electrical components of the control system. The pictures have approximately a little over 90% of the wires wired.

5.6 Final Product

5.6.1 Testing

We had very ambitious plans on how we were planning on testing our system. These plans, however, never came to fruition as there was no point in doing them because our system lacked many of the necessary features such as a fridge for the chemicals. Additionally, as we didn't have much time, we couldn't even do proper testing on the whole system since we started putting everything together in the last two weeks. Therefore, all our testing during the time of this report was done only on singular components, not on any complete/bigger subsystem or section. This kind of testing of course will be done to check that the system works but this will happen during the final week of PDP. Since we don't want our plans to go to waste, in this chapter we shall go through all our testing plans we had made. First, we shall go through the ones we had planned if we had finished different parts significantly sooner and the system could handle the full sample processing process. Then we shall go through what kind of testing we did before returning this report. And then we shall end this chapter by going over what kind of testing plans we have for the final week of PDP when we finally have put all parts of our system together.

So let us start with the testing we ideally would have done on the system during and after its development. The biggest potential problem for our system was the ability to drain the chemicals from the sample in a reasonable amount of time. Therefore, we would have done extensive testing on how long it takes to remove the liquids from the sample through the 20µm sieve to see whether we might require some type of pump or some other solution to speed things up. After this we would have tested how likely is it that the chemical residuals left in the pipes and valves when they vaporize would slowly start to glogg them. This is a real fear because enzyme powders are used in some of the chemicals, and we do not know how this powder will behave. Then we would have liked to do one whole sample processing run to see exactly how effective our system would be and how laborious is it for the user. Along the development we of course would also have done tested that every section and component of our system functions as we wanted it to.

Unfortunately, we couldn’t do any of the above testing because we didn’t finish our system early enough, and even if we did it would still be missing some of the necessary features making it incompatible with the whole processing process. Therefore, the testing was done mainly on singular components. The most basic testing was just simply connecting a component to a power supply which was done to solenoid valves, motors and heating element. Little bit more extensive testing was done on the PLC by checking every single input and output terminal. This was done by connecting button to an input terminals and small light bulb to output terminals. Then when you inputted correct amount of power to the other wire of the button and pressed it, the light bulb gets turned on. This test was then repeated for each terminal. After each terminal was proven to work, similar light bulb test was done using all of the relays to see that the digital output terminals are able to power the coils and that the switches work properly. The PID controller used for temperature control was tested just by connecting the temperature sensor to the controller and powering it on. The PID controller we used has the capability of directly powering heating elements, however we chose not to use this feature in our system because we wanted everything to be controlled by the PLC. Therefore, this feature was not tested.

And now the only thing left is what kind of testing will be done during the final week of PDP after returning this report. We have already tested all other individual components apart from the temperature data transfer from PID to the analog input of the PLC. Therefore, we will prioritize testing that this data transfer works before putting the system together. After the system has been assembled, we shall once again test that the PLC can control all the components to check that the wiring and component mounting has been done correctly. After this we will try to do at least one sped up run of the processing process where we have removed the long reaction periods used for the chemicals. During this time if any problems are found, they will be fixed, and these tests are repeated until we either run out of time or we fixed every major problem.

6 Challenges, Lessons Learned and Miscellaneous Topics

6.1 Did we underestimate the project scope?

The answer is simply yes. And this underestimation wasn't some tiny mistake because with our current knowledge we believe that it may have been too big of a task even if we had had this project from the beginning of the course. There were just too many things that the proper system would have to have such as fridges, proper heat insulation, air tightness, ventilation, temperature control and GUI. And since it was meant to be laboratory equipment everything had to be of very high quality, which just made everything more difficult and complex. So, all in all while we could have delivered significantly better product with more time, it would have been a death by a thousand cuts no matter what.

Now this begs the question of why we didn't notice this during our designing or early building phase. The first reason is that we had no previous experience in this type of system nor even in product development. Therefore, we vastly underestimated things such as delivery times, troubleshooting and just the general complexity. The second reason is that we were just naive since we believed the whole system to be simple because it consisted of multiple simple parts. This of course isn't the case, and the system quickly became significantly more complex when we had to start to make everything work together.

However, the biggest reason was simply the fact that we were quickly running out of time. We were able to get this topic for the first time a little before mid-February which meant that we had only about three months left before the final gala. And to make matters worse, during this time we also had to write the final report and prepare for the gala. Therefore, we didn't have much time to design the system nor to have extremely in-depth discussions about it. And even though we quickly started to realize the path we were on; it was already too late, and we had to continue. Certainly, we could have tried to make a new design, but that would have carried the risk of building almost nothing since the new design would take a significant amount of time. That is why, in hopes of receiving something other than the lowest grade, we chose to continue building a lacking product over a possibly not building anything at all.

6.2 Is our final system useful or relevant for our sponsors?

For ECsens, if they ever aim to expand the capabilities of their device, our type of system would most likely be required. This is because most samples will contain some type of contaminants that would likely be like the contaminants in microplastic samples. Therefore, they would have to remove them, which will likely become the bottleneck in the testing like is the case with microplastics. That is why, while not currently relevant, our system will most likely become relevant for ECSens in the future.

For SYKE, our topic is extremely relevant because it was targeted to help with their biggest microplastic research bottleneck, which is sample processing. we are currently in the process of validating the effectiveness of our system. However, with further development of several crucial subsystems, like chemical fridges and chemical waste processing, our systems would be ready for testing and use in the laboratories.

Therefore, at this stage, we are yet to determine the actual effectiveness of our system, and it primarily serves as a demonstration of a preliminary concept.

6.3 What would we do differently next time?

1. Establishing Clear Leadership: During the challenging period following the ECSens experience, having a leader with clear authority would have greatly benefited the team. This leader would have been able to make decisions when consensus was difficult to achieve and steer the team's focus back to specific topics, preventing confusion and excessive time wastage.
2. Defining Specific Tasks and Assigning Responsibilities: To enhance productivity and alleviate stress, it would have been beneficial to assign specific tasks to team members during that period. By clearly defining responsibilities and ensuring each task had a designated owner, the team would have experienced greater organization and efficiency.
3. Setting Strict Deadlines: The absence of specific deadlines contributed to the disorganization and overwhelming workload. By establishing clear deadlines and enforcing them strictly, the team could have better managed their time and prioritized tasks effectively.
4. Addressing Lack of Discipline: Many of the team's challenges stemmed from a lack of discipline. Having a leader with authority would have helped instill discipline and maintain focus. It would be helpful to proactively discuss potential situations and establish ground rules to address lapses in discipline, outlining measures that the leader can take to get the team back on track.
5. Proactive Measures: Learning from this experience, it would be wise to anticipate potential challenges in the future and establish preemptive measures. These may include discussions on potential scenarios, developing detailed ground rules, and

clarifying roles and responsibilities. By proactively addressing these issues, the team can prevent the recurrence of destructive cycles and maintain a more productive and harmonious working environment.

7 Ending Words and Final Thoughts

This experience has taught us valuable lessons about project scope assessment, realistic timelines, and the importance of early-stage planning and design discussions.

Overall, we are pleased with the team's effort and progress throughout the project. The team's ability to work in different subgroups and learn along the way was impressive. Even when faced with challenges, the team remained determined to deliver the prototype. We appreciate the team's dedication to the project.

This project was a valuable learning experience for the team and provided an opportunity to apply the knowledge and skills gained throughout the course. Although we did not achieve our initial goal, we gained valuable insights that will be useful for future projects.

Miran & Arkar