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Carlos Salas Bringas

Development, production and testing of a small-scale greywater biofilter

Utvikling, produksjon og testing av et småskala biofilter for gråvann

Carl Magnus Engelstad
Mechanical Engineering
Faculty of science and technology

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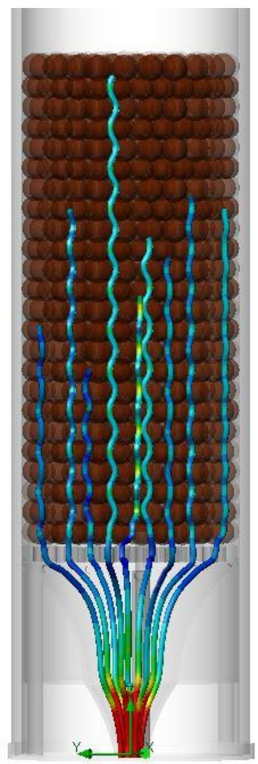
By

Carl Magnus Engelstad



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Preface

Through my years as a student in NMBU, I have learned a lot regarding product development, engineering calculations, rapid prototyping, CAD modelling, CFD analyzing along with many other subjects. I have had many topics in mind for the master thesis. When considering a subject, it has been important to choose something that catches my interest, and where I can show some of the knowledge I have obtained as a student. At the same time, it has become increasingly important for me to write about something that could contribute to minimize pollution of the earth. To have expertise in solving problems the planet will have for a long time ahead is also something I truly value.

When working in projects in the university, I have often been working in teams and enjoyed it a lot. For my master thesis, I wanted to try to work independently to improve my independent skills and to challenge myself. This project has taught me a lot about independent work, something I think can be helpful in the years to come.

Arve Heistad presented the challenge of developing a new greywater treatment system. A system which could allow more resources to be extracted from blackwater, and reduce pollution. I was very intrigued. I believe in the possibility that these types of systems could be valued in the future.

I would like to thank associate professor Carlos Salas Bringas for great work as my supervisor this semester. He has contributed with many valuable inputs and uplifting conversations. Associate professor Arve Heistad also deserves an appreciation for providing the idea for the thesis, and helpful inputs and conversations in a challenging period. Arne Svendsen, and Bjørn Tenge also deserves an appreciation for help during the construction process. I would also like to thank Melesse Eshetu for guidance during the testing phase, Frida Celius Kalheim for providing helpful inputs during the end, and Ola Sørby Omberg for help with 3d printing. Finally, I would like to thank all my classmates at “hemsen” for great company and interesting discussions this semester.

Ås 14th of May 2018 Carl Magnus Engelstad ______________________________

Abstract

This is a master thesis in machine and product development at NMBU by the Faculty of Science and Technology. Wastewater treatment and reuse is becoming increasingly important. By inventing efficient solutions regarding wastewater treatment, it is possible to limit the negative impact humans have on the environment.

The project is based upon a wastewater treatment system proposed by associate professor Arve Heistad, and supported by Ecomotive As. Several benefits arise when you separate wastewater from toilets (blackwater) and sinks, showers, washing machines (greywater), and treat the wastewater locally. For example, more valuable substances can be extracted and utilized, less resources are needed, and less transportation of wastewater is needed. Ecomotive AS have been working successfully with both greywater and blackwater systems for over 10 years.

A greywater system by Ecomotive is called A02 and is designed for households up to 6 people. By scaling up this system, Ecomotive is aiming for delivering a greywater treatment unit for clusters of houses of up to 50 people. This thesis is developing a small test filter for investigating a proposed pretreatment step for further upscaling or redesign of greywater treatment systems for urban use.

A small-scale pretreatment biofilter was developed, CFD tested, built, tested and compared with the pretreatment step of the Ecomotive A02 plant. The results showed that the test pretreatment filter performed better regarding BOD_5 and TSS at loading rate over 1.5 times the A02 loading rate.

The pretreatment system has the potential to increase efficiency of the upscaled version, both for buildings of up to 50 people and for larger systems. For further development of the system, the following parameters should be considered:

- Backwashing frequency
- Secondary treatment
- Measurements of relevant effluent parameters

Sammendrag

Dette er en masteroppgave i maskin, prosess og produktutvikling ved NMBU for Fakultetet for Realfag og Teknologi. Behandling og gjenbruk av avløpsvann blir mer og mer viktig fremover. Ved å utvikle effektive løsninger i for behandling av avløpsvann, er det mulig å begrense den negative påvirkningen mennesker har på miljøet.

Prosjektet har basert seg på et renseanlegg foreslått av førsteamanuensis Arve Heistad, og støttet av Ecomotive AS. Ved å skille avløpsvann toalettet (svartvann) og avløpsvann fra dusj, vask og vaskemaskiner (gråvann), og behandler dette lokalt, fremkommer det mange fordeler. Flere dyrebare ressurser i svartvannet kan utnyttes, det kreves mindre transport av vannet, og mindre energi kreves. Ecomotive har jobbet med slike systemer i over 10 år.

A02 er et gråvannsanlegg fra Ecomotive og er designet for hus/hytter med opptil 6 personer. Ved å skalere opp dette systemet, ønsker Ecomotive å levere et system for bygg med opptil 50 personer. Denne oppgaven omhandler å utvikle og teste et testanlegg for å undersøke et foreslått forbehandlingstrinn for videre oppskalering eller redesign av gråvannsanlegg for urbant bruk.

En småskala biofilter for forbehandling av gråvann har blitt utviklet, CFD testet, bygget, testet og sammenliknet med forbehandlings steget til Ecomotives A02 anlegg. Resultatene viste at småskala filteret presterte bedre for BOD_5 og TSS på belastning på over 1.5 ganger A02s belastning.

Forbehandlingssteget har potensiale til å øke effektiviteten for et oppskalert anlegg, både for anlegg opp til 50 personer og for større systemer. For videre utvikling av systemet, anbefales det å undersøke følgende:

- Frekvensen av tilbakespyling
- Valg av sekundærbehandling
- Målinger av relevante utløpsparametre

Contents

1. INTRODUCTION

A brief introduction to the project’s background will be given before a description of what the thesis will concern.

1.1 Background

Earth’s population is steadily increasing, along with the use of many valuable resources. It is therefore important to utilize our consumption of resources effectively. To adapt to these changes, it is beneficial to consider innovative solutions regarding resource management.

Wastewater from human consumption is often not properly cleaned before it enters the sea or groundwater. While this is not beneficial for the environment, valuable resources are discarded. The UN regards wastewater as a valuable resource (UNESCO, 2017), partly because the wastewater contains phosphorus, an agent widely used as a fertilizer in agriculture. A large amount of research has shown that plants fertilized with phosphorus will mature earlier and grow more vigorously than a plant not sufficiently fertilized with phosphorous. There is a growing concern that the world could run out of phosphorous in 50-120 years (Sattari et al., 2012). Water treatment plants are collecting this substance, though the effectiveness of this wary hugely, and many parts of the world do not have wastewater treatment plants at all. In addition, several treatment plants are leaking toxic wastewater directly into the groundwater, while valuable resources are not effectively extracted (DeSilva et al., 2005).

A reason wastewater is often poorly treated, is partly because it consists of both blackwater (sewage from toilets) and greywater (water from showers, sinks, and bathtubs). By separating blackwater and greywater, the treatment process could become easier and more effective. Most valuable agents are present in the blackwater, and can be extracted more efficiently without the presence of greywater (Paulo et al., 2013). There is an increasing interest in decentralizing waste water treatment because further economic and environmental benefits may be achieved (Zeman, 2012). Greywater could be treated in a separate unit, just where it is produced, neglecting the need for transportation of greywater in sewage systems. By implementing this system in a large scale, there is reason to believe that a phosphorous crisis could be reduced, pollution of groundwater could be reduced, as well as creating more sustainable jobs. (Massoud et al., 2009)

1.2 Preliminary work

Ecomotive AS has been working with decentralized wastewater systems for separating greywater and blackwater since the founding of the company in 2006. The idea is to extract resources from wastewater where they are produced, and excess water can be treated, before it either is poured directly into the groundwater, or some of the greywaters resources are being utilized. For example to be used in lettuce production (Eregno et al., 2017). The system is based on utilizing vacuum toilets that collects the blackwater in a separate system where phosphorous, nitrogen, and potassium can be extracted. This is called the blackwater system (Eshetu Moges et al., 2018), and will not be further explained in the thesis. Remaining greywater from showers and sinks are treated in another system before it flows into the groundwater (. This thesis will concern the system for filtering greywater.

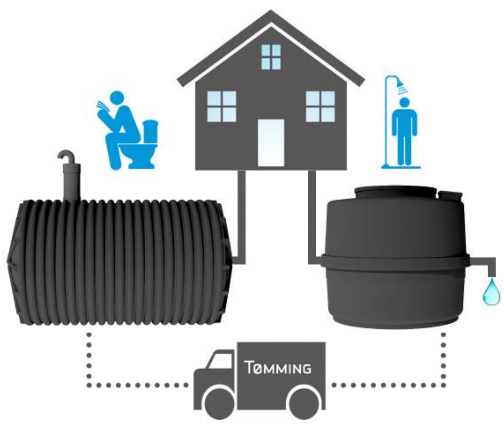


Figure 1.2-1 Blackwater treatment to the left, greywater filtration to the right.(Ecomotive, 2018)

A wastewater filter system already developed by Ecomotive AS, goes by the name A02. The product is distributed by the company Jets, which owns Ecomotive. A02 is being sold as a wastewater filtration unit for cabins and houses that wish not to be connected to other wastewater networks. The unit is around 2 meters in diameter and has a capacity of filtering roughly 600 liters/day. Water flows through 3 processing steps before it can be discarded into groundwater. First, we have the sedimentation chamber, shown with red arrows in Figure 1.2-2. After this section, water is being pumped up to the top of the system, before it is sprayed on top of the biofilter. Water will slowly trickle through the biofilter as illustrated with green arrows. This biofilter is made of small rocks of LECA (Light Expanded Clay Aggregate) which is decomposing organic material. The stream will then follow a tube down to the bottom of the system where another sedimentation process is happening. When this process is finished, water will enter the exit tube, illustrated with a blue arrow.

A02 is a fully functional greywater cleaning system that has been tested by NMBU (Heistad, 2014). The system has been successfully released in Norway, and are being sold to various cabins and households through the country.

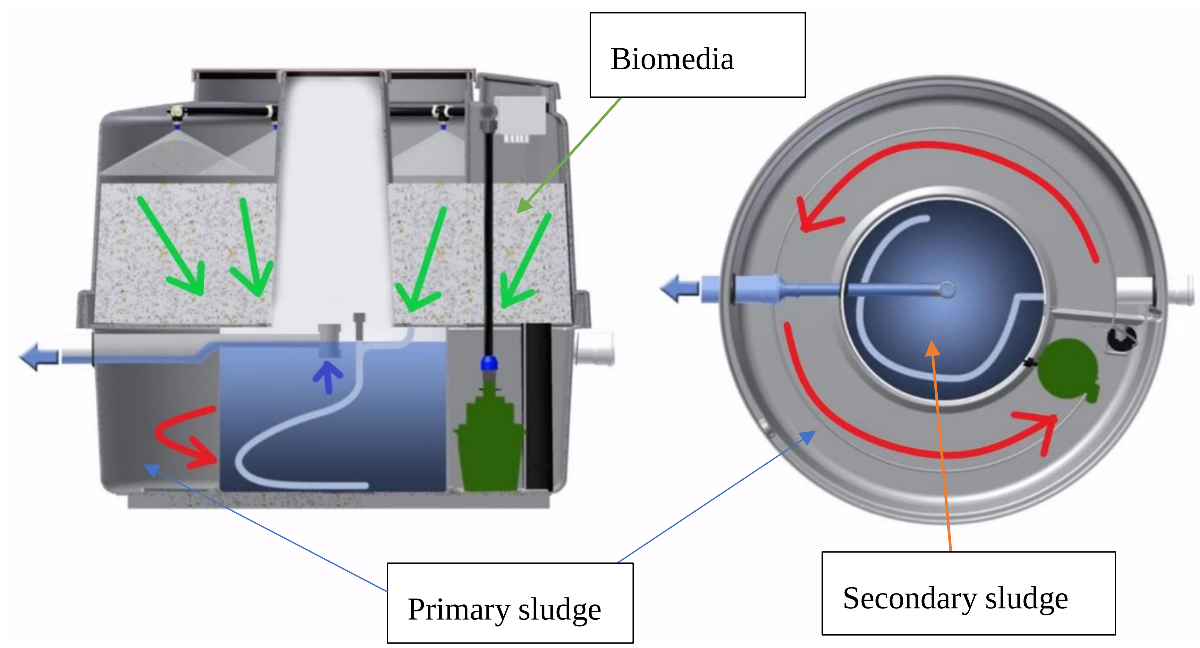


Figure 1.2-2 Working principle of A02

The described filter system can handle houses or cabins of about 6 people. Ecomotive is now interested in developing a system that can handle the capacity of larger buildings of up to 50 people. This thesis will concern the development of such a system. The A02 system has been tested when the pump has been malfunctioning, and the system is said to be operating in emergency mode. Data from this emergency mode has been collected by Ecomotive, and will be used to compare with the results of this project (Table 1.2-1).

Table 1.2-1 Specifications of the A02 sedimentation reactor.

<table>
<tr><th colspan="2">Specification</th><th colspan="2">Value</th></tr>
<tr><td colspan="2">Nominal hydraulic load</td><td colspan="2">600 l/day</td></tr>
<tr><td colspan="2">Primary sludge</td><td colspan="2">420 liters</td></tr>
<tr><td colspan="2">Secondary sludge</td><td colspan="2">260 liters</td></tr>
<tr><td colspan="2">Total residence time</td><td colspan="2">21.1 hours</td></tr>
<tr><td colspan="4" align="center">Treatment effects of primary sludge and secondary sludge. 3 measurements over 7 days.</td></tr>
<tr><td>Variable</td><td colspan="2">Value</td><td>Reduction</td></tr>
<tr><td>BOD5 influent</td><td colspan="2">175.6 mgO2/l</td><td rowspan="2" align="center">44.3%</td></tr>
<tr><td>BOD5 effluent</td><td colspan="2">97.8 mgO2/l</td></tr>
<tr><td>TSS influent</td><td colspan="2">78.5 mg/l</td><td rowspan="2" align="center">74.4%</td></tr>
<tr><td>TSS effluent</td><td colspan="2">20.1 mg/l</td></tr>
</table>

1.3 Similar solutions

When approaching the task of developing a greywater cleaning system of up to 50 people, it is important to investigate what similar systems that is already on the market. There is a low amount of competing systems for this type of solution, although some systems exist. This chapter will describe some of these solutions.

1.3.1 Huber

A German company called Huber is producing a solution for greywater reuse in large buildings of up to 500 people.

Figure 1.3-1 Huber wastewater system (Huber, 2018)

System concept:

1. Greywater from bathtubs, showers, washbasins, laundry washers, dishwashers and kitchen sinks
2. Blackwater from toilets
3. Sewer
4. Greywater storage tank
5. HUBER Membrane bioreactor
6. Service water storage tank
7. Service water for toilet flushing and laundry washing

This system is reusing the greywater for reuse in areas such as toilet flushing and laundry washing, whereas the proposed system in this thesis could possibly discard the greywater. While greywater is being treated and reused, blackwater looks like it is being discarded in the sewer and treated in an ordinary manner, thereby the pros of decentralized blackwater treatment is not part of the sales process. Although the Huber system could be more advanced and provide better cleaning than Ecomotives intended system, it is certainly a noteworthy competitor. The system could be more attractive in areas where freshwater is a scarcer resource than in Norway where freshwater is often very available.

1.3.2 Island Water technologies: REGEN

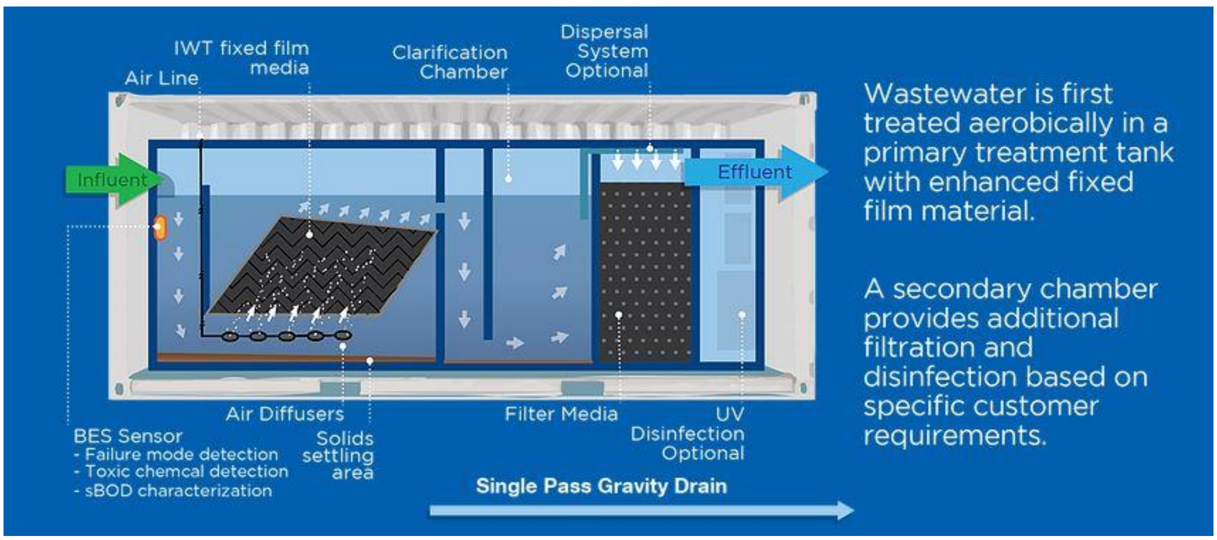


Figure 1.3-2 REGEN wastewater treatment unit (IslandWaterTechnologies, 2018)

Regen is a standalone system that is designed for rural communities, contingency operations, etc. It comes with solar panels and batteries to provide electricity to the system. The system is treating both black and greywater simultaneously. Thereby, there is not possible to extract phosphorous, nitrogen or potassium from the blackwater. Additionally, the system has a modular design, and is manufactured for rural communities, contingency operations, seasonal operations etc, meaning that the system is not directly competing with the concept in this thesis.

Review of similar solutions

Huber's system could be a close competitor to the proposed system, although not a lot of information could be obtained about the utilized systems in the treatment filter. In locations like Norway, it could be more economically efficient to discard the wastewater into the soil rather than reusing it. None of the systems include any collection of phosphorous, potassium or nitrogen. Combination with a greywater system, and a blackwater system, is something only Ecomotive are proposing, thus securing a major argument as to why this greywater system could be a success.

1.4 Scope of the thesis

The scope of this thesis is to develop a greywater treatment reactor with higher treatment efficiency than the A02 greywater treatment reactor. By performing a small-scale test of a proposed system, it could be possible to conclude if the solution has potential for upscaling.

1.5 Challenges and technological bottlenecks

In this subchapter, challenges for the development will be listed, as well as technological bottlenecks.

1.5.1 Challenges

Some challenges this thesis is aiming to solve, are listed below:

- Could an upstream biofilter be a solution in a first step treatment process for greywater?
- What is the treatment efficiency of a small scale upstream biofilter compared to A02?

1.5.2 Technological Bottlenecks

Technological bottlenecks are elements that could prohibit a successful development and production, and are listed in this subchapter.

- Test results are not accurate enough to indicate what the treatment efficiency is.
- Materials deteriorate inside the filter and inflicts the results
- Filter is not watertight
- Particles clogging up vital parts of the filter
- Filter size becomes too large, resulting in difficulties for manufacturing, or filter is difficult to handle.
- Components gets too expensive.
- Parts cannot withstand the pressure in the system.
- CFD analysis does not consider vital parameters
- Methods for measurement and control of the filter are not accurate or performing optimally

2 Project objectives

This chapter will include a detailed plan for the progress of the master thesis, including goals, timetable and limitations.

2.1 General objective

For this project, the following project goal has been developed:

To develop, model, produce, and test a small scale biofilter. Compare results of biofilter with relevant results from the A02 system.

The project will contribute to further development of a greywater treatment system for buildings up to 50 people.

2.2 Specific objectives

The following intermediate goals contribute to reach the main goal:

- Evaluate the challenges associated with developing a greywater treatment system.
- Define objectives and limitations
- Perform literature study on relevant topics.
- Calculate parameters for test system
- Decide solutions for test tube
- Create CAD model
- Run CFD analysis
- Build test rig
- Test relevant parameters
- Discuss the results and evaluate the systems performance compared with A02

2.3 Timetable

A timetable is an illustration of the process of the project is shown in Figure 2.3-1. The plan is a rough estimate of what objectives should be worked with at specific times.

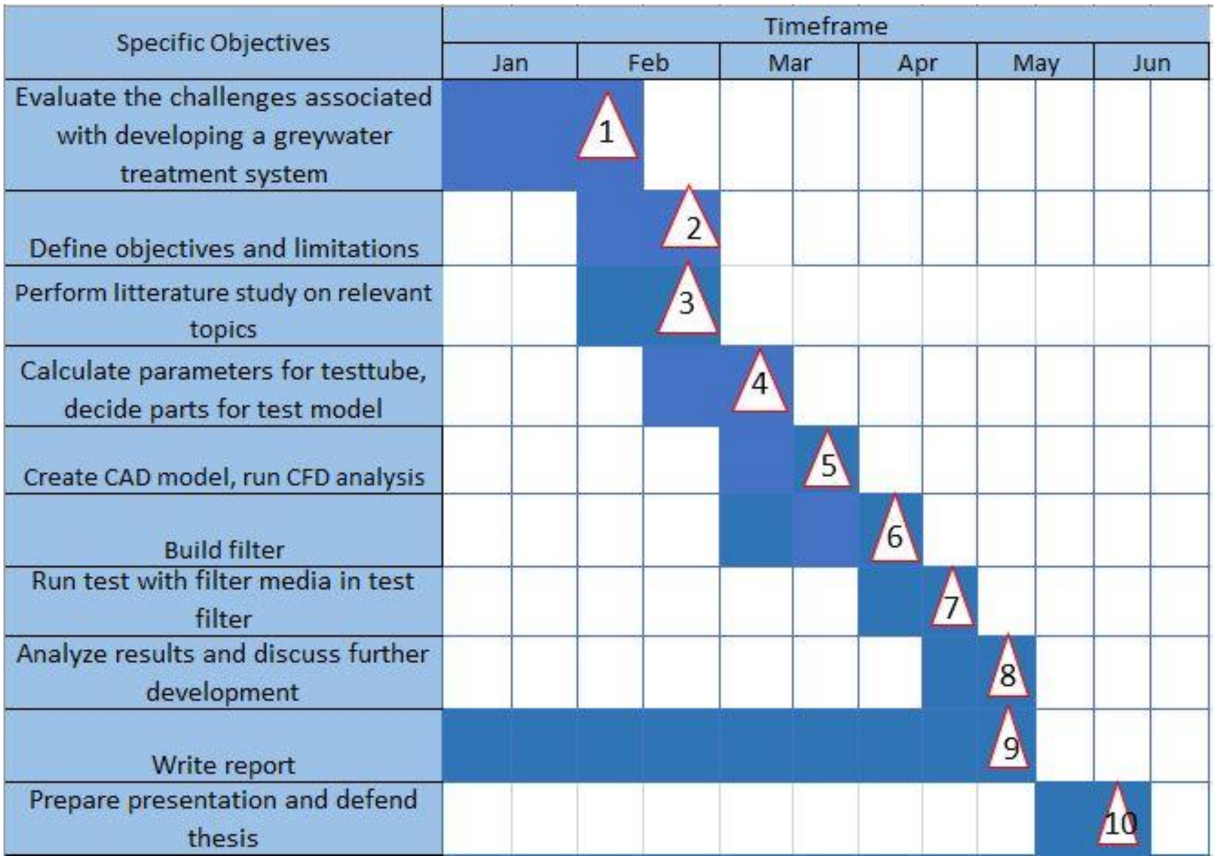


Figure 2.3-1 Timetable with milestones. The milestones are marked with numbered triangles.

Building of the filter has been considered to take longer time than the other objectives, as this is often a time-consuming process. The report should be finished by the 15th of May.

2.4 Limitations

This project could be very comprehensive if all aspects would be regarded. 900 hours is included in the thesis, and the following limitations are set to the project.

- A thorough consideration of the best choice of biofilter will not be made
- Marked demand for such a system will not be regarded, only comparison with similar systems

- An optimal test period for the filter would be a lot longer than what is possible with the given time frame.
- It was not possible to model the biomedia especially accurate in the CAD program to simulate the actual flow.
- The filter inlet was clogged several times during the experiment, which is influencing the results of the filter.

3 Methods

This chapter will describe various methods and tools used in the thesis, as well as descriptions of symbols, concepts, and shortenings will be listed.

3.1 Symbols

Relevant symbols are listed in Table 3.1-1.

Table 3.1-1 List of symbols used

Symbol	Description	SI Unit
$\boldsymbol{m}$	Mass	kg
$\boldsymbol{g}$	Gravity	$\frac{m}{s^2}$
$\boldsymbol{v}$	Velocity	$\frac{m}{s}$
$\boldsymbol{P_h}$	Hydrostatic pressure	$\frac{N}{mm^2}$
$\boldsymbol{\rho}$	Density	$\frac{kg}{m^3}$
$\boldsymbol{h}$	Height	m
$\boldsymbol{Q}$	Volume flow	$\frac{m^3}{s}$
$\boldsymbol{Q_a}$	Surface load	$\frac{l}{m^2 \cdot h}$
$\boldsymbol{\tau}$	Theoretical detention time	seconds
u	Fluid velocity	m/s
$\boldsymbol{\sigma_\theta^2}$	Variance of normalized tracer response curve	s^2

Table 3.1-2 List of symbols used, ontinued

σ_c^2	Variance of normalized tracer response curve	s^2
d	Dispersion number	unitless
t_i	Time at which tracer first appears	minutes
C_i	Concentration at *i*th measurement	$\frac{\mu S}{m^2}$
$\bar{t}_{\Delta c}$	Mean detention time based on discrete time step measurements	minutes
ΔW	Difference in weight	
σ	Standard deviation	

3.2 Concepts

This subsection contains relevant concepts used in the thesis (Table 3.2-1)

Table 3.2-1 Relevant concepts

Concept	**Explanation**
Microcontroller	An integrated circuit containing fewer components than a computer. Microcontrollers are often used in electric control units within automation, and in mechatronic systems (Andersen, 2018).
3d printing	Production method allowing real objects to be built layer by layer from a digital model (Mælhum, 2018).

Table 3.2-1 Relevant comcepts continued.

Aerobic biological processes	**Biological reactions with the presence of necessary oxygen (Ødegaard, 2014).**
Anaerobic biological processes	Biological reactions without necessary oxygen (Ødegaard, 2014).
Axial dispersion	"Dispersion is the term used to describe the axial and longitudinal transport of material brought about by velocity differences, turbulent eddies, and molecular diffusion." (Tchobanoglous, 2003)
Theoretical detention time	The calculated time water will use traveling through a wastewater treatment reactor (Tchobanoglous, 2003).
Single factor anova analysis	A statistical method to test equality between two or more data sets. (Løvås, 2013)

3.3 Formulas

A list of formulas used in the thesis, are listed here (Table 3.3-1).

Table 3.3-1 Relevant formulas

Description	**Equation**	**Equation number**
Flow rate	$Q = v \cdot A$	(1)
Hydrostatic pressure	$P_h = \rho g h$	(2)
Surface load	$Q_a = \frac{Q}{A}$	(3)

Table 3.3-1 Relevant formulas continued

Theoretical detention time	$\tau = \frac{V}{Q}$	**(4)**
Mean residence time	$\bar{t}_{\Delta c} = \frac{\sum t_i C_i \Delta t_i}{\sum C_i \Delta t_i}$	(5)
Variance	$\sigma^2_{\Delta c} = \frac{\sum t_i^2 C_i \Delta t_i}{\sum C_i \Delta t_i} - (\bar{t}_{\Delta c})^2$	(6)
Dispersion number	$\sigma^2_{\theta} = \frac{\sigma^2_c}{\tau} = 2\frac{D}{uL} = 2d$	(7)
Effect	$P = UI$	(8)
Suspended Solids	$SS = \frac{\Delta W}{L}$	(9)

3.4 Abbreviations

Table 3.4-1 explanation of relevant abbreviations used in the thesis

Shortening	**Description**
IPD	Integrated product development
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
HRT	Hydraulic Retention time
BOD_5	Biochemical Oxygen Demand
TSS	Total Suspended Solids

3.5 Methods and computer tools

This chapter will describe the various methods used in the thesis, as well as a description of various computer tools applied.

3.5.1 Methods

Product development methods used in the thesis will be applied in this subsection.

Integrated product development

A widely used method in product development for selecting important elements in a project. The main purpose of the method is to secure development in the right order so important concepts are not forgotten (Bøe, 2016b).

PUGH method

The PUGH method is a matrix used for decision making relating solutions to challenges. Important parameters are selected and rated from certain criteria's that have given a weighted value. By comparing alternatives total value, the most promising alternative should have the highest value if weighting is done correctly. This method can help deciding difficult challenges in a fair and unbiased manner (Bøe, 2016a).

3.5.2 Computer tools

A short explanation of the various computer tools used in the thesis will be listed in this subsection.

Microsoft Word 2016

A word processing tool applied to write the thesis, add pictures, tables etc

Excel 2016

A data processing tool applied to sort data during the experiment

SolidWorks 2017

A CAD modeling software used to model the test biofilter

SolidWorks Flow Simulation 2017

A CFD software used to analyze the liquid flow inside the modeled biofilter.

Arduino IDE

Open source software to code the Arduino microcontroller using the C programming language.

CES Edu Pack 2015

A material database containing relevant specifications regarding various materials.

Endnote X8

Software for bibliography and reference management.

Fritzing 0.9.3

A program for producing schematics from various microcontrollers.

3.6 Quality Assurance

Relevant standards will be followed to ensure quality of the system performance. Standards and handbooks that are intended to be followed are listed in Table 3.6-1

Table 3.6-1 List of standards and handbooks used in the thesis.

Topic	Standard or handbook
Measurement of Turbidity and TSS	Håndbok for beregning av måleusikkerhet ved miljølaboratorier (Magnusson, 2008)
Quality assurance	ISO9000

When gathering relevant information for the thesis, literature from approved books, reports and scientific papers will be used. Results produced by the filter will be quality assured by relevant standards if possible.

3.7 Process

Steps in the development process are shown in Figure 3.7-1 Development steps for the thesis. During the development, some steps backwards in the process were made to adjust certain parts of the thesis.

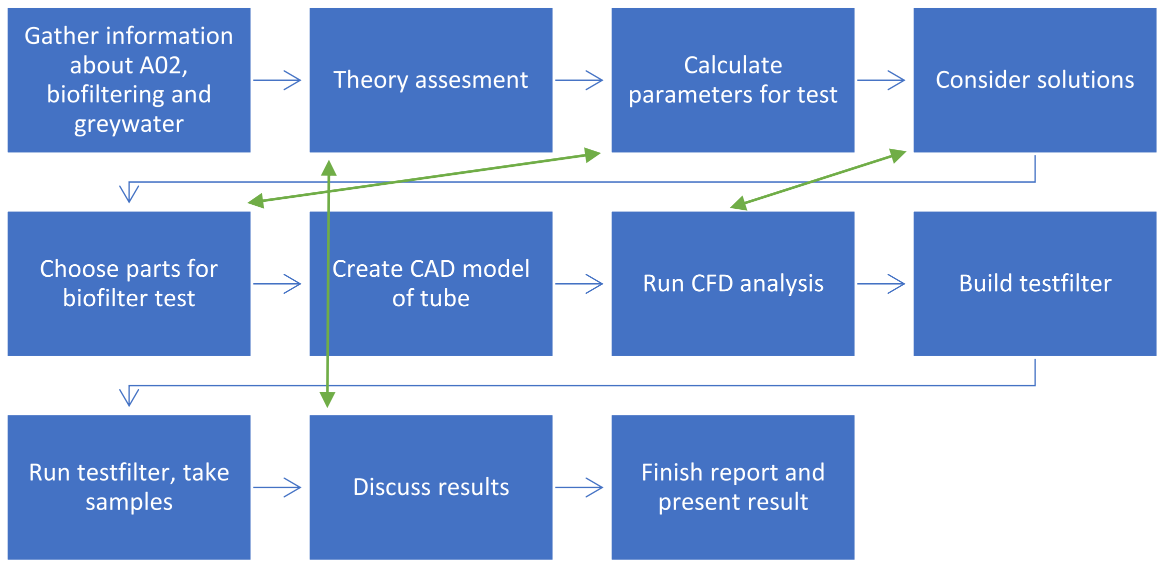


Figure 3.7-1 Development steps for the thesis

As the project was proceeding, some of the development steps were done in different order than first planned. Theory assessment was further considered when discussing the results regarding BOD_5, and TSS samples. Calculating some parameters for testing was not possible to do before the test tube was chosen. Because of this, the development step was changed. Furthermore, solutions regarding the water and air inlet was considered after the CFD analysis. Apart from this, the development steps were followed.

4 Theory and Technology Assessment

This chapter will give an introduction relating the theory of greywater filtration.

4.1 Greywater

Greywater is defined as the part of wastewater from regular households that can be traced to waste from kitchen, bathrooms and washing rooms. Toilet waste is not included (Forurensingsforskriften, 2007). Greywater contains a variety of particles, varying of many factors such as, who are producing the greywater, what systems are being utilized to distribute the greywater, etc. Most greywater has a lower concentration of fecal contaminants than blackwater sources (Jefferson et al., 2004).

4.2 Sedimentation

Sedimentation is a common process used in various waste water systems. The process is utilizing the fact that particles heavier than water will sink given the liquid is flowing slowly enough. By reducing volume flow, a significant number of particles will be removed from the water. This process is typically used in the early or last stage of the filtration process. Particles will sink with a specific velocity related to particle size, buoyancy and velocity while traveling through the sedimentation area. (Ødegaard, 2014).

4.3 Biological wastewater treatment

Biological treatment is a process widely used for treating wastewater. Particles and agents in the waste water are converted by microorganisms into simple compounds, like CO_2, and into new cellular mass, which is then separated from the water as biological sludge. The microorganisms can grow on surfaces in the biofilter. These surfaces are called biomedia, which can be present in the reactor. When microorganisms grow on the biomedia, they are forming a biofilm. This certain type of reactor is called a biofilm reactor (Chaudhary et al., 2003). Usually, biofilters containing various shapes of plastic media are used. It is possible to use bulk solids of LECA (Light Expanded Clay Aggregate) instead of plastic media. LECA consists of several pores of air, meaning they will float in water. After around a month submerged in water, pores will soak up water, resulting in biomedia beginning to sink (Heistad, 2018).

Biological aerated Filters (BAF)

Wastewater filters utilizing biomedia in an aerobic process are called biological aerated filters, and have been developed since the late 1980s (Paffoni et al., 1990). Modern BAFs have some advantages; they provide a great performance at high loading rates, while keeping a low filter footprint. One disadvantage is that more maintenance than other reactors is needed. Last 30 years, these filters have become an increasingly popular choice to traditional treatment plants (B. et al., 1999). Selection of packing media is important regarding the hydraulic efficiency and a high specific surface area (Mendoza-Espinosa & Stephenson, 1999). No literature has been found regarding this type of system utilized specifically for greywater treatment.

In operation of a BAF, it is important to regularly add air from the bottom of the filter. The air adds three purposes to the reactor; providing enough oxygen for microorganisms, maintaining the activated sludge in suspension and stirring the filter media when needed (Gonzalez-Martinez & Wilderer, 1991). Oxygen level of the processing water is the driving parameter of the reaction, and is often measured to evaluate the efficiency of the reactor. Small air bubbles will transfer more oxygen than larger bubbles, meaning a high performing reactor utilizes as small bubbles as possible (Boller et al., 1994).

Backwashing of the filter is necessary to remove captured solids and excess biomass after a treatment period (Park & Ganczarczyk, 1994). The process of backwashing should be performed when the growth of microorganisms on the biofilm is declining. The process of backwashing is also necessary to prevent clogging, and to maintain an active biofilm (Robinson A et al., 1994). Measuring relevant parameters in the output water can indicate when the backwashing should start. When backwashing of a greywater filter is initiated, aeration should be increased enough for the fixed media to stir, as well as the waterflow should be increased. The stirring is resulting in a process where biofilm is detaching from the biomedia, and the effluent water from the backwash should be lead to another place than treated greywater. After backwashing, the bioreactor should be able to start again without a significantly reduced reactor performance (Bacquet et al., 1991). The effluent from the backwashing are discarded in another tank than the treated water, as the backwashing effluent consists of more organic waste. The period between backwashing should be maximized to reduce down-time and costs of backwashing. By measuring the turbidity of a reactors effluent, it is possible to indicate when a backwash should begin (Yang et al., 2010).

4.4 Methods for analysis

This subchapter will describe what methods for analysis were utilized in the project.

4.4.1 Hydraulic characteristics in reactors

The hydraulic efficiency of a treatment reactor could be measured. By inserting a salt solution into the reactor, the increase in conductivity out of the reactor could be continuously evaluated. The salt solution should have the same density and temperature as the greywater to not affect the flow (Bachmann & Tsotsas, 2015). The salt solution will flow through the reactor and the conductivity of the water will be affected. The interesting part is how fast the increase and decrease of conductivity in the water is. A sudden and fast increase is desirable, as it would implicate an even flow of water through the reactor, meaning the reactor is performing efficiently. A slow increase is not optimal, as it would implicate that water is flowing faster in some channels than others in the filter, resulting in lower efficiency of the reactor. The values of the increase in conductivity can be graphed with time, and the dispersion coefficient could thereby be calculated (Kramers & Westerterp, 1963). Before a tracer test can be conducted, the theoretical detention time should be measured to know the length of the testing.

Tap water has a lower conductivity than greywater. Thereby, it is also possible to investigate the hydraulic efficiency by starting the filter with tap water, and while inserting tap water, the increase in conductivity can be graphed. The more steep and sudden this increase is, the better the hydraulic efficiency is (Tchobanoglous, 2003). For measuring conductivity, the measurement tool Multi 3430 by WTW is utilized in this project.

4.4.2 BOD_5

BOD_5 is a shortening for biochemical oxygen demand and is often used to decide the amount of organic matter in wastewater. The method has flaws, but is still widely used. Aerobic bacteria oxidize the organic matter into CO_2 or H_2O under controlled processes before the consumption of oxygen has been through the filtering process, and it is possible to measure their values. The BOD_5 – analysis provides an estimate of what happens to the organic material through a process, not only a measurement of amount of organic matter, like other methods. In this thesis, there will be used a method called the vacuum method. BOD_5 was measured using the analysis tool OxiTop ® Control OC 100. Samples were added nitrification inhibitor and NaOH-capsules to collect carbon dioxide produced by decomposing organic material. Oxygen consumption over 5 days were measured by the pressure difference automatically by the analysis tool. The tests were set to 0-400 mg/L. The tests were then incubated in 5 days, constantly stirred by a magnet. A result in mgO_2/l are provided after 5 days (Ødegaard, 2014).

4.4.3 Turbidity

Water can have a presence of small particles which will make the water sludgy (turbid). The amount of turbidity can be measured by a turbidimeter. This parameter is useful when it is more important how much particles are present, than how the distribution of the particles is. A turbidity meter is directing a beam of light at a sample of the certain water, before the transferring light is being measured. Turbidity is in this thesis measured in relation with NTU (Nephelometric Turbidity Units). Turbidity measurement is often used for measuring the clarity in drinking water and greywater (Yang et al., 2010). When measuring turbidity in this thesis, 3 samples were taken at the specific time, before measured independently in 2100 IS Turbidimeter from Hach. Each test was poured into a specific glass for the turbidimeter, and cleaned with a cloth before measurement. This was to ensure no smudge would disturb the measurement. The glass was cleaned with water after each measurement.

4.4.4 Total Suspended solids (TSS)

Determination of suspended solids is a method of measuring particles over a given size. By filtrating a specific amount of water through a filter, the weight of solids left on the filter can be measured. Water was filtrated through a filter with a pore opening of 1,2 μm and a diameter of 47 mm by utilizing a vacuum pump. The filters are weighed before and after this process. Before weighing after filtration, the filter is dried in a heater so that no water will be present in the weighing. Thereby the weight of the particles can be calculated. This parameter is very often used when measuring various types of waste water (Ødegaard, 2014).

Procedure for measuring SS was the following:

1) Acquire 3 samples for each data point
2) Acquire 3 filters placed in 3 aluminum cases
3) Weighed each filter with aluminum case and placed them in a heater for 2 hours.
4) Aluminum cases with filters were measured
5) SS (g/l) was calculated by equation (9)

5 Specifications

This chapter will present the necessary specifications for the filter.

5.1 Framework

Associate professor Arve Heistad has proposed a test system based on his 20 years of experience with wastewater treatment. The idea is to treat greywater through a biofilter where the stream flows upwards past the biomedia. To ensure aerobic consumption of bacteria on the biomedia, the necessary amount of air should be added under normal operation. Backwashing should be performed in accordance with backwashing for BAFs.

By conducting a computer simulation of this system, as well as a physical test, it should be possible to gain knowledge about the filters dispersion and treatment efficiency. This information will contribute in reaching the objective of developing an expedient prototype.

In a biofilter, a certain residence time is needed to ensure proper filtration of particles. If water can achieve higher velocity in some areas of the filter, the residence time will be depending on the faster flowing water. Moreover, it is preferred that water experience an equally fast velocity through the entire filter. By running a CFD analysis, it could be possible to investigate the hydraulic efficiency of the filter (Findikakis, 2016).

Output greywater could be processed through a proper membrane, before filtrated water could be treated sufficiently to be discarded into the groundwater.

For running the test, it is necessary with a tube containing the biomedia, along with several other parts to guide fluid and air correctly. An illustration of Arve Heistad's proposed test system is shown in Figure 5.1-1 Arve Heistad's proposed system.

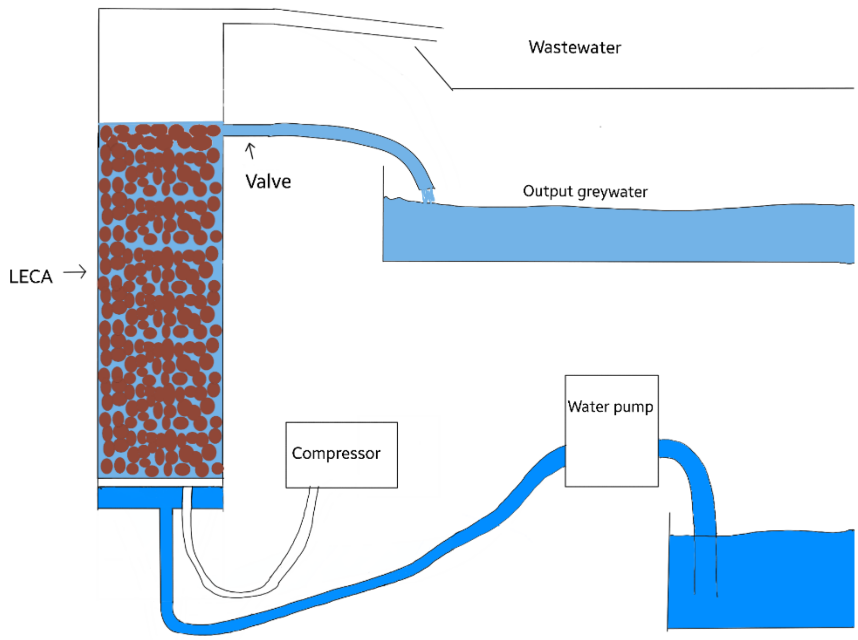


Figure 5.1-1 Arve Heistad's proposed system

Greywater could be pumped into the tube and flow upwards through an air filter, before flowing through a column of LECA bulk solids. This should be LECA with grain size from 10mm to 20 mm in diameter. Furthermore, the greywater will flow through an outlet tube, and into a container. The air filter will be used to distribute air from the compressor to satisfy aerobic treatment. After the process has continued a certain time, the biofilm of the LECA bulk solids have reached maximal capacity for aerobic consumption of microorganisms, the backwashing process will start. The hypothesis is that the air will loosen extra bacterial colonies on the LECA, providing a method for regularly cleaning the filter. During this process, the valve will be closed, and wastewater will flow out from the top of the tube. The particle reduction from the greywater to the output greywater will be analyzed and compared with the A02 system from Ecomotive.

5.2 Important features

The following properties for the biofilter should be achieved:

- The biofilter should consist of a tube which can be filled with biomedia, and that allows users to view what happens inside the tube.

- Specific amount of water should be pumped inside the tube from the bottom and upwards at an even rate throughout the reactor.
- Specific amount of air should be released evenly beneath the biomedia in the biofilter
- One closable outlet for cleaned water should be placed above the biomedia in the biofilter
- One outlet for backwashing should be placed above the cleaned water outlet in the biofilter.

5.3 Ranking of features

When selecting solutions for achieving the important features, a ranking of the solutions will be described to easily select optimal features in Table 5.3-1. Some of the parameters will not be relevant for the given selection and therefore not be included.

Table 5.3-1 Ranking of relevant features. Each feature is given a value between 1 and 5 in relation to the importance of the specific feature where 5 is important, and 1 is unimportant.

Parameter	Description	Importance	Reason
Performance	Performance of the specific feature.	5	How well the feature performs gives critical results.
Complexity	The difficulty of designing and producing the feature	4	A low complexity system is easier to produce, and easier to investigate errors.
Usability	How easy it is to use the specific feature	3	It is important that the system is easy to use.
Dependability	How dependable the feature may be	5	Problems in running the system could be fatal for the results.
Cost	The price of the specific feature	4	The system should be cheap to manufacture.

As the project is aiming to gain knowledge about the performance of the system, the performance of the system has the highest importance. Because of the timeframe of the project, the complexity regarding time to manufacture the specific feature is given a high importance. Usability is not given a high importance as the product will not be developed for a consumer market. As the filter should be performing over a long period of time, the dependability is very important. Cost of the specific features should not be especially high if possible.

6 Concept development

The functions of the test reactor will be showed in this chapter. Additionally, various concepts and methods for developing the test reactor will be discussed.

6.1 Function analysis

An analysis of the various functions of the test reactor will be conducted to select the best solutions for the filter to function optimally. The analysis is showed in Figure 6.1-1.

Figure 6.1-1.

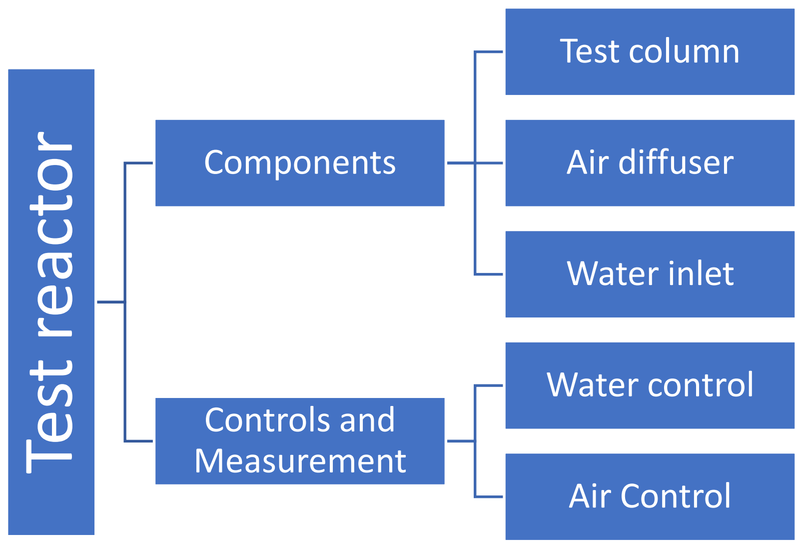


Figure 6.1-1 Description of the test reactors functions.

From the analysis, there are 5 functions that should be selected. This will firstly be regarding the components; what the test column should look like, thereby how the air diffuser should be developed, as well as the water inlet. Furthermore, the control of water into the filter, and the control of airflow to the filter. The following subchapter will evaluate and select different solutions to the function analysis.

6.2 Function alternatives

Alternative solutions for the various functions will be considered, selected and described in this chapter.

6.2.1 Test tube

The tube used as the main part of a reactor should be made from a clear material to allow the user to view what is happening inside the tube. A clear acrylic tube was obtained from the workshop with specifications listed in Table 6.2-1. The tube was easy to handle by one person, and easy to modify for the experiment. A PVC connection was glued to the bottom part of the tube, which would allow for easy connection of inlet connections. A minor damage was also present on the side of the tube, but was easily fixable (Figure 6.2-1 B).

The backwashing outlet should be placed above the greywater outlet, allowing 25% expansion when the backwash process is initiated (Basu et al., 2016). A rough estimate for the placement of the greywater outlet is calculated. Assuming biomedia will be present in 60 cm of the tube, the increase of biomedia would be 15 cm. Thereby, the greywater outlet was drilled 15 cm below the backwash outlet.

Table 6.2-1 Specifications of tube

Parameter	Value
Outer Diameter	150 mm
Inner Diameter	141 mm
Height	1000 mm

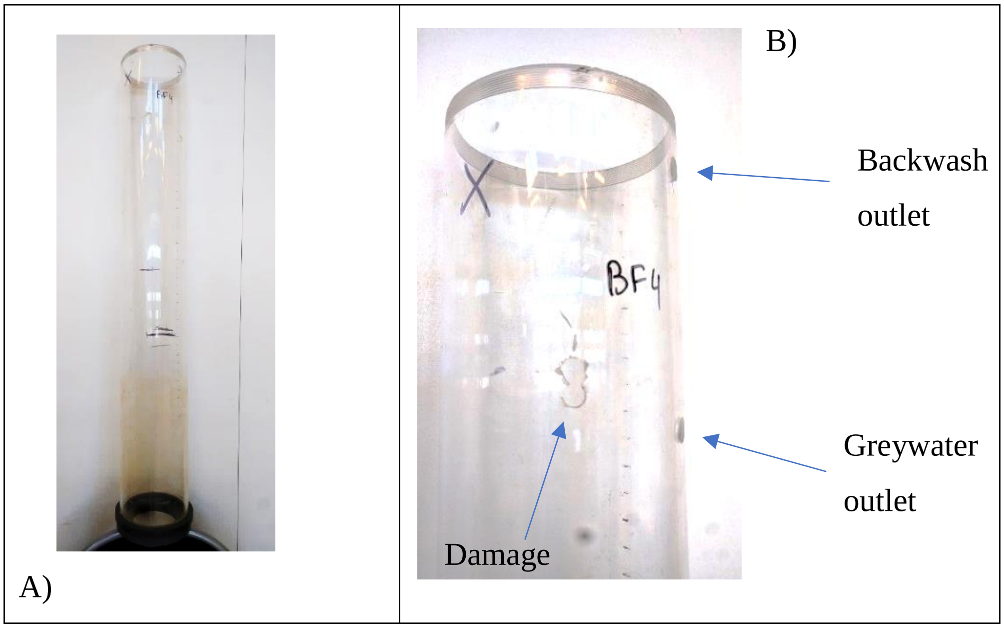


Figure 6.2-1 A) Overview of column chosen to work with. B) Top outlets drilled for outflow of column, and damaged part

With the tube chosen, it is possible to calculate important parameters for the experiment. The flow rate through A02 is known as $600\ l/day$. The flowrate and volume of A02 will be compared to the test filter to compare their efficiency. The volume of the water and biomedia will be included for the calculation of the biofilter. From Table 1.2-1, relevant specifications are extracted.

Calculating the theoretical detention time:

$$\tau = \frac{V}{Q} = \frac{0.680m^3}{0.600m^3/day} = 1{,}13\ days \qquad (3)$$

Cross sectional area of filter is 0,0156 m^2, and the maximal flowrate of the filter is set to 50 l/day. The height of the filter volume is set to 0.7 m. For comparison, the size of the filter is important, thereby the biomedia in the biofilter is not included. Theoretical detention time becomes:

$$\tau = \frac{V}{Q} = \frac{(0.0156m^2 \cdot 0.7m)}{50\ l/day} = \frac{0.01092\ m^3}{50\ l/day} = 0{,}22\ days \qquad (3)$$

Comparing retention times, the calculation becomes:

$$\frac{1.13}{0.22} = 5{,}14$$

Operating at 50 l/day, the filter has a theoretical detention time of 5,14 times shorter than in A02. This will be the maximal load the filter would be tested to. The same calculation is performed for 3 flow rates that are selected for testing the biofilter treatment efficiency:

Table 6.2-2 Surface load efficiency compared to A02

Volume flow	50 l/day	24 l/day	15 l/day
Detention time compared to A02	5.14	2.6	1.55

Amount of added air will be calculated by the amount of BOD present in the greywater and the greywaters volume flow. The maximal reading of BOD_5 in the greywater is: $\frac{120 mgO_2}{l}$ Necessary air will therefore be given by:

$$Q_{air} = 50\frac{l}{day} \cdot 110\frac{mgO_2}{l} = 5.5\frac{gO_2}{day}$$

Air consists of 20.95% oxygen (Toolbox, 2003) thus, the amount of air necessary for biofilm to consume organic material is given by:

$$Q_{air} = \frac{1}{0{,}2095} \cdot 5{,}5\frac{gO_2}{dag} = 26.25\frac{gAir}{day}$$

1 liter of air has a weight of 1,3 grams, needed air will be:

$$\frac{\frac{26{,}25 gAir}{day}}{1{,}3 g/l} = 20.2\frac{l}{day}$$

Because of the low airflow, it could be a challenge to measure this airflow. This calculation is considering all oxygen to be consumed by the biomedia, which could not be the case if air is not properly diffused (Mavinic & Bewtra, 1974). Because of this, the amount of air could be increased even more.

6.2.2 Air diffuser

To distribute the right amount of air evenly through the biomedia, an air diffusor is needed. It should allow water to flow evenly through the diffusor, and allowing air to be released from the top The smaller holes for air on the diffuser, the better the performance of oxygen transfer in the biofilter (Mavinic & Bewtra, 1974).

Alternative A:

A circular diffuser with large solid holes for water to travel through, and an air distribution chamber. Water transfer holes are 0.9 cm in diameter to prevent biomedia from passing through the filter. On one side, a high density of small holes is present, which should allow air to be pumped out of. The diffuser can be produced by 3d printing in two parts and glued together (Figure 6.2-2).

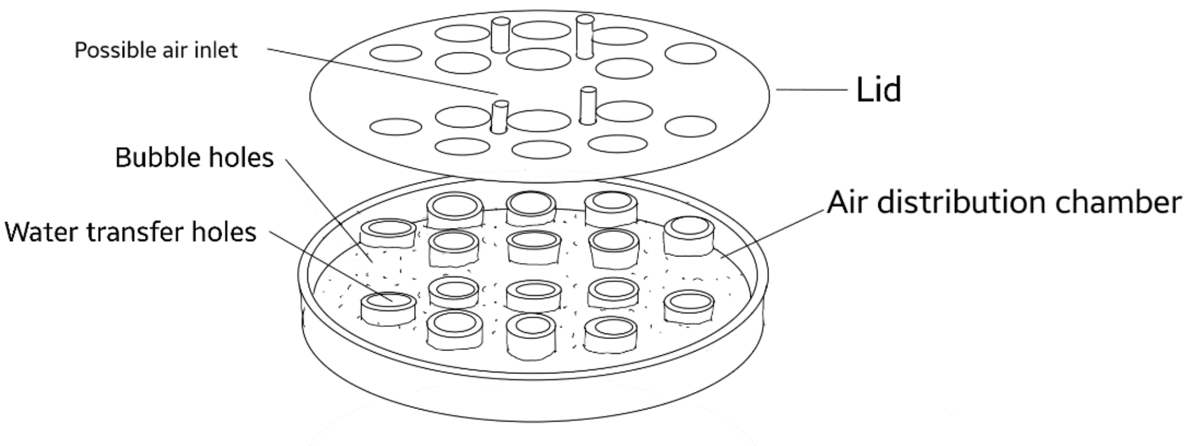


Figure 6.2-2 Design in two parts to be glued together.

Alternative B:

Similar diffusor as proposed in alternative B), now designed in a more complicated way allowing for the entire part to be 3d printed. Internal walls have an angle so that there is no horizontal roof. Thus, eliminating the need for glue. Water transfer holes openings are created with a diameter of 0.9 cm for the same reason explained for alternative A.

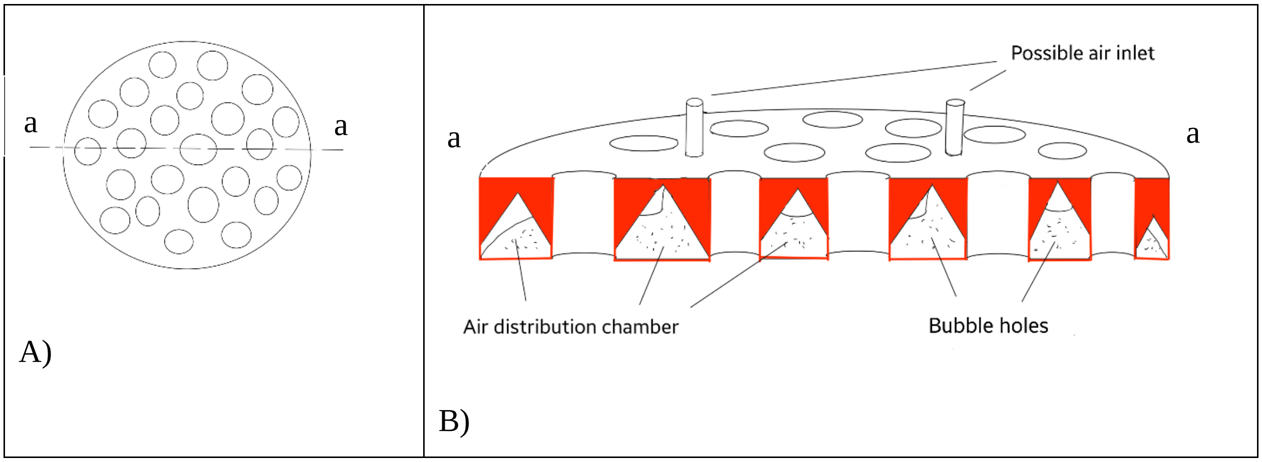


Figure 6.2-3 A) Complete diffusor seen from below. B) Cross section of part where inside structure is viewed.

Alternative C:

The diffusor could be designed with inspiration from a spider web as shown in Figure 6.2-4. Design is allowing a lot of water to travel through the diffuser, and will have little interference with the water velocity. Distance between openings should be 0.9 cm.

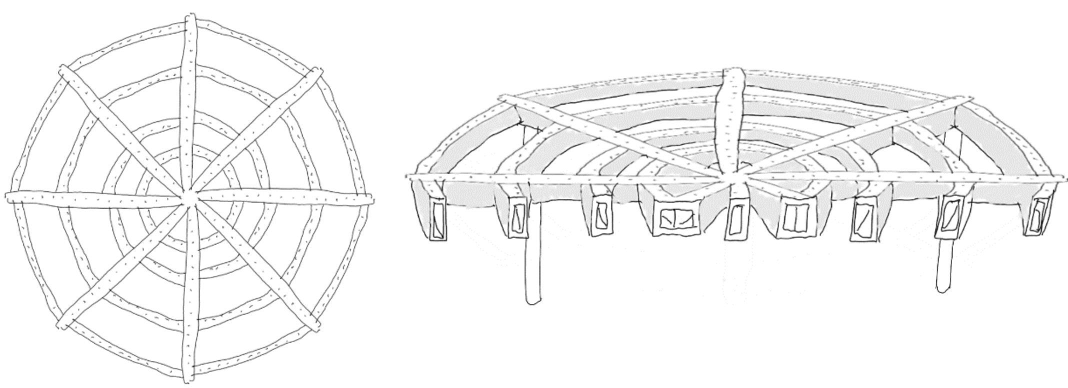


Figure 6.2-4 Diffuser design with air inlets beneath, and air outlets on top.

Pros and cons are considered for easier comparison of the diffusers in Table 6.2-3.

Table 6.2-3 Pros and cons listed for the alternatives of the diffusers.

Alternative	Pros	Cons
A)	• Likely even distribution • Quick to manufacture	• May leak air • Difficult to glue
B)	• Likely to distribute air evenly • Easy to manufacture	• Complex design
C)	• Likely even distribution of air	• Complex design • Difficult to manufacture

Selection of air diffuser:

To select the optimal solution for the air diffuser, a PUGH – Matrix is utilized. In Table 6.2-4, values between 1 and 5 is given to the specific alternatives in relation to the set criteria described in chapter 5.3.

Table 6.2-4 Selection of air diffuser in a PUGH – Matrix.

Criterias	Importance [%]	A)	B)	C)
Performance	40	4	5	3
Complexity	20	3	3	3
Usability	5	4	5	4
Dependability	30	3	5	5
Cost	5	4	4	4
Total value		3.5	4.55	3.7
Chosen solution		No	Yes	No

Solution C is chosen as the solution for the air diffusor because of the good score evaluated from the matrix.

6.2.3 Air Inlet

Different alternatives for the air to enter the air diffuser are discussed in this subchapter.

Alternative A: Entering from above.

Air inlets could be leaded into the air diffuser from the top of the filter with tubes (Figure 6.2-5). This would not require modifications with the column, although it would inflict with biomedia, and reduce its effective volume.

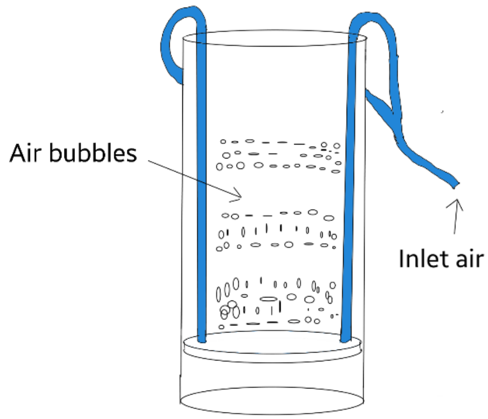
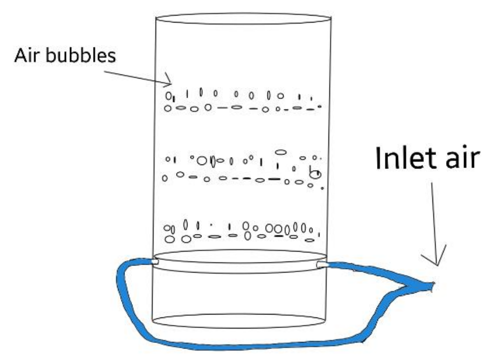


Figure 6.2-5 Inlets from the top of the reactor.

Alternative B: Air inlets from the side of the column.

By creating holes in the side of the column, it could be possible to pump air into the side of the air diffuser (Figure 6.2-6). This method would minimize inflictions with the water inlet in the bottom.



the side of the filter

Alternative C: Inlets from beneath the filter

Air inlets could also be placed beneath the filter close to the water inlet (Figure 6.2-7). The air tubes can be moved to the edges of the inlet to minimally inflict with the water inlet.

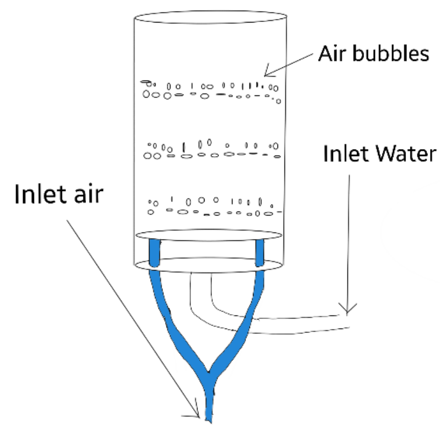


Figure 6.2-7 Air entering from beneath the filter

Pros and cons are summarized in Table 6.2-5 to get an overview of the different methods.

Table 6.2-5 Pros and cons relating alternatives to air inlet

Alternatives	Pros	Cons
A)	• Easy to produce • Easy to assemble • Does not conflict with water inlet	• May limit backwashing • May cause less efficient filter
B)	• Does not conflict with the biomedia or water inlet	• Difficult area to drill • Difficult to assemble
C)	• Does not conflict with biomedia • Easy to assemble	• May conflict water inlet

Different alternatives are evaluated in Table 6.2-6 by the specific criteria's and their weighting.

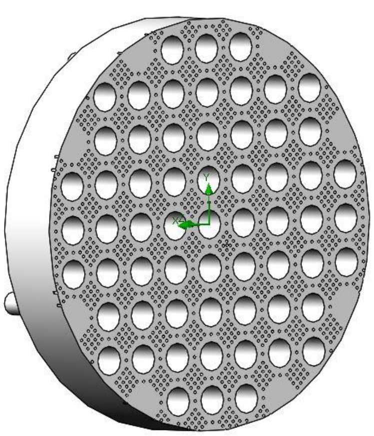
Table 6.2-6 Selection of concept for air inlet. A score between 1 and 5 is given each and multiplied by the given weighting.

Criteria	Weight	A)	B)	C)
Performance	40	2	4	4
Complexity	20	5	3	4
Usability	5	4	4	4
Dependability	30	3	4	5
Cost	5	4	4	4
Total value		3.1	3.8	4
Chosen solution		No	No	Yes

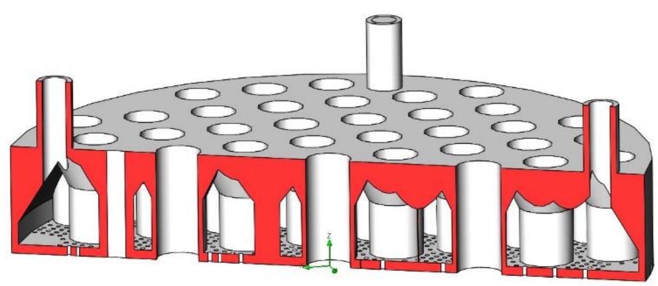
Alternative C) Inlets from beneath the filter scored best in the matrix. This alternative solves the air inlet challenge in a practical and efficient way.

Working principle of air diffuser:

As the air diffuser has been selected, and the air inlets position are selected, the CFD test of the air diffuser will be performed. The air filter was designed in SolidWorks with a complex structure allowing for 3d printing of the entire part. See Figure 6.2-8 A) and B).



A)



B)

Figure 6.2-8 A) Air filter with small holes for air, and large holes for water. B) Cross section of air filter with special roofing structure to avoid support structure when 3d printed.

The design went through an iterative process in SolidWorks Flow Simulation to ensure an even distribution of air exiting the holes in the filter. The thickness of the diffuser was increased, and the number of air inlets were changed.

As the filter will perform better utilizing smaller holes for bubbles, it was necessary to identify the smallest holes possible to 3d print. A small part of the diffuser was printed with holes of 0.5 mm and 1 mm. From the testing it became evident that the smallest printable holes were 1 mm (Figure 6.2-9).

Figure 6.2-9 Part of air diffuser

To provide air, the compressor La-80B from MEDO was provided by Ecomotive, and was considered sufficient when tested. The inlet flow rate for the CFD calculation was decided by dividing the compressor flow rate by the number of inlets. From the specifications of the compressor, it was found that its flowrate was 80 l/min. As Solidworks units are noted in kg/min, it was calculated that the airflow becomes:

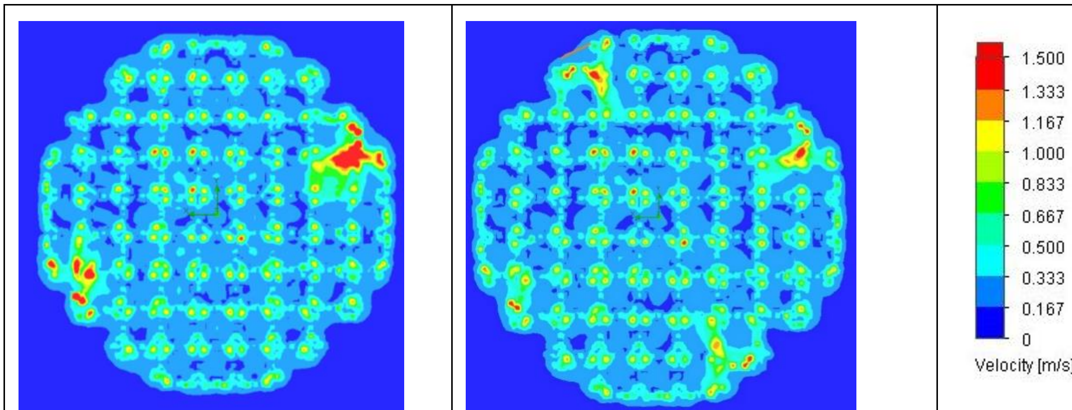
$$Q = \frac{80l}{min} \cdot \frac{1{,}3g}{l} = 104\frac{g}{min} = 0.104\frac{kg}{min}$$

The airflow into the filter should then be 0.104 kg/min. Settings in the flow simulation is showed in Table 6.2-7. Settings not shown are set to default. See Appendix 1 for meshing.

Table 6.2-7 Settings in SolidWorks Flow simulation

General settings	
Analysis type	Internal
Fluids	
Fluids	Air (liquids)
Wall Conditions	
Wall thermal condition	Wall temperature
Roughness	0 µm
Mesh	
Total cell count	77384
Initial conditions	

Parameter Definition	User Defined
Thermodynamic pressure	101325 Pa
Temperature	293.2 K
Mass flow rate (air inlets combined)	0.104 kg/min



A) B) C)

Figure 6.2-10 A) Cut plot of diffuser with 2 inlets of air B) Cut plot of diffuser with 4 inlets of air C) Velocity bar

Cut plots close to the filter with 2 inlets (Figure 6.2-10 A) and 4 inlets (Figure 6.2-10 B) showed that 4 filters give a better air distribution through the filter. Even more inlets could be attached to the diffuser to distribute air even better, but it is not considered necessary when regarding the increasing complexity of connecting more filter inlets trough the column inlet.

6.2.4 Water inlet

Water can enter the reactor in different ways, this subsection will discuss the most effective ways to pump water into the filter.

When the greywater is being pumped into the column from a small tube, the flow will be expanded. This could result in turbulence by the inlet of the reactor if the cross-sectional increase is too high, which would lead to a high level of sedimentation of particles by the inlet. A solution to this challenge could be a cone that would reduce the turbulence. A CFD analysis were conducted with different cones. The column with biofilter was modeled in Solidworks to make the model realistic for the inlet evaluation and because the biomedia would be modeled for later analysis regardless. Biomedia was replicated by designing a geometrical pattern with spheres with a diameter of 1.5 cm as the mean value of the biomedia of 1-2 cm diameter. Figure 6.2-11 illustrates this design consisting of two layers of spheres duplicated 8 times each, resulting in a geometrical pattern of 16 layers. Biomedia in the reactor will not have a geometrical pattern, it will be completely at random and with variating sizes and surfaces. Because of this, the CAD model is not accurate in predicting the flow through the biomedia, although it gives an indication of what could happen. Furthermore, this CAD model consists of 16 layers of biomedia resulting in 40 cm of biomedia, whereas the test

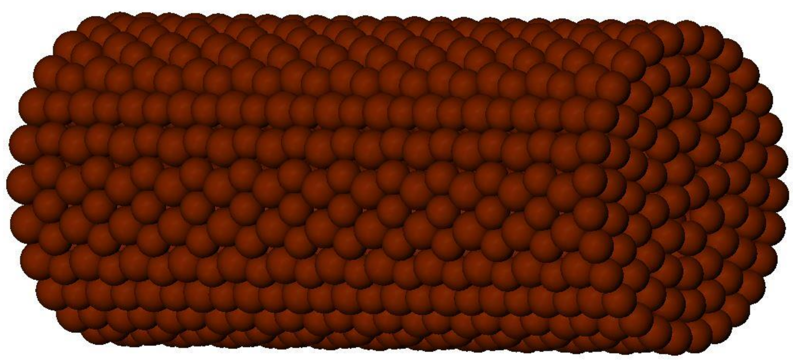
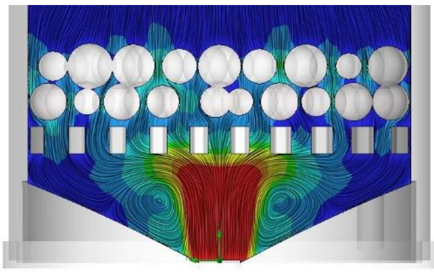
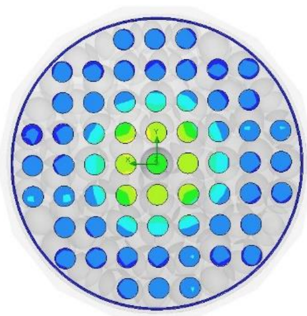
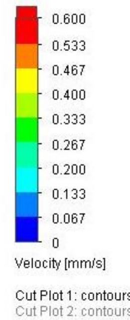
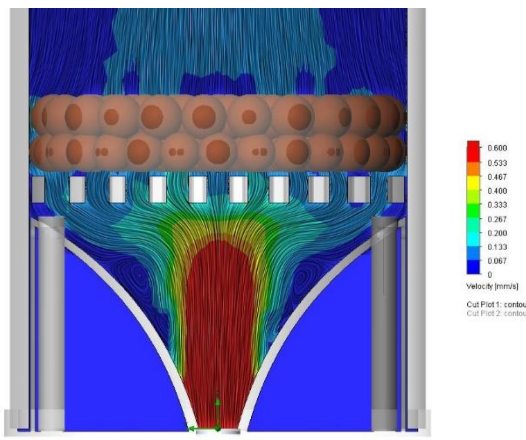
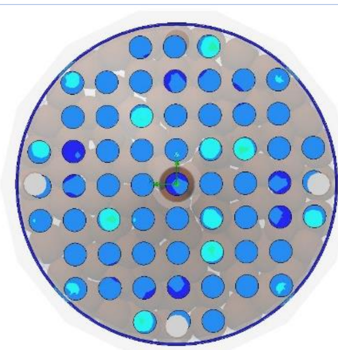
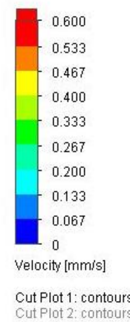
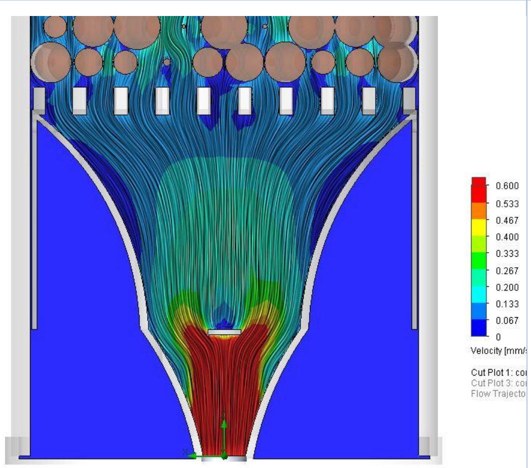
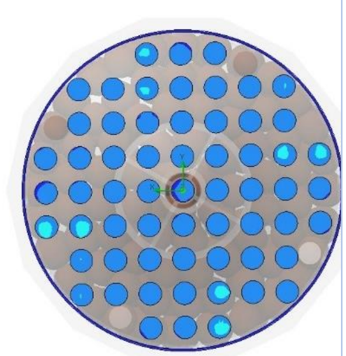
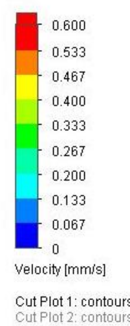


Figure 6.2-11 CAD model of a part of the biomedia placed in the column.

filter will have close to 70 cm. This is done because the CAD model with many spheres becomes challenging for the computer. Several cones were tested in Solidworks flow simulation to compare their performance. The inlet velocity was set to 50 liters per day, which is the highest velocity of the tests that will be conducted. Results can be seen in Table 6.2-8

Table 6.2-8 CFD simulations of different cones

Cone	CFD illustration 1	CFD illustration 2	Velocity bar
1			
2			
3			

From Table 6.2-8, Cone 1 in CFD illustration 1 can be observed to have a presence of turbulence. This could result in sedimentation in the beginning of the filter (Matko et al., 1996). Sedimentation could result in clogging of the inlet over time as the formation of sedimentation could build up. From the CFD illustration 2 of Cone 1, it can be observed that the velocity of water entering the biomedia will be higher in the center. This could lead to an increased flow dispersion. Looking at Cone 2, CFD illustration 2, the cut velocity distribution has been improved. From Cone 2, CFD illustration 1, turbulence can still be observed. Cone 3 appears to have no turbulence and even flow distribution when observing illustration 1 and 2. Cone 3 is therfore selected as the cone to be 3d printed and further tested. It is printed on a Zortrax 3d printer with Z-ultrat filament material.

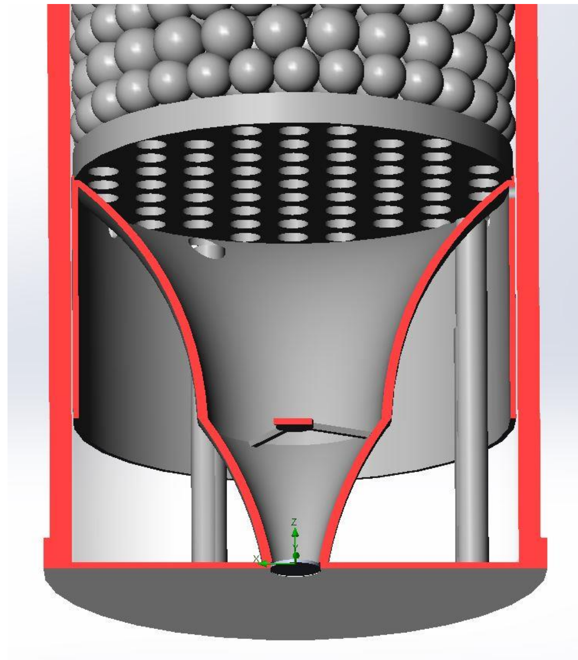


Figure 6.2-12 CAD section view of the chosen cone placed in the filter.

6.2.5 Air control

Distributing the small amount of air to be pumped into the filter can be done differently.

Alternative A: Continuous flow

Continuous flow of air through a filter by utilizing an air pump, a throttle valve and a flow meter to pump the specific amount of air into the reactor. The low amount of air which would pass through the diffuser could result in air not being equally distributed out of the filter (Figure 6.2-13).

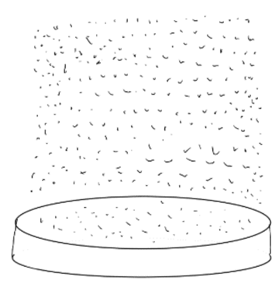


Figure 6.2-13 Air bubbles continously exiting the diffuser

Alternative B: Pulsating flow

Pulses of air could be sent into the filter by controlling a compressor with a microcontroller to inject the specific amount of air at the right time. Each pulse of air would have to be measured to decide how many pulses is needed to produce the specific amount of oxygen needed (Figure 6.2-14).

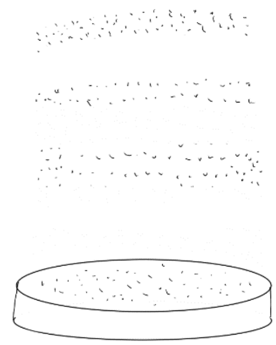


Figure 6.2-14 Pulses of air bubbles evenly distributed out of the diffuser.

Pros and cons will be listed to easily evaluate the alternatives.

Table 6.2-9

Alternatives	Pros	Cons
A)	• Simple solution • Easy to build	• Could be uneven airflow • Hard to get measuring equipment
B)	• Provides even airflow	• More complex solution • Difficult to measure airflow.

Selection matrix for deciding airflow solution Table 6.2-10:

Table 6.2-10 Selection of concept for air inlet. A score between 1 and 5 is given each and multiplied by the given weighting.

Criteria	Importance [%]	A)	B)
Performance	40	2	4
Complexity	20	5	3
Usability	5	4	4
Dependability	30	3	5
Cost	5	5	4
Total value		3.15	4.1
Chosen solution		No	Yes

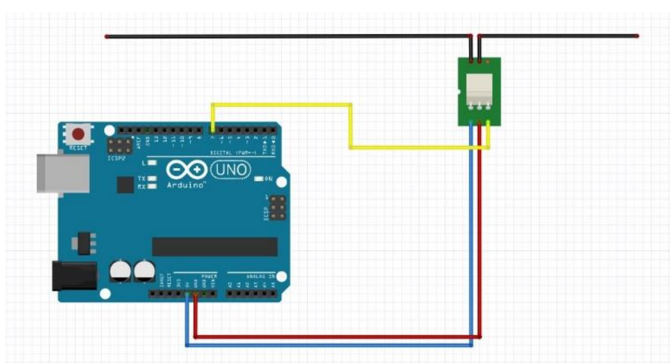
Alternative A: pulsating air flow is chosen as the selected method for further development. The alternative had the highest score and was thereby the following choice.

Working principle:

To control the system so that the compressor is started and stopped at the right time, an automatic control system should be utilized. An Arduino microcontroller is a good solution to this challenge. This is an easily programmable microcontroller that can be connected to a relay that is capable of controlling 230v and has a rated current of 10A. The amount of power it can control is calculated by:

$$P = UI = 230v \cdot 10A = 2300\ W \qquad (8)$$

This system will be connected as shown in Figure 6.2-15 A). The top black wire represents the positive wire in the power cable to the compressor. The code programmed into the microcontroller is an infinite loop where the relay is switched on for 350 ms and then off for 300 000 ms (roughly 6 minutes). Why these values are set, will be explained later in the thesis. The code used to control the Arduino can be seen in Figure 6.2-15 B).



A)

```
int relay_pin = 7;
int led_pin = 13;
void setup(){
  pinMode(relay_pin,OUTPUT);
  pinMode(led_pin,OUTPUT);
digitalWrite(led_pin,HIGH);}
void loop(){
  digitalWrite(relay_pin,HIGH);
  delay(350);
  digitalWrite(relay_pin,LOW);
  delay(300000);
}
```

B)

Figure 6.2-15 A) Wiring of the Arduino microcontroller B) Programmed code used in the microcontroller

A compressor delivering high volume flow is provided by Ecomotive, and is connected to the arduino. The compressor is called LA-80B from Medo, and can be viewed in (Figure 6.2-15).

Table 6.2-11 Compressor

Power supply	**230 v**
Rated Pressure	0.15 bar
Airflow at rated pressure	80 l/min
Power consumption	86 W

6.2.6 Water Control

For running tests with a water pump, the pump should deliver water in the range of 15 l/day up to 50 l/day. Converting 12,5 l/day to ml/min gives:

$$15\,\frac{l}{day}\cdot\frac{1000\,ml}{24\,h\cdot 60min} = 10.42\,ml/min$$

The same conversion for 50 l/day gives:

$$50\,\frac{l}{day}\cdot\frac{1000\,ml}{24h\cdot 60\,min} = 34.7\,ml/min$$

A pump provided by Ecomotive is Heidolph Pumpdrive 5201 illustrated in Figure 6.2-16. This pump was tested to deliver 10 ml/min and far beyond 34.7 ml/min, thereby it was considered sufficient.

Table 6.2-12 Peristaltic pump

	Power supply	**230v**
 ***Figure 6.2-16 Peristaltic pump***	Minimum flow rate	10 ml/min
	Maximal flow rate	729 ml/min

6.3 Other challenges

Connection of parts

Various parts in the filter had to be fastened or sealed. The cone had to be connected to the bottom plate, outlets from the top and backwashing outlet sould be sealed. It was also important to secure no leakage from the water inlet, and the backwashing and greywater outlet.

It was chosen to use super glue, glue gun and Tec7 due to ease of avalability and rapid connections.

7 CFD analysis and Construction of the filter

A CFD analysis of the reactor will be conducted, as well as a description of how the test filter was constructed.

7.1 CFD analysis of the filter

A CFD analysis on the filter could produce valuable information regarding the performance of the filter. The analysis will investigate the dispersion of fluid through the profile, velocity differences in the column, at flowrates of 50, 25 and 15 l/day. There is reason to believe that water could travel faster along the edges of the filter than the rest of the filter as there could be more space between biomedia along the edges. Air pulses from the diffuser will not be included in the analysis, which could affect the results. Although the CFD analysis will exactly predict the flow in the filter, it could give an indication as to what to expect from the test filter. CFD settings not listed in

Table 7.1-1 Settings for CFD analysis. settings not shown are set to default

General settings	
Analysis type	Internal
Gravity	Yes
Gravity direction	-Z
Fluids	
Fluids	Water (liquids)
Wall Conditions	
Wall thermal condition	Wall temperature
Roughness	0 µm
Initial conditions	
Parameter Definition	User Defined
Thermodynamic pressure	101325 Pa
Temperature	293.2 K
Velocity parameters	0 m/s
Mass flow rate	50, 24, 15 l/day

Figure 7.1-1 CAD model used in CFD analysis

Table 7.1-2 CFD results of biofilter

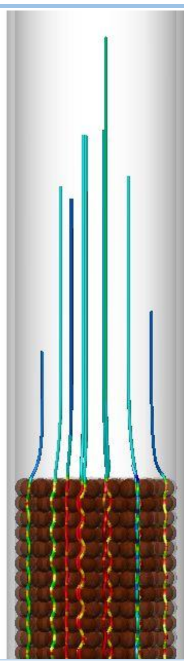
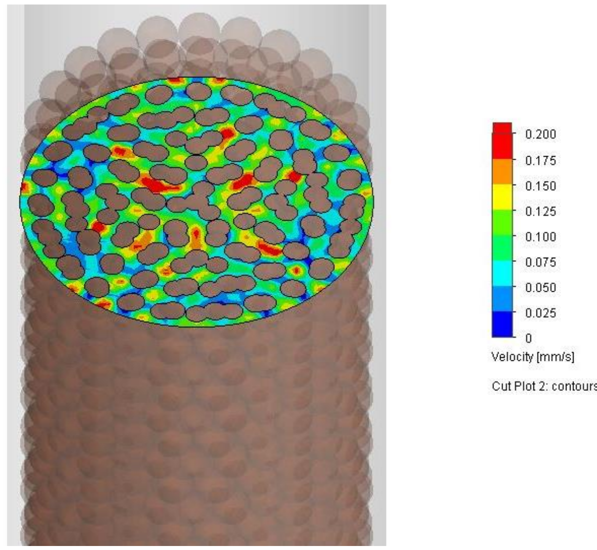
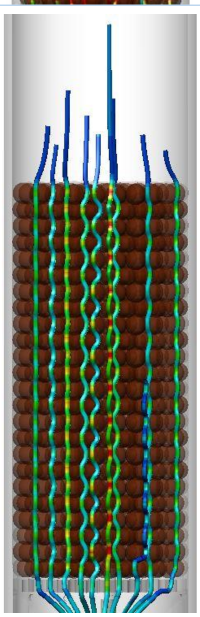
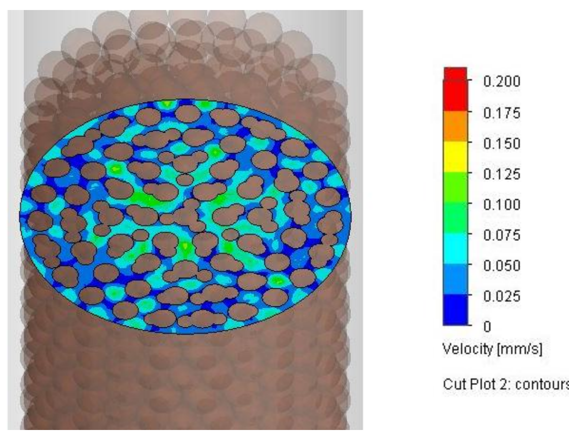
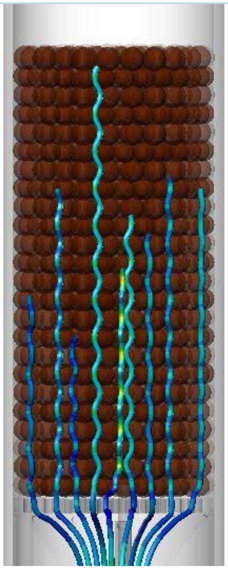
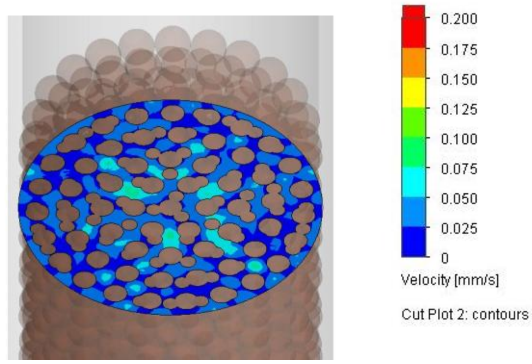
Q [l/day]	20 flow trajectories for 8000 seconds	Velocity cut plot
50	 *A)*	 *B)*
25	 *C)*	 D)

Table 7.1-2 CFD results of biofilter continued

15	 **E)**	 **F)**

In Table 7.1-2, on the left side, it is shown 20 different flow trajectories lasting for 8000 seconds. At the right side it is shown three cross sections of the velocity present at 40 cm away from the filter inlet. Starting at 50 l/day from the top, further to 25 l/day, and ending up at 15 l/day. From the results, it can be observed that along the edges there are no significant increase in velocity at any of the flowrates. Therefore, no extra measures will be taken regarding the inside of the tube. Hydraulic efficiency for the tube is indicated to not be optimal due to the differences in the lines through the biomedia. The 20 randomized trajectories are traveling different distances during the same time frame, indicating some dispersion in the filter. Still, it is difficult to indicate what the actual efficiency is for the real model with biomedia.

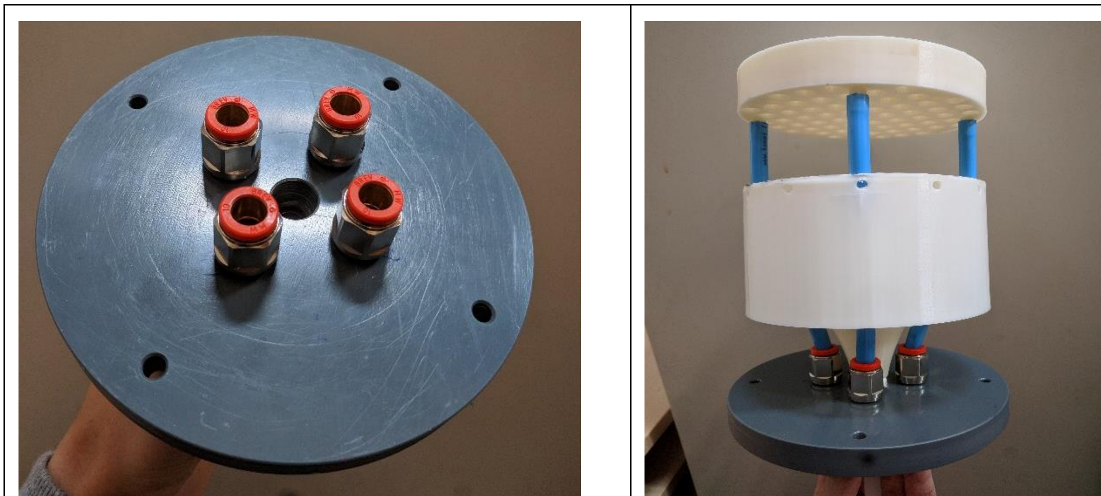
7.2 Test model

The air diffuser and cone selected in chapter 6.2.2 and 6.2.3 was 3d printed, and it was a concern that the parts could float due to air trapped inside the structure. This could result in glue not being sufficient to secure the parts. The parts were submerged in water, and their buoyancy was decided to be too small to be of any importance.

It was decided to conduct a test of the diffuser in water to ensure it was performing optimally. Flexible piping to contain pressurized air was acquired, 5 meters of PUR-10/7,5 (PUR C98A) was bought. Splitters for this piping was also needed, tree MA27-10 10 from Cmatic was bought. The filter was then connected to the compressor and tested underwater (Figure 7.2-1).

Figure 7.2-1 A) Diffuser submerged with splitters B) Diffuser tested underwater with compressor.

From the test is was concluded that air was evenly distributed, and the diffusor was performing as intended.



A) B)

Figure 7.2-2 A) Bottom plate with air connectors B) Bottom inlet connected with cone, air diffuser and piping.

Bottom plate of the reactor should have 4 inlets for air, and one for water. The bottom inlet was produced in PVC with proper connections to pneumatic fittings for air inlets, as well as a connection for the water inlet in center (Figure 7.2-2 A). Furthermore, the cone and air diffuser was connected to the bottom inlet with piping (Figure 7.2-2 B).

The bottom plate was bolted with 4 bolts onto the column with a packing in between to prohibit leakage, and with the diffuser, cone and 4 tubes connected on the other side (Figure 7.2-3 A). Water inlet was connected to a rubber hose for connection to the peristaltic pump, and secured with strips. When pouring water into the column, the water inlet was leaking, and the leak was fixed with glue gun. This fix can be viewed in Figure 7.2-3 B).

A) B) C)

Figure 7.2-3 A) Bottom plate connected to column with diffuser and cone. B) Closeup of sealed water inlet. C) Overview of assembled filter without biomedia.

To guide treated water and greywater out of the top outlets, steel plates were formed to the diameter of the column for each side, and the inner side was welded with a steel pipe. The steel plates were then secured with Tec7 to the column to ensure no leakage would be present. As the column had a hole close to the treated water outlet, this hole was filled by attaching bitumen to a plastic plate and covering the hole (Figure 7.2-3 C). The system was furthermore tested with water for identifying leakage, and no leakage was found. The Arduino microcontroller was coded, and connected to the relay controlling the compressor before connected to the system. By testing the compressor, airflow out of the diffuser was observed to be equally distributed at 350 ms. This was the lowest time the compressor could deliver an even air distribution through the filter with water present.

Assembled prototype and CAD model comparison

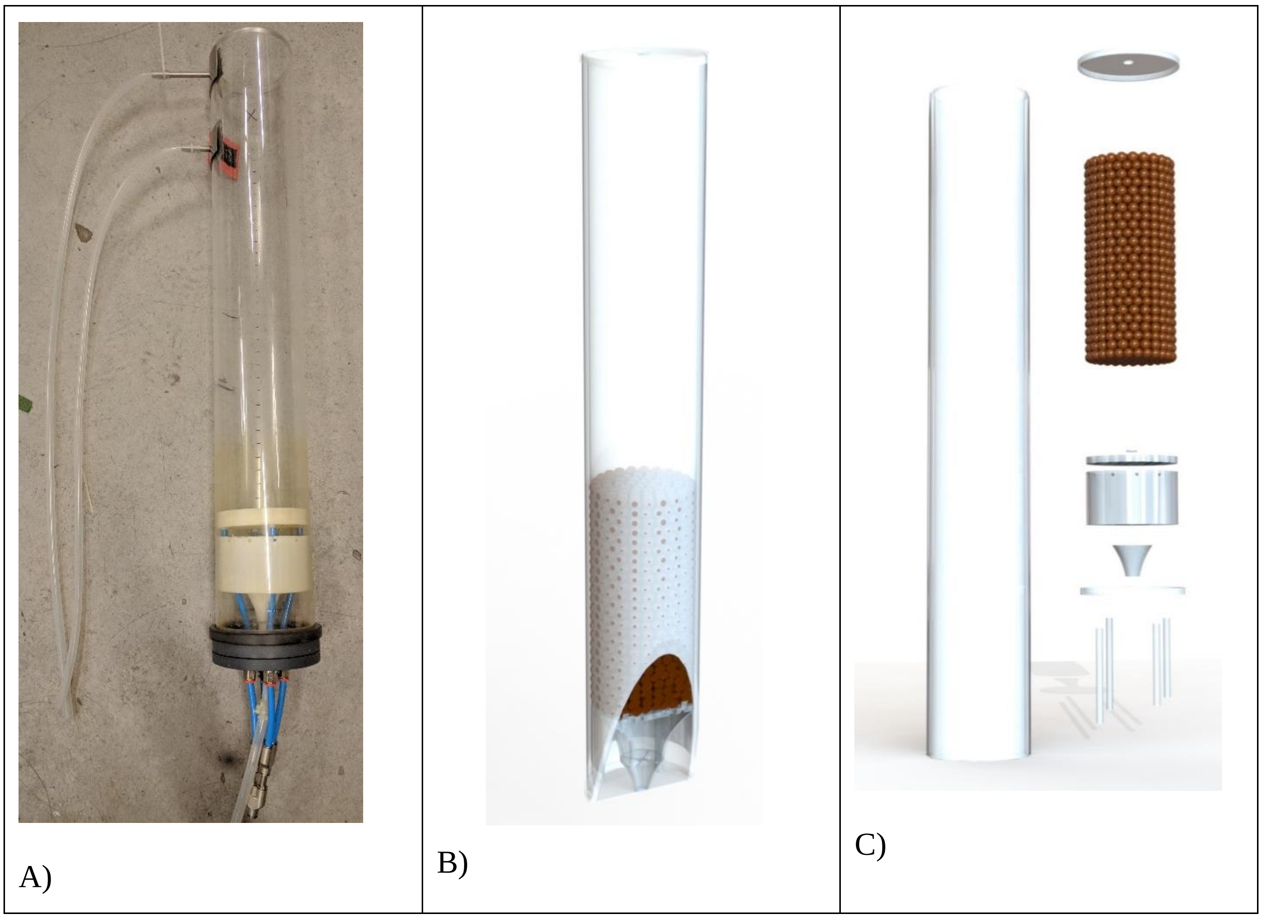


Figure 7.2-4 A) Assembled biofilter without biomedia B) Cad model of biofilter C) Exploded view of CAD model.

Figure 7.2-4 A) Illustrates the assembled biofilter, while Figure 7.2-4 B) shows the CAD model of the test filter. The CAD model has some simplifications. The inlet hoses for air is not included in the inlet of the reactor, as they will not interfere with the waterflow outside the cone. As can be viewed from Figure 7.2-4 C), the hoses are included in in the CAD model, but they are only present in the flow between the cone and the air diffuser.

Theoretical residence time

To give an estimate of the time needed for the water in the column to be exchanged, the formula for theoretical residence time should be utilized.

$$\tau = \frac{V}{Q} \tag{4}$$

For further use of the formula, it is vital to know the amount of water needed to fill the reactor with the presence of biomedia. A bucket containing 9 liters of water were poured into the reactor until the water level reached the exit tube. The bucket was then weighed with the containing water, as well as the weight of only the bucket. The weight of the water was then calculated:

$$Weight\ of\ 9\ liters\ of\ water + weight\ of\ bucket - \ weight\ of\ bucket\ and\ rest\ of\ water =$$

$$9000\ g + 328g - 1857\ g = 7471\ g = 7471\ ml$$

The biofilter volume is thereby given as 7.471 liters.

7.3 Cost estimation of prototype

This subchapter contains the costs for development of the biofilter. Some parts were obtained for free, but the cost estimation regards prices as if they should be obtained from a dealer. Rough cost estimates of all parts and the prototype development are presented in Table 7.3-1.

Table 7.3-1 Cost estimates of test system.

Parts	Item description	Quantity	Price each [NOK]	Sum [NOK]
Acrylic tube	Ø 0.141mm	1	1359	1359
Pneumatic couplings	GWS10-8 from Misumi	8	26	209.5
Pneumatic splitters	MA27 10	3	86.5	194.63
Compressor	LA-80B	1	553	553

Table 7.3-1 Cost estimates of test system.

Peristaltic pump	**Heidolph™ PD 5201 Pump Drive**	**1**	**29711**	**29711**
Piping	Pur-10/7,5 (5m long)	1	125	125
3D printed parts	3D printing filament Z-ultra t	1	539	539
Glue	Super Glue	1	109	109
Glue gun	Glue gun	1	129	129
Tec7	Grout	1	178	178
Bitumen	Adhesive dampening	1	69	69
Microcontroller	Arduino Uno	1	229	229
Relay	SRD-05VDC-SL-C	1	100	100
Wiring and Power supply	3 male to female Arduino wires and 6-20v USB connection	1	99	99
Total material cost [NOK]				**33604.13**

8 Experimental phase

The test reactor was assembled, and necessary equipment needed to conduct the experiment was collected. Before any tests with greywater were started, tests with water was conducted to check that the system was performing properly. The treated biomedia were poured into the reactor, before the water was poured in. Most of the biomedia were floating, and when all the water was filled up to the first outlet, the column of biomedia would float roughly 10 cm up from the air diffuser. Because of this, the biomedia is present in 50 cm of the column (Figure 7.3-1 B).

A) B)

Figure 7.3-1 A) Overview of biofilter system in operation with biomedia with grown biofilm B) Column in test phase with biomedia without biofilm.

The compressor was connected to a pneumatic tube, and then led up above the water level before it entered the connection to the bottom of the column. The column was held up by a fastener mounted in a fixed structure (Figure 7.3-1 A).

Greywater for the test was provided by a 1500 liters tank containing greywater from 24 households of 48 residents nearby, as earlier used in greywater studies (Todt et al., 2015). A tube was placed into the tank, guided up 3 meters, and into the biofilter in the next room.

8.1 Washing biomedia

The utilized biomedia was severely crushed in some areas, resulting in the presence of particles a lot smaller than 10mm in diameter. As the air diffuser was designed to filter out particles larger than 0.9 cm in diameter, it was a challenge that the biomedia was damaged. To remove these particles, a special strainer was made. The strainer consisted of a steel plate perforated with small holes of 8 mm in diameter screwed onto a transparent acrylic tube Figure 8.1-1. The biomedia was inserted into the strainer and washed with tap water. Small particles were then screened from the filter, resulting in a biomedia with less dense areas that could increase dispersion (Zarook et al., 1998).

A)

B)

Figure 8.1-1 A) Strainer filled with biomedia B) Strainer

8.2 Air dosage

To ensure an aerobic process in the biomedia, 20.2 liters/day of air is needed. To know how many pulses of air is needed through one day, the volume of each pulse will be calculated. By controlling the compressor with a microcontroller, short pulses of air could be sent into the filter. A plastic bag which volume was measured, were used to measure the amount of pulses needed to fill the plastic bag. Thereby the volume of each pulse of 350 ms from the compressor could be calculated.

To check that the openings of the reactor was air tight during the experiment, water with bubble soap was sprayed onto the possible leakage spots when the pulses of air were sent. A sheet metal plate was placed on top of the filter with a 10-kg weight placed on top of the tube to prevent air from leaking out of the top. Spots where air was leaking could easily be identified and improved, thereby the reactor was sealed, as can be shown in Figure 8.2-1.

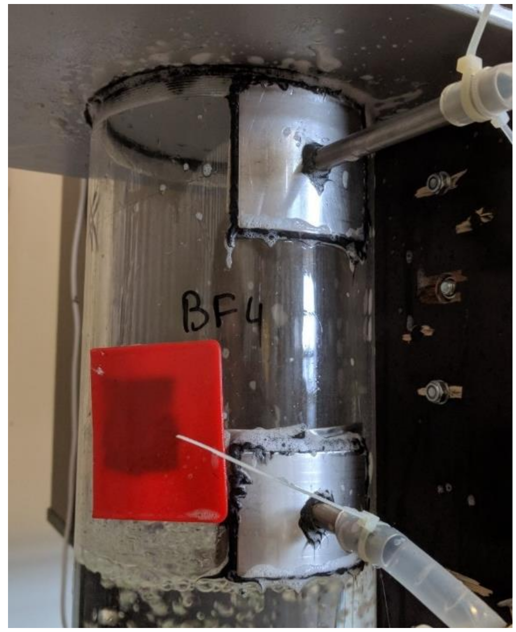


Figure 8.2-1 Air tight sealing.

Table 8.2-1 Data used to measure volume of plastic bag

Pulses to fill plastic bag		**Water in plastic bag**	
Test	Value (count)	Test	Value [ml]
1	16	**1**	1270
2	18	**2**	1202
3	17	**3**	1238
Sum	17	**Sum**	1236.7

The lower tube outlet was sealed off, and the top outlet kept open. A small plastic bag was connected to a hose and sealed with strips and heated glue to avoid leakage. The plastic bag was then sprayed with bubble soap and inflated, so that leakages could be identified and fixed with additional glue (Figure 8.2-2A). With the plastic bag sealed, the bag was filled with water which was then poured onto a weight (Figure 8.2-2 B). This process was repeated 3 times, and the values presented by the weight can be seen in Table 8.2-1. Furthermore, the plastic bag was connected to the top hose while almost completely deflated. The number of pulses needed to fill the bag completely was then counted (Figure 8.2-2C). The process was repeated 3 times, and the number of pulses needed can be seen in Table 8.2-1.

A) B) C)

Figure 8.2-2 A) Plastic bag sealed onto a hose. B) Weight of water collected from the plastic bag being measured. C) Plastic bag mounted onto reactor.

The plastic bag was then connected to the reactor almost completely deflated. The pulse of the compressor was then set to be on for 0.35 seconds, and off for 5 seconds. It was then easy to count the number of pulses needed to fully inflate the plastic bag. The test was done 3 times, and the average of these values was chosen.

Each pulse is then calculated by:

$$\frac{1236.7ml}{17} = 72.8ml$$

Number of pulses needed each day:

$$\frac{Air\ needed\ each\ day}{Air\ from\ pulse} = \frac{20200ml}{72{,}8ml} = 277.5\ pulses/day$$

Pulses each minute:

$$\frac{277{,}5\ pulses}{24\ hours \cdot 60\ minutes} = 0.193\,\frac{pulses}{minute}$$

Seconds between each pulse:

$$\frac{60\ seconds}{0.193\,\frac{pulses}{minute}} = 310\ seconds$$

This gives that there should be 310 seconds between each pulse. To ensure that the air filter supplies sufficient oxygen, the pulse will be set more frequent. One negative side of inserting more air than necessary is an increased energy usage. A value of 300 seconds between each pulse is chosen.

The system setup was finished. To test the performance of the biofilter, BOD_5 and TSS will be tested to evaluate the performance of the system, and for comparison with Ecomotives model A02. A summary of the comparable results from A02 in emergency mode from chapter 1.2 are listed in Table 8.2-2.

Table 8.2-2 BOD_5 and TSS results from A02 in emergency mode.

<table>
<tr><th colspan="1">Specification</th><th colspan="2">Value</th></tr>
<tr><td>Total residence time</td><td colspan="2">27.2 hours</td></tr>
<tr><td colspan="3">Treatment effects of primary sludge and secondary sludge. 3 measurements over 7 days.</td></tr>
<tr><td>Variable</td><td>Value</td><td>Reduction</td></tr>
<tr><td>BOD₅ influent</td><td>175.6 mg/l</td><td rowspan="2">44.3%</td></tr>
<tr><td>BOD₅ effluent</td><td>97.8 mg/l</td></tr>
<tr><td>TSS influent</td><td>78.5 mg/l</td><td rowspan="2">74.4%</td></tr>
<tr><td>TSS effluent</td><td>20.1 mg/l</td></tr>
</table>

The influent greywater from the steel tank are variating. A study by Ecomotive from 31/3/2013 to 1/12/2013 have logged the temporal fluctuation of the greywater in this steel tank from the same households which are used in this thesis.

Table 8.2-3 TSS and BOD_5 fluctuations in influent greywater

	TSS [mg/l]	BOD_5 [mgO_2/l]
Mean ± std	95.9 ± 36.8	139.3 ± 41.1
Minimum	51.0	50.6
Maximum	278.0	250.0
Count	49.0	38.0

By measuring turbidity from both the influent and the effluent of the biofilter, indications about the waters containments of particles can be made. For backwashing of the biofilter, turbidity can provide an indication of when the backwashing should start. When the turbidity from the biofilter effluent is increasing, the backwashing process should be initiated (Tchobanoglous, 2003).

8.3 Experiment

This subchapter will explain the execution of the experiment.

8.3.1 Water flowrate 24 l/day – test 1

Prior to running the first test of the filter, it had been running for 5 hours with water before the inlet was switched over to greywater. To know how long before the effluent consists of only greywater, the theoretical detention time at this flowrate is calculated.

$$\tau = \frac{V}{Q} = \frac{7471ml}{16{,}7\ ml/min} = 447.4\ min = 7.45\ hours \quad (4)$$

By allowing the filter to run for over 2 times the theoretical detention time, only treated greywater is assumed to exit the column. Turbidity measurements was taken each day with 3 tests to get an impression of the water quality coming in and out of the filter. Turbidity tests were taken from influent and effluent at the same time, meaning that the turbidity tests do not indicate the proper efficiency of the filter because of the detention time between samples, although the results provide an indication. Turbidity tests were performed in this manner through the entire testing.

The filter was left running for 35 hours before BOD_5 were tested from the influent and the effluent. Results can be viewed in Table 8.3-1.

Table 8.3-1 BOD_5 results from test 1

BOD_5 results			
Load	BOD Influent [mgO_2/l]	BOD Effluent [mgO_2/l]	Reduction [%]
24 l/day	124	70.3	43.3

Figure 8.3-1 Clog in the filter inlet before the pump.

After 4 days, the inlet tube to the reactor had clogged during the night, as the clog was discovered in the morning. Particles clogging the tube was removed and greywater from the tube outlet was let flowing for about 30 seconds to remove more clogged particles present in the greywater tube. Similar clogging happened the 5th night, with the same cleaning of the clog in the morning. When the clog was removed, the greywater for the tube was let flowing out for 30 seconds to remove water that could have clogged other areas in the tube. The clog can be seen in Figure 8.3-1

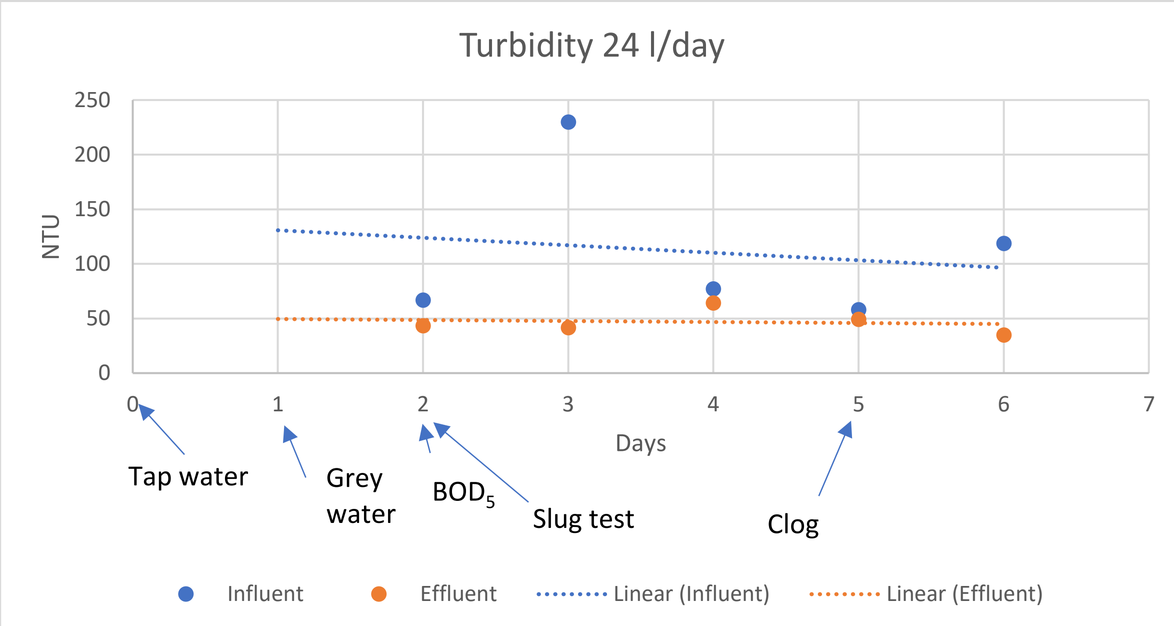


Figure 8.3-2 Turbidity measurements and notable events

Test 1 comments:

From the BOD_5 results, a reduction of 43,4% is indicating a close value as A02, even with a higher load. Figure 8.3-2 illustrates an overview over the test. The high value of 230 NTU in the inlet at day 3 could be because of a refill of the greywater tank, or difficulties with the tube placed in the tank. Considering the TSS maximum from greywater has been as high as 278 mg/l, and that there is a correlation between turbidity and TSS (Jefferson et al., 2004), the result could be due to a refill in the tank, as it can variate substantially (ref Table 8.2-3). As the influent turbidity has a standard deviation of 46,7 (appendix 3) it is difficult to evaluate the performance of the filter based on these results. TSS measurements was attempted, but issues with the testing resulted in invalid results.

8.3.2 Water flow rate 47,5 l/day - Test 2

The pump was set to 16 rpm and the flow rate was measured to 33 ml/min, the closest setting for 50 l/day. Theoretical detention time was calculated to:

$$\tau = \frac{V}{Q} = \frac{7471ml}{33\ ml/min} = 226.4\ min = 3.7\ hours \tag{4}$$

A slug tracer test was performed after 12 hours to obtain more information about the hydraulic efficiency of the filter. Outlet greywater from the reactor was measured to have a conductivity of 456 µS/cm. When one liter of this water was added with a dosage of a 5ml concentrated salt solution (Saline XS 5ml), the conductivity in one liter of outlet greywater was measured to be 578 µS/cm.

Assuming that 4 dosages of this salt solution is mixed in half of the reactor (Heistad, 2018). Comparing with the one liter experiment, the calculation becomes:

$$Volume\ of\ half\ the\ reactor = \frac{7.417}{2} = 3.71\ l$$

The increase in conductivity was 578 – 456 = 122. The volume is 3.71 times bigger, and the dosage is four times the previous. This gives:

$$Assumed\ maximal\ increase\ in\ conductivity = \frac{122}{3.71} \cdot 4 = 131.5$$

This indicates an assumed maximal measurable increase in the reactor. Adsorption of salt to the biomedia could result in a lower increase. The slug test was performed by injecting 4 salt solutions into the filter inlet, and the results can be viewed in Figure 8.3-3.

From the data set of the test, the dispersion number can be calculated (Appendix 4).

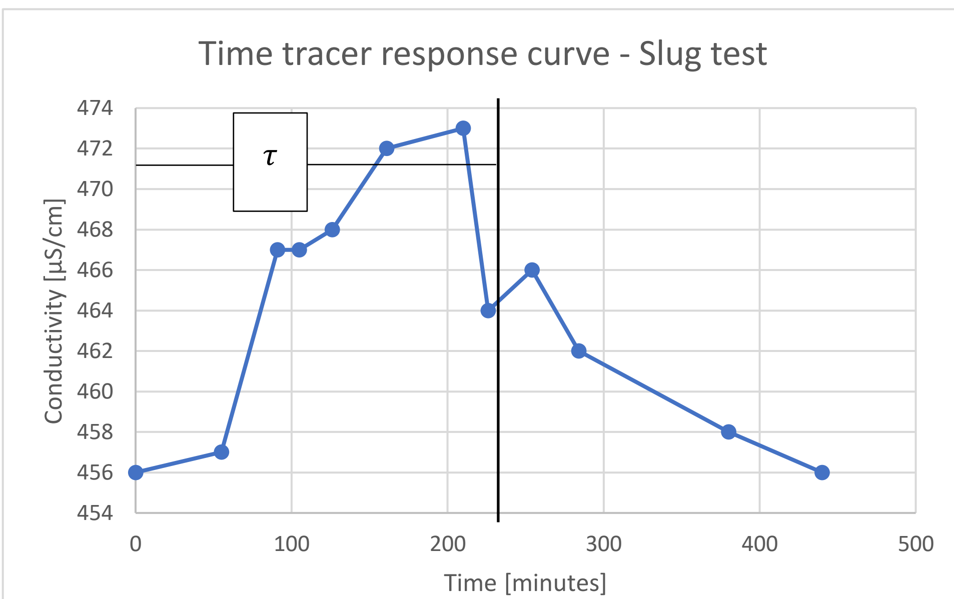


Figure 8.3-3 Data from slug test at 47.5 liters per hour.

$$\bar{t}_{\Delta c} = \frac{\sum t_i C_i \Delta t_i}{\sum C_i \Delta t_i} = \frac{16681}{94} = 177.45 \qquad (5)$$

$$\sigma_{\Delta c}^2 = \frac{\sum t_i^2 C_i \Delta t_i}{\sum C_i \Delta t_i} - (\bar{t}_{\Delta c})^2 = \frac{3396843}{94} - (177.45)^2 = 4644.576 \qquad (6)$$

$$d = \frac{1}{2}\frac{\sigma_{\Delta c}^2}{\tau^2} = \frac{1}{2}\frac{4644{,}576}{226.4^2} = 0.045 \qquad (7)$$

The dispersion number is calculated to 0.045, wich indicates low dispersion (0.05>d) (Tchobanoglous, 2003).

This flowrate was running for 5 days, until the inlet clogged completely, and the test was stopped. In the days leading up to the clog, the inlet tube was partly clogged at the 4th and 5th day during the night, and then fixed in the morning upon notice (Figure 8.3-2).

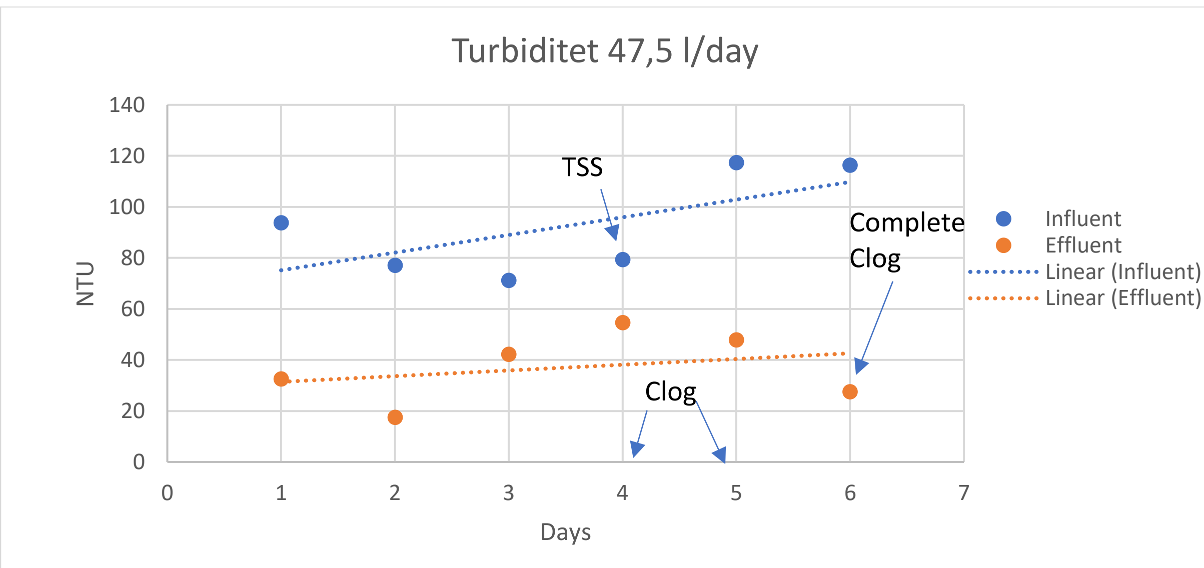


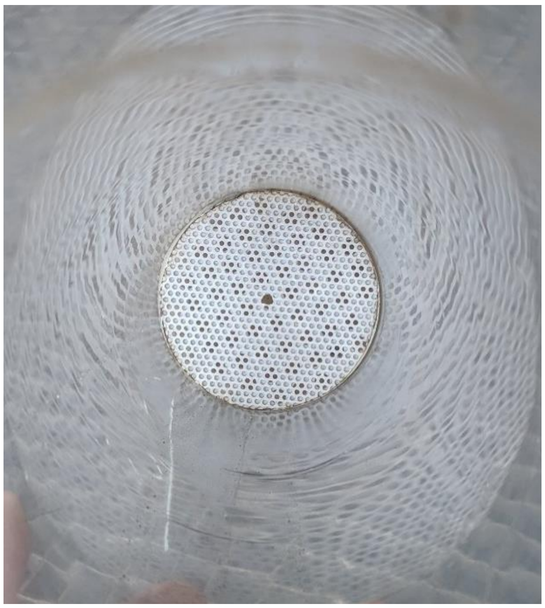
Figure 8.3-4 Turbidity and notable events at 47.5 l/day

Suspended solids were tested from the influent and the effluent, and can be viewed in Table 8.3-2.

Table 8.3-2 Results from suspended solids test.

Suspended solids results			
Load	SS Influent [mg/l]	SS Effluent [mg/l]	Reduction [%]
47,5 l/day	74	47	40.1

At the end of this test, the water inlet opening was completely clogged. Clearing the clog was attempted by exerting high water pressure in the opening with no luck. The water and biomedia was removed, and the inlet was dismantlet to remove the clog (Figure 8.3-5 B). Biomedia had fallen through the air diffuser and ended up clogging the water inlet. To contiune the experiment, a new steel filter was made and placed on top of the air diffuser (Figure 8.3-5 A).



A)

B)

Figure 8.3-5 A) Perforated plate placed on top of air diffuser. Viewed from above the column B) Clog in the filter`s water inlet

Test 2 comments:

No BOD_5 were completed during the test, as the filter were expected to perform longer until this test would have been completed. The tube sucking greywater from the steel tank was moved to a position further away from the inner walls to improve the differences in turbidity from the inlet greywater. A reduction in turbidity can be noted in Figure 8.3-4, indicating an even treatment of the greywater.

8.3.3 Water flowrate 14,7 l/day – Test 3

The column was filled with tap water, and the inlet was started with greywater. Theoretical residence time of water in the reactor is given by:

$$\tau = \frac{V}{Q} = \frac{7471ml}{10{,}2\ ml/min} = 732.5\ min = 12.2\ hours \qquad (4)$$

After 27 hours, the filter was tested for BOD_5, Suspended Solids and turbidity. The water had theoretically been changed over two times.

Table 8.3-3 Results from test 3

Suspended solids results			
Load	TSS Influent [mg/l]	TSS Effluent [mg/l]	Reduction [%]
14.5 l/day	96.7	47.7	40.1
BOD_5 results			
Load	BOD_5 Influent [mgO_2/l]	BOD_5 Effluent [mgO_2/l]	Reduction [%]
14.5 l/day	110	47.9	56.3
Turbidity results			
Load	Turbidity Influent [NTU]	Turbidity Effluent [NTU]	Reduction [%]
14.5 l/day	96.7	47.7	51.2

Test 3 comments:

The filter is operating at 2.2 times the load of A02, and the BOD_5 reduction of 56.3% are better than A02. The TSS result is not performing as high as the results from A02, but the biofilm on the biomedia have not been developed, so the filter is not expected to function optimally yet.

8.3.4 Water flowrate 24 l/day – biofilm – Test 4

It was concluded that an effective method to obtain biomedia with biofilm quickly, would be to place biomedia with already grown biofilm was extracted from a working A02 bio chamber. The biomedia was carefully moved with a bucket over into the test filter. As the biomedia had been present in A02 for over a year, most of the biomedia would not float in the reactor, resulting in a 60-cm long presence of biomedia. The column was filled with tap water as greywater was pumped in. A slug tracer test was then performed. BOD_5, TSS and turbidity tests was performed 24 hours after test start, long after the theoretical retention time of 7.45 hours (Figure 8.3-6). During day 5 of the experiment, the Arduino microcontroller was moved, and the relay was accidentally started for about one second. This resulted in a short stirring of the biomedia.

BOD_5 results			
Load	BOD_5 Influent [mgO_2/l]	BOD_5 Effluent [mgO_2/l]	Reduction [%]
24 l/day	158	49.3	68.8
24 l/day	190	78,9	58,5
Total Suspended Solids results			
Load	TSS Influent [mg/l]	TSS Effluent [mg/l]	Reduction [%]
24 l/day	63.67	39.69	37.7
24 l/day	134	39.33	70.6

Table 8.3-4 BOD and TSS results

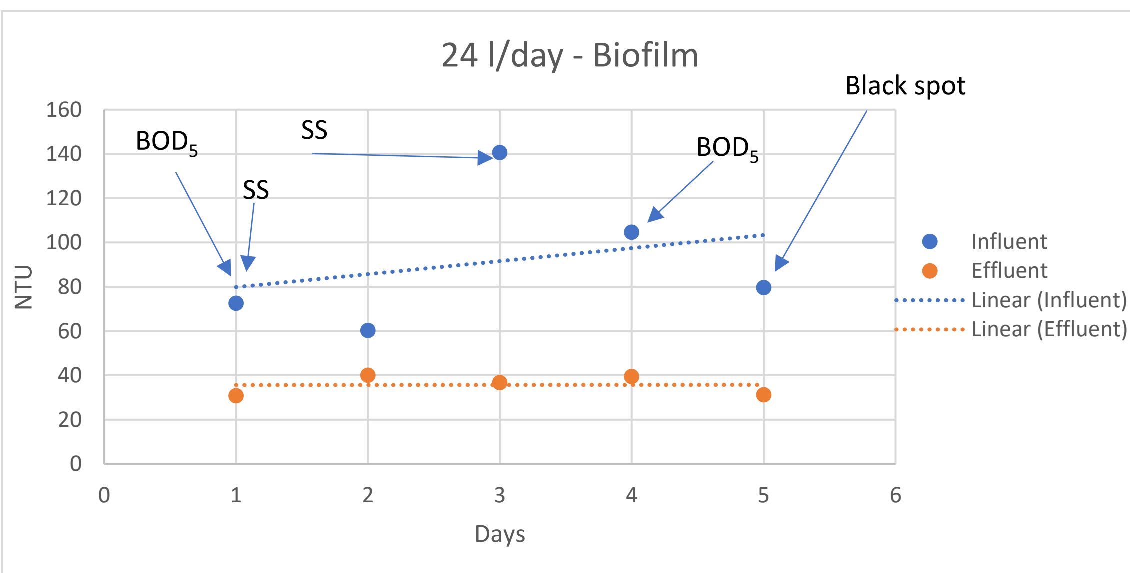


Figure 8.3-6 Turbidity and notable events during the test

Test 4 comments:

With this flowrate, the effluent results in effluent turbidity have dropped to a mean of 35.7±3.9 NTU (see appendix 3), which is lower than the previous results. Indicating that the filter has a higher treatment efficiency than previously. From Table 8.3-4, it can be observed that the BOD_5 results indicate a better reduction than from A02, and the reduction in TSS is variating more than BOD_5, but both values are below 74.4 %. The TSS influent has a great variance, and the second TSS influent measurement of 134 is a lot higher than the rest of the measurements in the test (See appendix 3). Thereby, it is indicated that the reduction of TSS is not performing as well as when compared with A02.

8.3.5 Water flowrate 14,7 l/day – biomedia – test 5

The reactor was observed to have a darker part in the bottom of the reactor. This could indicate anaerobic reaction. To counteract this, the Arduino code was changed to pause the relay for 100 seconds, and switched on for 450 ms. This was a high rate of air to be pumped into the filter without biomedia moving noticeably based on observations. Measurements were performed 27 hours after test start, well after the theoretical detention time of 12.2 hours The filter did not clog a single time during this test. Results are present in Figure 8.3-7

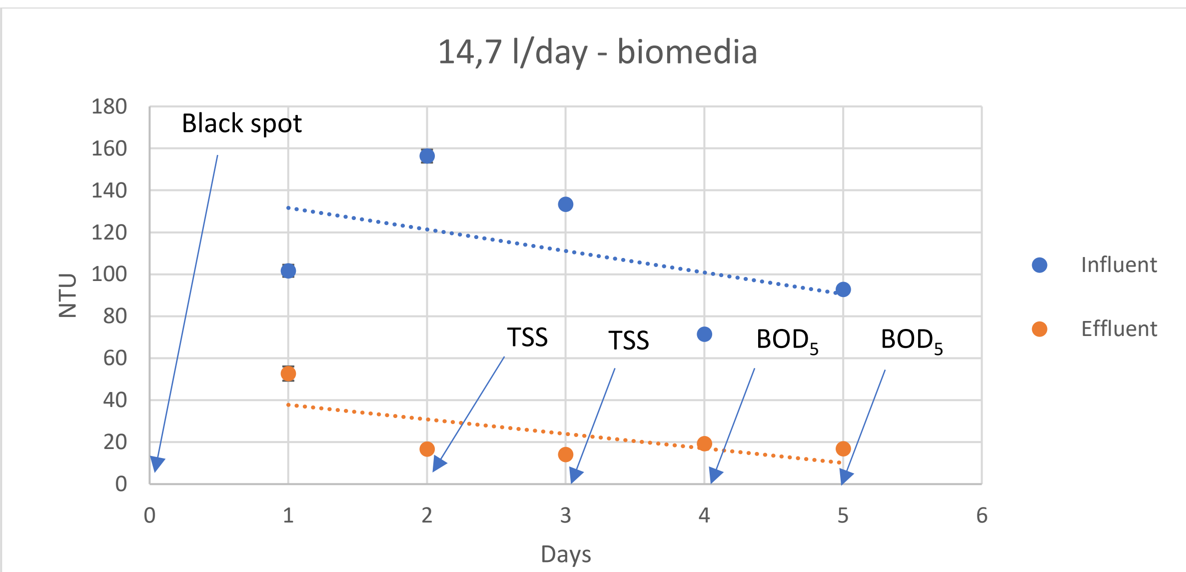


Figure 8.3-7 Turbidity and noticeable events during the test

During day 1 and 2, a slug tracer test was conducted to investigate the hydraulic efficiency of the filter (Appendix 5).

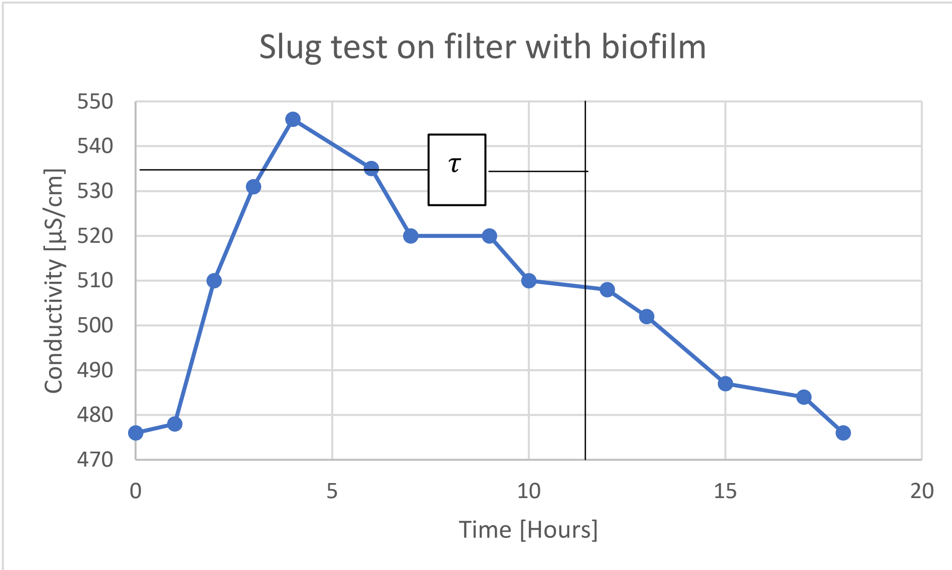


Figure 8.3-8 Conductivity values on filter with biofilm present

$$\bar{t}_{\Delta c} = \frac{\sum t_i C_i \Delta t_i}{\sum C_i \Delta t_i} = \frac{176160}{407} = 404.9 \quad (5)$$

$$\sigma_{\Delta c}^2 = \frac{\sum t_i^2 C_i \Delta t_i}{\sum C_i \Delta t_i} - (\bar{t}_{\Delta c})^2 = \frac{96429600}{419} - (404.9)^2 = 53381.2 \quad (6)$$

$$d = \frac{1}{2}\frac{\sigma_{\Delta c}^2}{\tau^2} = \frac{1}{2}\frac{53381.2}{732,5^2} = 0.0497 \quad (7)$$

Dispersion number is 0.0497, which qualifies for low dispersion: $d < 0.05$

Table 8.3-5 BOD_5

BOD_5 results			
Load	BOD_5 Influent [mgO_2/l]	BOD_5 Effluent [mgO_2/l]	Reduction [%]
14.7 l/day	142	31	78
14.7 l/day	193	26.1	86.5

Table 8.3-5 TSS results

Total Suspended Solids results			
Load	TSS Influent [mg/l]	TSS Effluent [mg/l]	Reduction [%]
14.7 l/day	94	17.3	81.6
14.7 l/day	92	30	67.4

Test 5 comments:

The biomedia was stirred the last day of the previous test, which could be why the effluent turbidity has a high value first day of this test. Effluent turbidity has low value of less than 20 NTU in the rest of the testing, indicating the highest performing treatment efficiency of the tests yet. From the BOD_5 results, the mean value of the percent reduction is 82.5. Total suspended solids for this flowrate have a mean value of 74,5% reduction. The slug tracer test resulted in low dispersion. The emergence of a dark colored area in the bottom 20 cm of the column is an indication of anaerobic formation (Elawwad et al., 2013). Images of the anaerobic formation can be seen in Figure 8.3-9.

 Day 1	 Day 3	 Day 5	 Day 7

Figure 8.3-9 Development of anaerobic formation in the biomedia. Day 1 is the first day the formation is noticed, and the aeration is increased.

Figure 8.3-9 shows that after a week, the anaerobic development was slightly decreased.

8.4 Results

This subchapter will include a summary of the results from the testing of the biofilter.

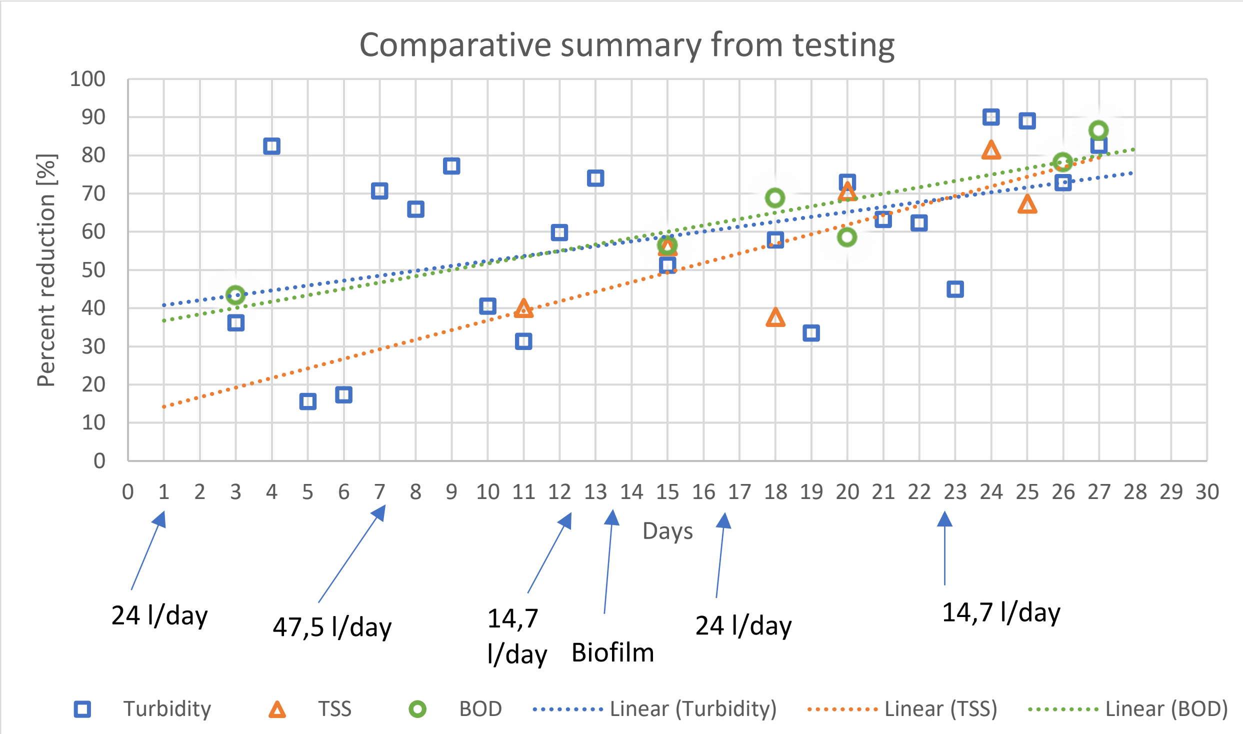


Figure 8.4-1 Comparative summary of all results from testing

In Figure 8.4-1, a summary of the results from the biofilter has been graphed. From the beginning of 24 l/day and 47.5 l/day, one can see that the results are dispersed. Results of TSS, BOD_5 and turbidity are showing a higher reduction percentage towards the end, as can be seen from the linear trendline.

Comparable results from Ecomotive's model A02 in emergency mode are listed in Table 8.4-1.

Table 8.4-1 Results from Ecomotives model A02 operating in emergency mode

Bod_5 influent [mgO_2/l]	**BOD_5 effluent [mgO_2/l]**	**Reduction**	**TSS Influent [mg/l]**	**TSS Effluent [mg/l]**	**Reduction**
175.6	97.8	44%	78.5	20.1	74%

Ecomotive provided results from the greywater tank which the inlet tube was transporting from at the period of testing. These results are presented in Figure 8.4-2.

Figure 8.4-2 Greywater tank measurements. Days are correlating with days from Figure 8.2-1

Day	TSS [mg/l]	Turbidity [NTU]	BOD [mgO_2/l]
6	55	75	137
10	65	100	124
17	63	81	110
20	67	80.2	134

Table 8.4-2 BOD_5 results from biofilter testing

BOD_5 results				
Load [l/day]	Biofilm	BOD Inlet [mgO_2/l]	BOD Outlet [mgO_2/l]	Reduction [%]
24	No	124	70.3	43.3
14.7	No	110	47.9	56.5
14.7	Yes	158	49.3	68.8
24	Yes	190	78.9	58.5
14.7	Yes	142	31	78.2
14.7	Yes	193	26.1	86.5

Table 8.4-2 shows the results from biofilter testing. A single factor Anova analysis of BOD_5 values from the the steel tank from the test period, and the BOD_5 inlet to the filter. The result was a P-value of 0.344, concluding that the BOD_5 results are not statistically different.

Table 8.4-3 TSS results from biofilter testing

TSS results				
Load [l/day]	Biofilm	TSS Inlet [mg/l]	TSS Outlet [mg/l]	Reduction [%]
14.7	No	74	44.3	40.1
47.5	No	84	42	56.3

Table 8.4-3 Continued

TSS results				
Load [l/day]	Biofilm	TSS Inlet [mg/l]	TSS Outlet [mg/l]	Reduction [%]
14.7	Yes	63.67	39	37.7
24	Yes	134	39.3	70.6
14.7	Yes	94	17.3	81.6
14.7	Yes	92	30	67.4

The same analysis was completed for the TSS inlet and the steel tank, resulting in a P-value of 0.0321, meaning the data sets are statistically different. The highest data point from the TSS inlet was removed from the results, and the same test was run again, resulting in a P-value of 0.06, meaning the data sets could not be statistically different.

Table 8.4-4 Results for effluent turbidity

Effluent Turbidity			
Flowrate	Grown biofilm	Average [NTU]	Standard deviation
24 l/day	No	110.2	63.4
47.5 l/day	No	93.7	18.5
14.7 l/day	No	47.8	0.5
24 l/day	Yes	35.7	3.9
14.7 l/day	Yes	23.9	14.5

All turbidity inlet results from the steel tank were compared with the inlet turbidity to the filter. This resulted in a P-value of 0.94, meaning they are not statistically different.

8.5 Experimental discussion

During the experiment, three flowrates were tested without grown biofilm, and 2 flowrates with biofilm attached to the biomedia. The experiment had challenges with the inlet clogging, which in some cases could have made the residence time longer, and treatment efficiency higher than it should in certain cases. As the filter inlet results were compared with results from the greywater tank, it was not shown a statistical difference between the results for BOD and turbidity, although it was a statistical difference for TSS which could indicate some errors were made during the measurements. Especially when the highest value is 134 mg/l, which is significantly higher than the rest of the values. It could also be the case that after a clog, several particles were collected by the inlet, and were not properly cleared out of the tube before the TSS tests were made. The data sets were not statistically different when the highest data point from TSS inlet were removed. This could implicate that there was a measurement error on the specific measurement, and there were no issues with the filters inlet tube. It could also be the case that due to the low amount of recorded values for the TSS in the greywater tank, the high TSS values were not measured due to the intervals of the measurements. The fact that all BOD_5 and TSS values from the influent are within the min/max range listed in Table 8.2-3, supports the argument that the values are not measured incorrectly. Natural fluctuations in the greywater productions from the households could be the explanation to the variations.

From the two slug tracer tests that were performed, the results indicated low dispersion in both tests. The hydraulic performance of the filter is thereby considered better than most reactors (Arceivala, 1983).

As Figure 8.4-1 illustrates, the measurements of TSS, BOD and turbidity measurements were improved with the presence of biomedia and even more with the lowest flowrate in the end of the experiment. All BOD_5 reduction results from the filter with presence of biomedia were higher than the comparable from A02 listed in Table 8.4-1. This gives a clear indication that the removal of organic pollution is higher in the filter than A02 in emergency mode.

Results from 24 l/day with biomedia are worth noticing. At this flowrate, the system is removing 37.7% and 70.6% of TSS (Table 8.4-3). Not as high as A02, but the filter is operating at 2.6 times the detention time. Because of the high deviation between these results, it is difficult to know what the TSS removal efficiency is at this flowrate.

BOD removal was in all cases with biomedia higher than A02s reduction of 44%. This shows that the filter is reducing more organic material than A02. Comparing results with typical BOD_5 and TSS removal in primary sedimentation tanks (Greeley, 1938), there is reason to believe the results are accurate, and the filter has been performing as intended.

Considering TSS removal at 14.7 l/day, the filter was performing 81.6% and 67,4% (Table 8.4-3). The mean of these values is 74.5%. The timespan for the measurements of A02 is 7 days, while the measurements for the biofilter at 14.7 liters are 4 days. Thereby the results are not directly comparable because of the difference in timespan. By including the last BOD_5 and TSS values from 24 l/day, the means become respectively; 74.7% and 73.2%. By including these values, the results are comparable as the timespan of both samples are 7 days. Thereby, TSS and BOD_5 are measured with detention times higher than in A02.

9 PROCESS EVALUATION AND DISCUSSION

This chapter will contain the evaluation and discussion for the thesis

9.1 Development work

This thesis has been a challenging task touching into several topics. A lot of new information regarding environmental engineering has been obtained to develop the test system. From earlier classes it has been useful to learn methodology in which to plan the development of the thesis.

As this thesis has been concerning product development and wastewater engineering, it would have been an advantage with more knowledge within wastewater engineering. During the experiment, some errors were made that could have been avoided if a better understanding of biofilters were obtained. Biomedia from A02 could have been placed in the filter at an earlier stage. This could have improved the test accuracy, allowing more testing to be completed. Due to shortage of time, the backwashing process was not completed.

The concept development could have been done differently. Clogging of the inlet was a cautious parameter which was identified from an early stage, and still not enough measures were made to ensure the filter did not clog. There is also potential for a control test of the filter according to relevant standards.

9.2 Design evaluation, production, cost reduction

Various notes regarding design and production that could have been differently will be discussed.

- The inlet water fitting could have been changed to a water tight fitting to eliminate efforts to seal the fitting.
- The air diffuser could have had smaller water holes to prevent clogging of the water inlet.
- The water inlet could have had a system for discarding sunken biomedia to prevent clogging.
- The Arduino microcontroller could have been connected in a safer way to prevent accidental start of the compressor.

10 CONCLUSION

Through the thesis, there have been ambitious goals of what should be accomplished. In the end, there was not sufficient time to perform the thought testing, although valuable information was obtained by the completed testing.

During this thesis, a small-scale pretreatment biofilter has been developed, built and tested utilizing CAD and CFD software. The biofilter has been tested, and results have been compared with relevant parameters from Ecomotives A02 tests. The general objective has thereby been met.

From the development and testing of the biofilter, the following results has been given:

- Higher reductions of BOD_5 and TSS were measured for the biofilter than from the A02 in emergency mode, with a loading rate of more than 1.55 times higher than in A02.
- The distribution of air allows for aerobic biofiltration to take place in the biofilter.
- Control of the compressor, and closing of effluent tube allows backwashing of biomedia to take place.
- Transparent column gives user a view of the biomedia.

Recommendations for further work

For developing the next prototype which will provide more data to develop a greywater treatment unit for buildings of up to 50 people, the following recommendations could be considered.

Further testing on the biofilter:

- Conduct turbidity tests each day on 14.7 l/day, and identify time needed between each backwash.

The prototype could:

- Be a small-scale treatment unit with room for easy modifications.
- Consist of an upstream biological aerated filter for primary treatment with LECA, and a membrane filter for secondary treatment.
- Include two water pumps with variable flowrates and a compressor. One water pump for each treatment step.
- Include a control unit for the control of compressor.

- Have a transparent primary treatment chamber to identify anaerobic conditions etc.
- Have a system allowing for easy discarding of crumbled LECA.
- Have possibility of taking samples from the effluent of the primary treatment and the secondary treatment.

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12 APPENDIX

Appendix 1 – Diffuser meshing

Appendix 2 – Filter meshing

Appendix 3 – Data from measurements, Turbidity, TSS and BOD_5

Appendix 4 – Data from slug test 1

Appendix 5 – Data from slug test 2

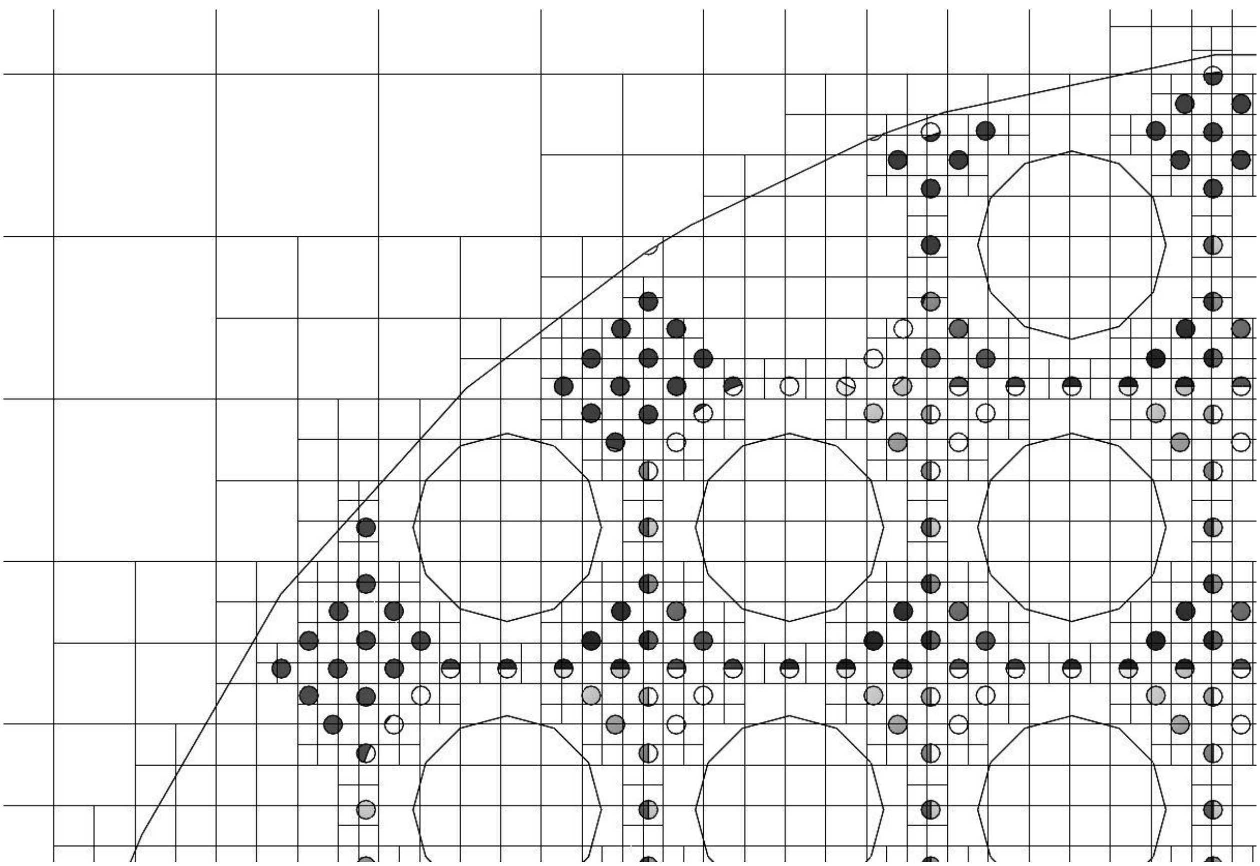
Appendix 6 – Data provided by ecomotive

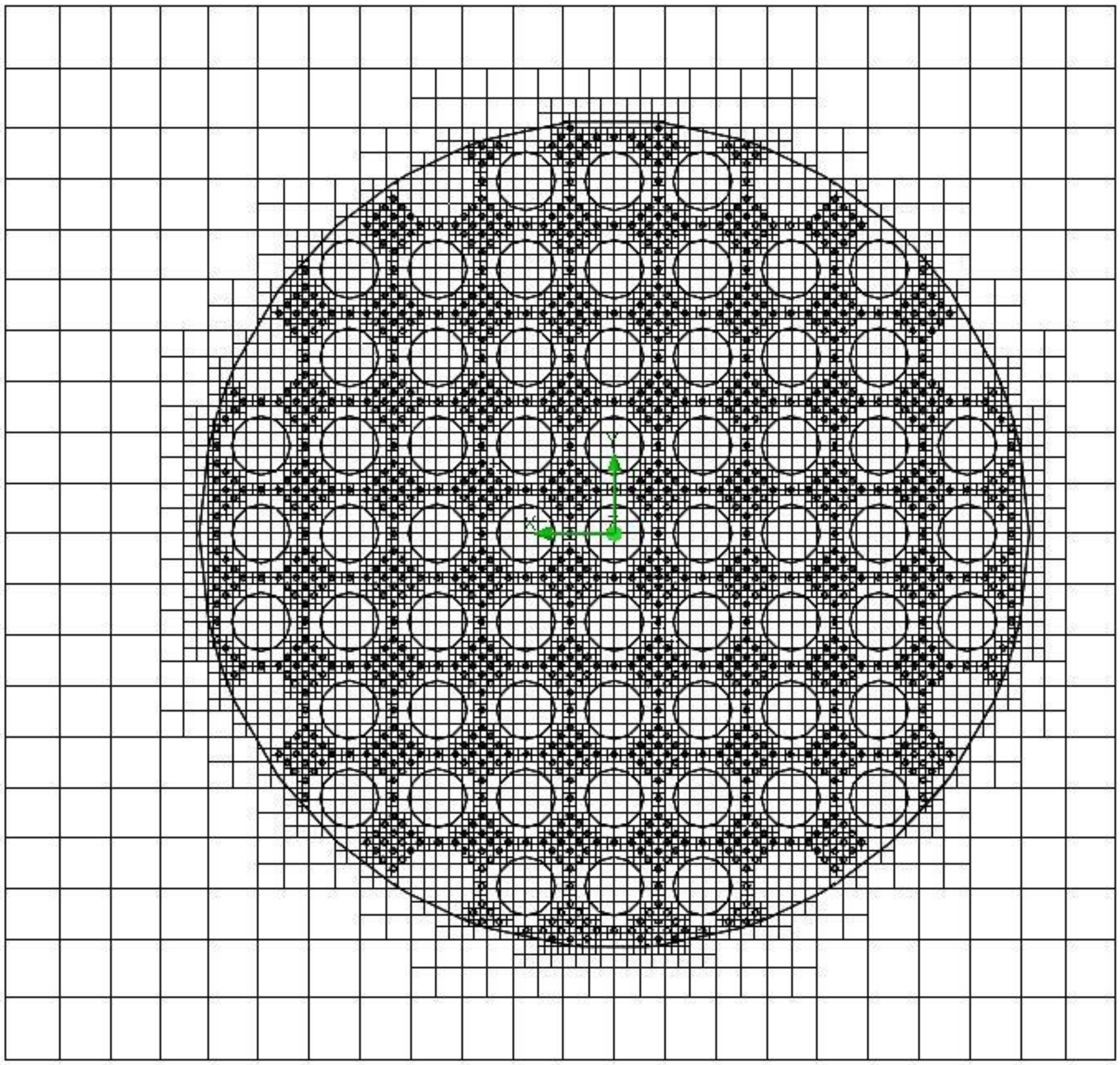
Appendix 7 – Technical drawings

Appendix 1 diffuser mesh

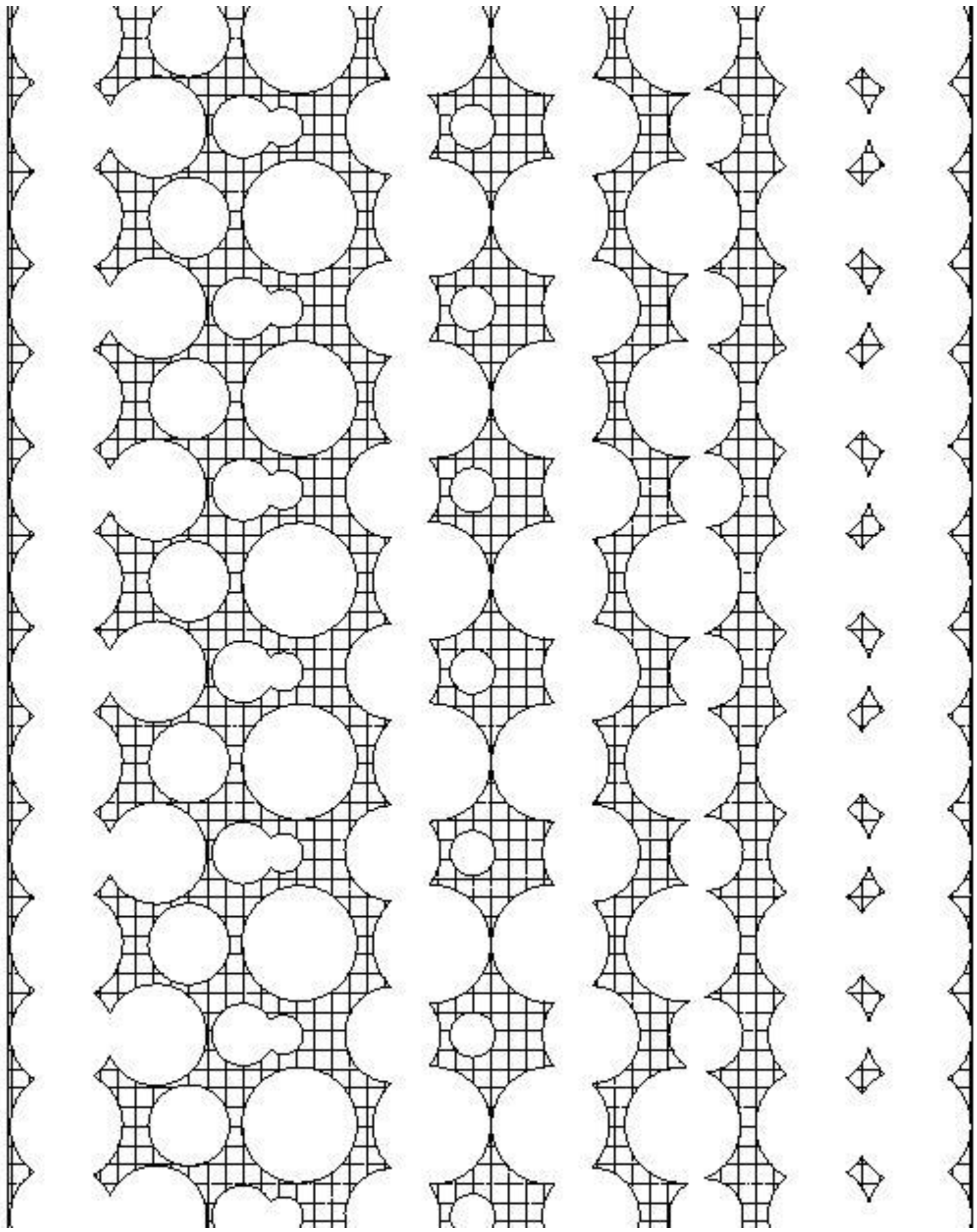
Diffuser mesh

Total Cell count:	77859
Fluid Cells:	77859
Solid Cells:	47319
Partial Cells:	41257
Trimmed Cells:	0



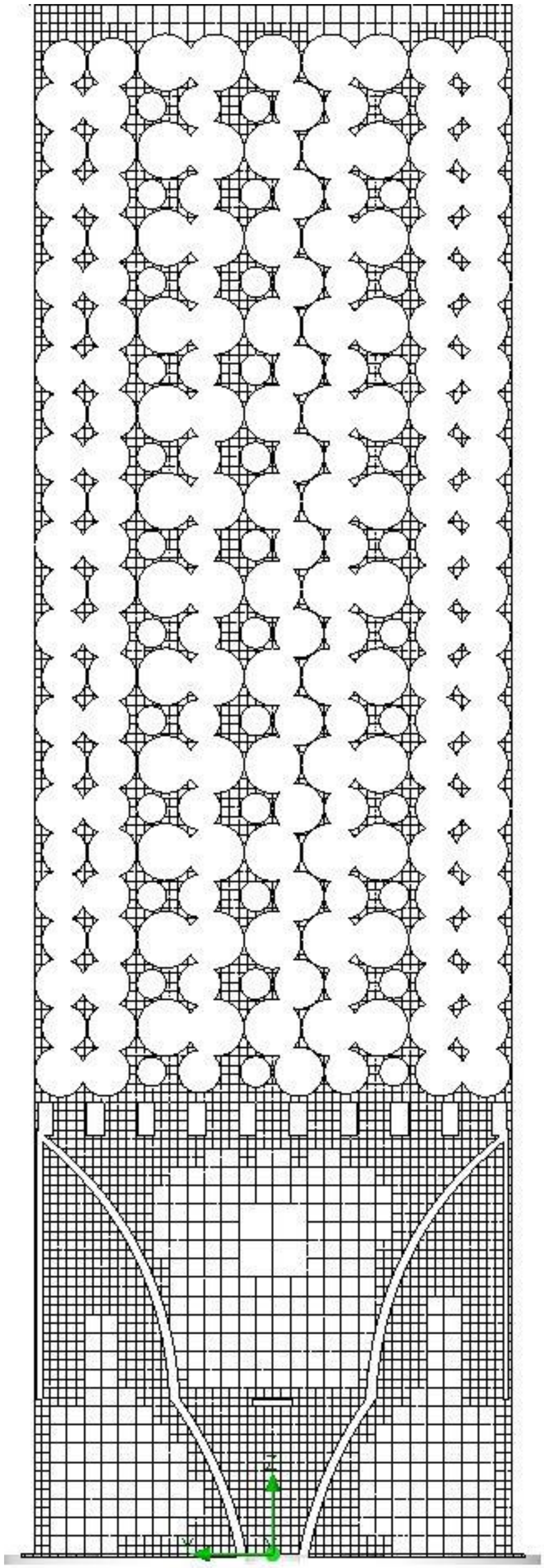


Appendix 2 – filter mesh



Analysis Mesh

Total Cell count:	295379
Fluid Cells:	295379
Solid Cells:	388715
Partial Cells:	220898
Trimmed Cells:	0



Appendix 3 – Turbidity, TSS and BOD_5 results

Turbidity [NTU]

L/day	Date	Inlet samples 1	2	3	Mean	St. dev	Outlet samples 1	2	3	Mean	St. dev	Reduction
24	6th April											
	7th April											
	8th April	68	67	66	67	0.816497	43.3	44.2	42.8	43.43333	0.579272	36.1%
	9th April	250	210	230	230	16.32993	43	42	40.5	41.83333	1.027402	82.4%
	10th April	79.7	71.8	80	77.16667	3.796782	64.3	63.1	65.2	64.2	0.860233	15.5%
	11th April	56	58	60	58	1.632993	49	51	48	49.33333	1.247219	17.2%
	12th April	118	120	118	118.6667	0.942809	35	35.5	34.8	35.1	0.294392	70.7%
47.5	13th April	95	90.2	96	93.73333	2.531578	32.5	33	32	32.5	0.408248	65.9%
	14th April	77	78	76	77	0.816497	17.5	17.3	17.6	17.46667	0.124722	77.1%
	15th April	68.8	73.1	71.4	71.1	1.768238	41.5	42.8	42.3	42.2	0.535413	40.5%
	16th April	75.1	81.7	81	79.26667	2.960105	53.6	55.6	54.5	54.56667	0.817856	31.2%
	17th April	114	117	121	117.3333	2.867442	47.8	48.3	47.2	47.76667	0.449691	59.8%
	18th April	117	119	113	116.3333	2.494438	29	23.2	30.3	27.5	3.08653	74.0%
14.7	19th April											
	20th April	97	94	99	96.66667	2.054805	47.8	48.3	47.2	47.76667	0.449691	51.2%
	21st April											

24	22nd April											
	23rd April	72.1	73.7	71.9	72.56667	0.805536	31.1	30.8	30.6	30.83333	0.20548	57.8%
	24th April	59.7	60.2	60.9	60.26667	0.492161	40.4	39.8	40.1	40.1	0.244949	33.5%
	25th April	148	138	136	140.6667	5.249339	36.4	35.5	38.1	36.66667	1.078064	72.9%
	26th April	100	110	104	104.6667	4.109609	39.4	40.5	38.5	39.46667	0.817856	63.2%
	27th April	78.6	79.2	81.4	79.73333	1.203698	31.3	32.4	30.1	31.26667	0.939267	62.2%
14.7	28th April	105	98	102	101.6667	2.867442	54	48	56	52.66667	3.399346	44.9%
	29th April	158	159	152	156.3333	3.091206	18.2	16.3	15.7	16.73333	1.065624	90.0%
	30th April	135	133	132	133.3333	1.247219	13.4	14.3	14.7	14.13333	0.54365	89.0%
	1st Mai	71.2	72.5	70.4	71.36667	0.865384	18.9	19.7	19.4	19.33333	0.329983	72.8%
	2nd Mai	94.5	90.4	93.5	92.8	1.74547	16.4	17.8	16.1	16.76667	0.74087	82.7%
	3rd Mai											

Suspended solids

L/day	Date	Inlet [mg/l] 1	2	3	Average		Outlet [mg/l] 1	2	3	Average		Reduction
24	6th April											
	7th April											
	8th April		0.00936	143								
	9th April		1.38									
	10th April											
	11th April											
	12th April											
47.5	13th April	2	11.5	8.5			21	4.5	7.5			
	14th April											
	15th April											
	16th April	76	71	75	74	2.160247	45	41	47	44.33333	2.494438	40.1%
	17th April											
	18th April											
14.7	19th April											

	20th April	84	104	100	96	8.640988	34	48	44	42	5.887841	56.3%
	21st April											
24	22nd April											
	23rd April	67	60	64	63.66667	2.867442	38	39	42	39.66667	1.699673	37.7%
	24th April											
	25th April	126	148	128	134	9.93311	42	42	34	39.33333	3.771236	70.6%
	26th April											
	27th April											
14.7	28th April											
	29th April	84	98	100	94	7.118052	18	12	22	17.33333	4.109609	81.6%
	30th April	90	88	98	92	4.320494	32	32	26	30	2.828427	67.4%
	1st Mai											
	2nd Mai											
	3rd Mai											

L/day	Date	BOD Inlet [mgO_2/l]	Outlet [mgO_2/l]	Reduction
24	6th April			
	7th April			
	8th April	124	70.3	43.3%
	9th April			
	10th April			
	11th April			
	12th April			
47.5	13th April			
	14th April			
	15th April			
	16th April			
	17th April			
	18th April			
14.7	19th April			
	20th April	110	47.9	56.5%
	21st April			
24	22nd April			
	23rd April	158	49.3	68.8%
	24th April			

	25th April	190	78.9	58.5%
	26th April			
	27th April			
14.7	28th April			
	29th April			
	30th April			
	1st Mai	142	31	78.2%
	2nd Mai	193	26.1	86.5%
	3rd Mai			
	4th Mai			

24 l/day effluent turbidity	Mean	Standard deviation
43.43333	46.78	9.8190427
41.83333		
64.2		
49.33333		
35.1		

47.5 l/day effluent turbidity	Mean	Standard deviation
32.5	32.5	12.540601
17.46667		
42.2		
54.56667		
47.76667		
27.5		

14.7 l/day effluent turbidity	Mean	Standard deviation
47.8	47.76667	0.4496913
48.3		
47.2		

24 l/day effluent turbidity	Mean	Standard deviation
30.83333	35.66667	3.9450109
40.1		
36.66667		
39.46667		
31.26667		

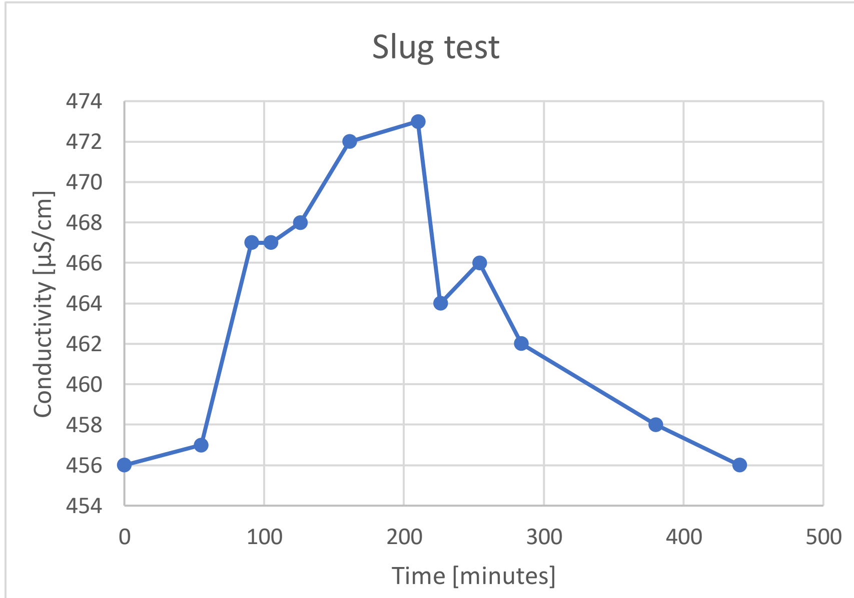
14.7 l/day effluent turbidity	Mean	Standard deviation

52.66667	23.92667	14.463785
16.73333		
14.13333		
19.33333		
16.76667		

Appendix 4

Slug test 1 – fresh biomedia

Time [Minutes]	Conductivity
0	456
55	457
91	467
105	467
126	468
161	472
210	473
226	464
254	466
284	462
380	458
440	456



Time [minutes]	Concentration [C]	$t_i C_i \Delta t_i$	$t_i^2 C_i \Delta t_i$
0	0	0	0
55	1	55	3025
91	11	1001	91091
105	11	1155	121275
126	12	1512	190512
161	16	2576	414736
210	17	3570	749700
226	8	1808	408608
254	10	2540	645160
284	6	1704	483936
380	2	760	288800
440	0	0	0
Sum	94	16681	3396843

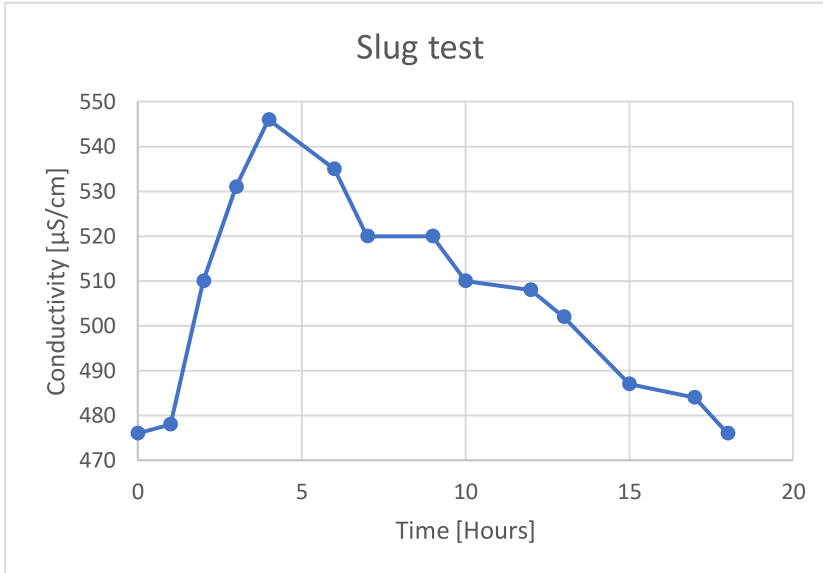
$$\bar{t}_{\Delta c} = \frac{\sum t_i C_i \Delta t_i}{\sum C_i \Delta t_i} = \frac{16681}{94} = 177.45 \tag{5}$$

$$\sigma_{\Delta c}^2 = \frac{\sum t_i^2 C_i \Delta t_i}{\sum C_i \Delta t_i} - (\bar{t}_{\Delta c})^2 = \frac{3396843}{94} - (177.45)^2 = 4644.576 \tag{6}$$

$$d = \frac{1}{2}\frac{\sigma_{\Delta c}^2}{\tau^2} = \frac{1}{2}\frac{4644{,}576}{226{,}4^2} = 0.045 \tag{7}$$

Slug test – grown biomedia

Time [Minutes]	Conductivity
0	476
60	478
120	510
180	531
240	546
360	535
420	520
540	520
600	510
720	508
780	502
900	487
1020	484
1080	476



Time [minutes]	Concentration [C]	$t_i C_i \Delta t_i$	$t_i^2 C_i \Delta t_i$
0	0	0	0
60	2	120	7200
120	34	4080	489600
180	55	9900	1782000
240	70	16800	4032000
360	59	21240	7646400
420	44	18480	7761600
540	44	23760	12830400
600	34	20400	12240000
720	32	23040	16588800
780	26	20280	15818400
900	11	9900	8910000
1020	8	8160	8323200
1080	0	0	0
Sum	419	176160	96429600

$$\bar{t}_{\Delta c} = \frac{\sum t_i C_i \Delta t_i}{\sum C_i \Delta t_i} = \frac{176160}{407} = 404.9 \quad (5)$$

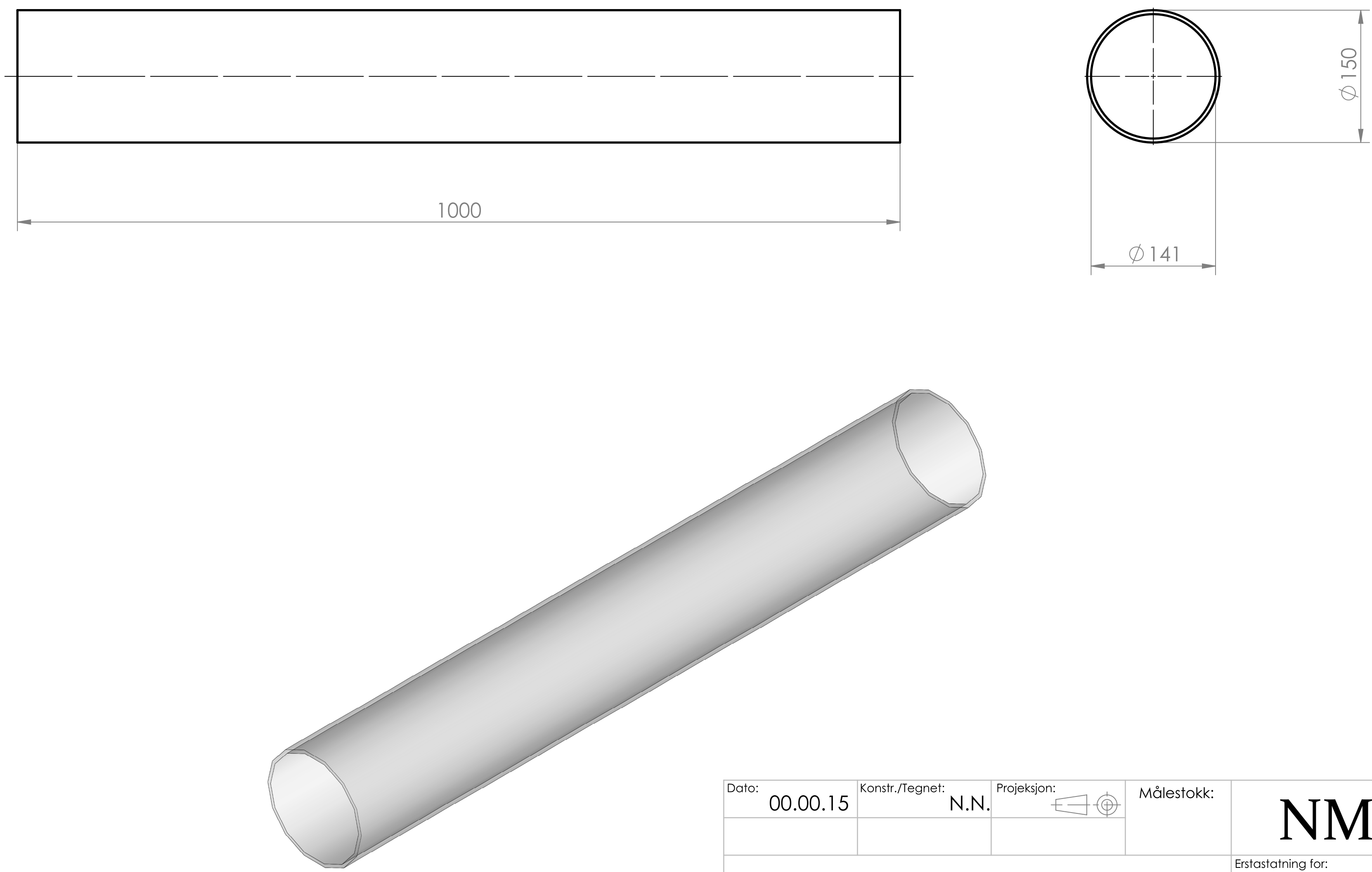
$$\sigma_{\Delta c}^2 = \frac{\sum t_i^2 C_i \Delta t_i}{\sum C_i \Delta t_i} - (\bar{t}_{\Delta c})^2 = \frac{96429600}{419} - (404.9)^2 = 53381.2 \quad (6)$$

$$d = \frac{1}{2}\frac{\sigma_{\Delta c}^2}{\tau^2} = \frac{1}{2}\frac{53381.2}{732{,}5^2} = 0.0497 \quad (7)$$

Appendix 6

Data provided by Ecomotive regarding the greywater tank

Date	TSS [mg/l]	Turbidity NTU	BOD_5 [mg/l]
1/15/2018	40	138	197
1/17/2018	x	139	143
1/22/2018	55	71.8	x
1/24/2018	66	66	160
1/30/2018	x	94.9	x
2/8/2018	65	90	170
2/11/2018	64.67	96.7	93
2/14/2018	98.67	101	168
2/17/2018	67	106	x
2/20/2018	69	135	x
2/28/2018	73	80.3	125
3/5/2018	67	104	155
3/7/2018	67	119	154
3/12/2018	62	129	121
3/21/2018	49	78.4	104
4/4/2018	58	96.1	135
4/11/2018	55	75	137
4/15/2018	65	100	124
4/22/2018	63	81	110
4/25/2018	67	80.2	134
4/29/2018	84	94.5	No data
5/2/2018	72	96.3	No data
5/4/2018	86	106	No data



Dato: 00.00.15	Konstr./Tegnet: N.N.	Projeksjon:	Målestokk:	NMBU
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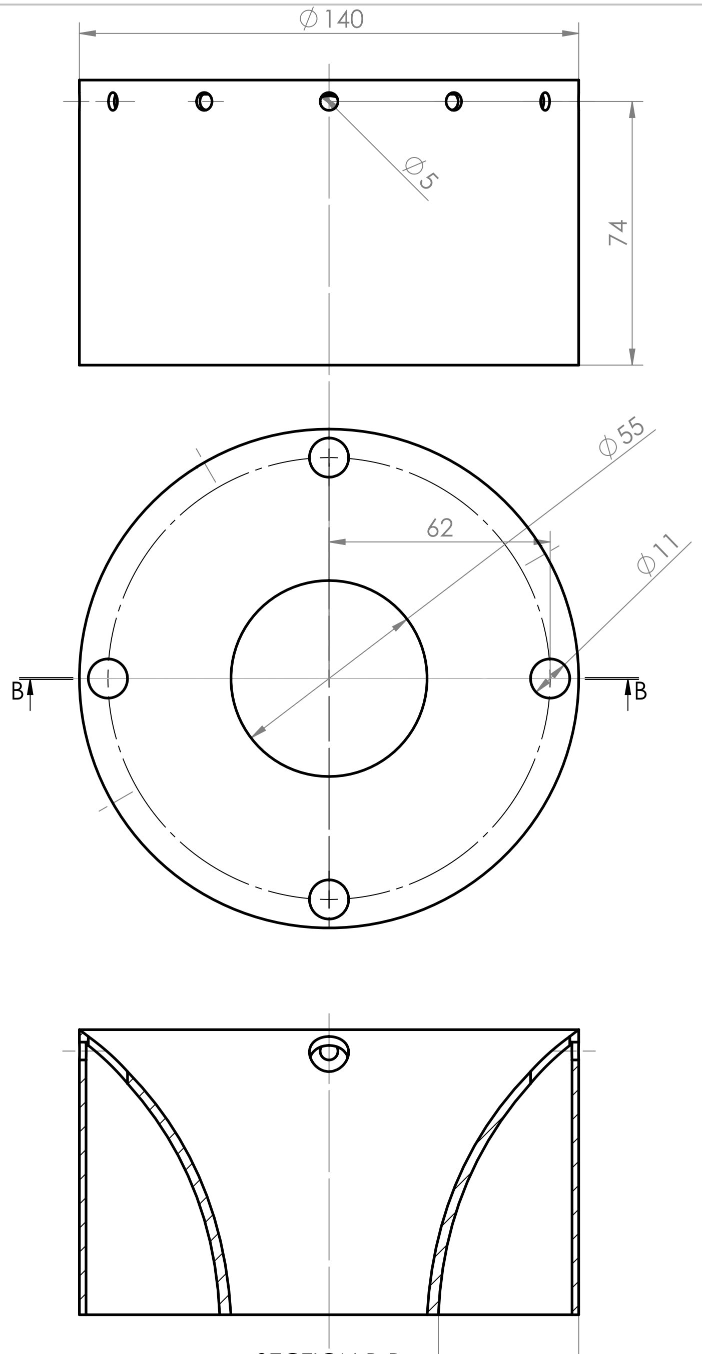
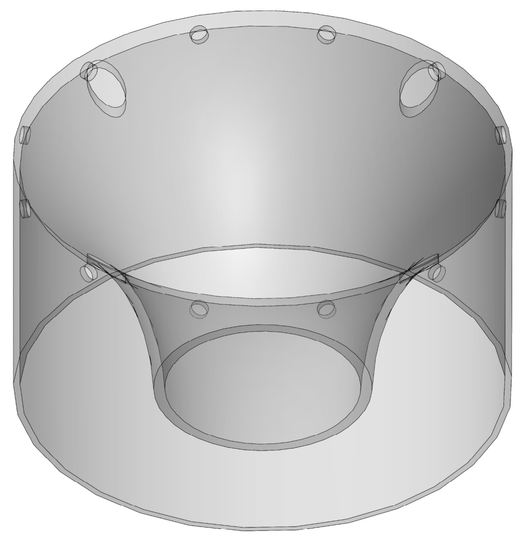
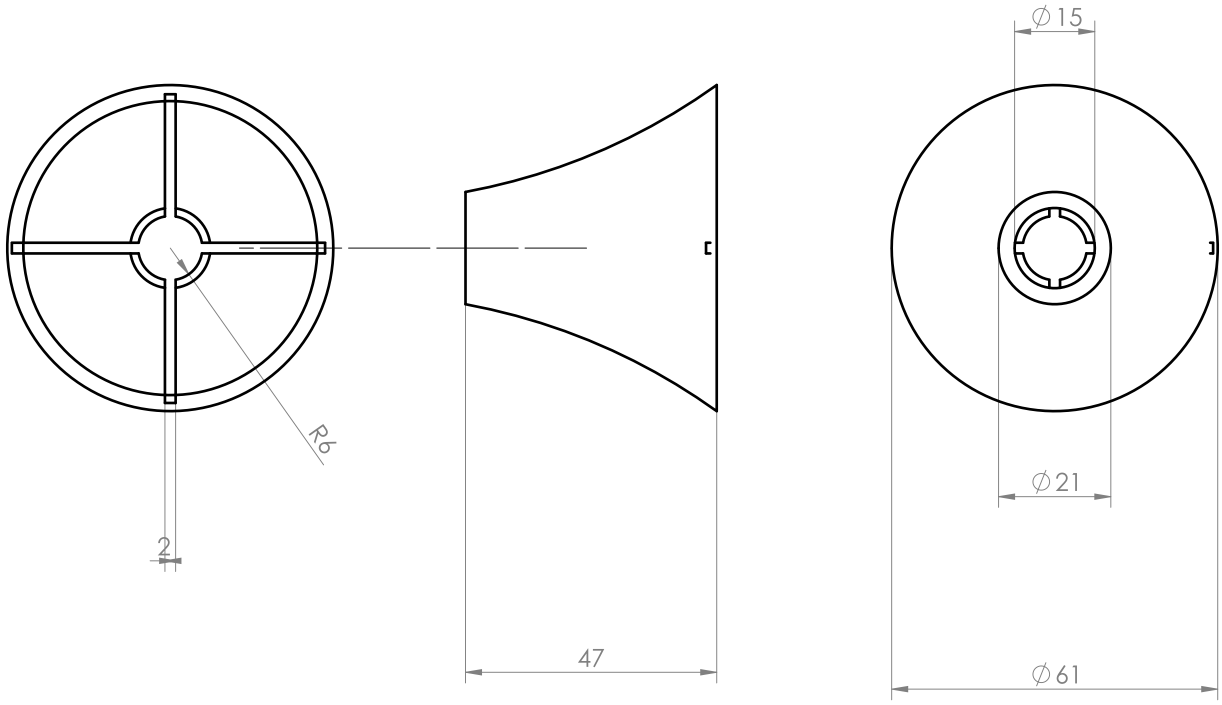
Henvisning:	Beregning:			

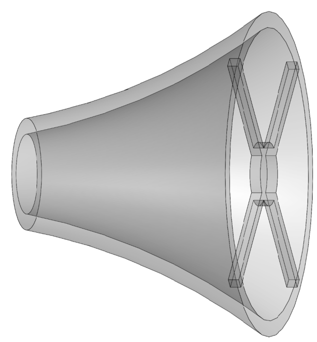


SECTION B-B
SCALE 1 : 1.5



Dato:	Konstr./Tegnet:	Projeksjon:	Målestokk:	NMBU	
	Qty: 1				
Part 2				Erstatning for:	Erstatattet av:
Henvisning:		Beregning:			





Dato:

Konstr./Tegnet:

Projeksjon:

Målestokk:
1:1

NMBU

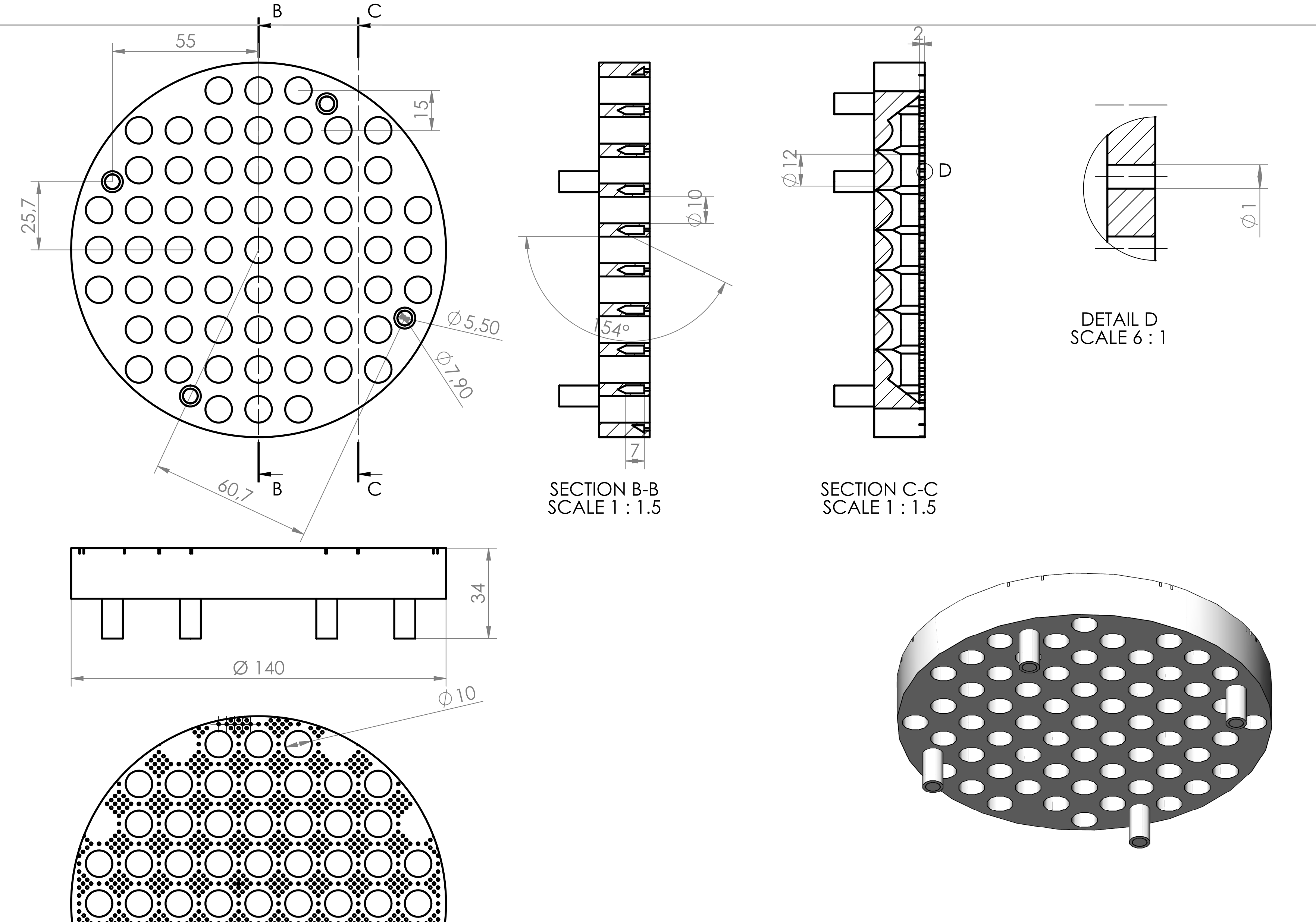
Part 3

Henvisning:

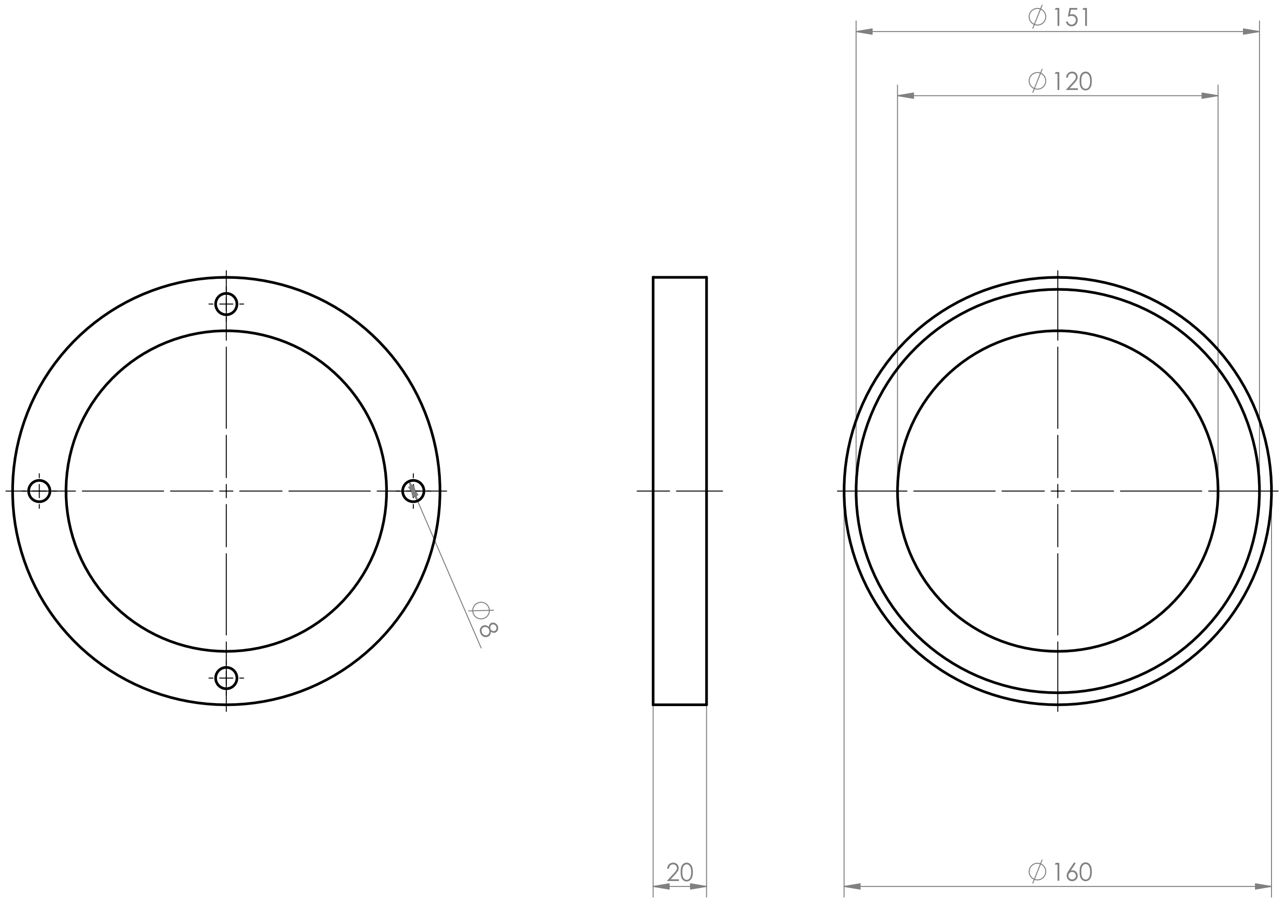
Beregning:

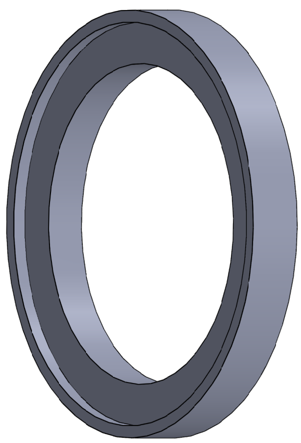
Erstatning for:

Erstattet av:



Dato:	Konstr./Tegnet:	Projeksjon:	Målestokk: 1:1	NMBU
Part 4				Erstastatning for: / Erstastattet av:
Henvisning:	Beregning:			





Dato:

Konstr./Tegnet:

Projeksjon:

Målestokk:
1:2

NMBU

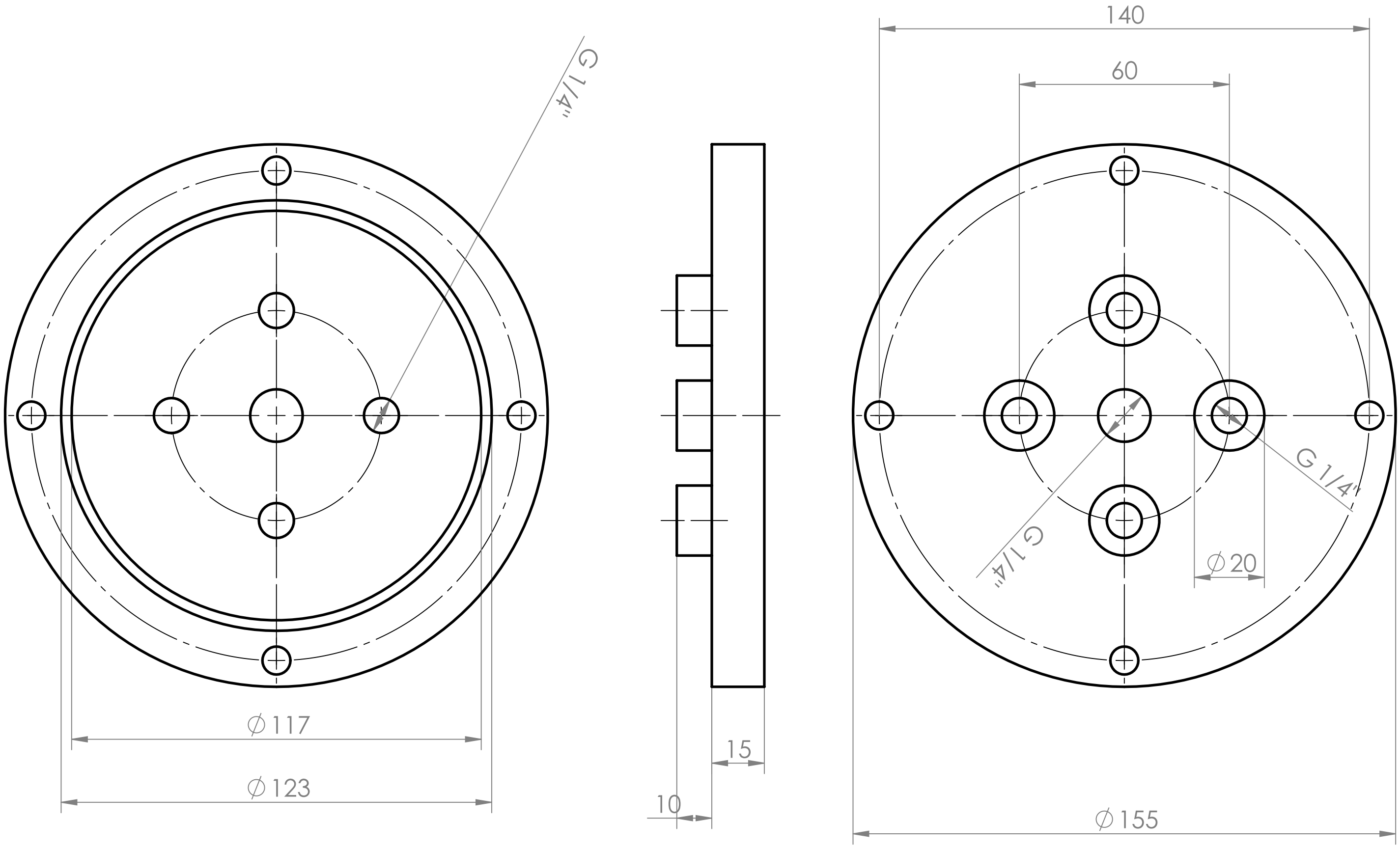
Part 5

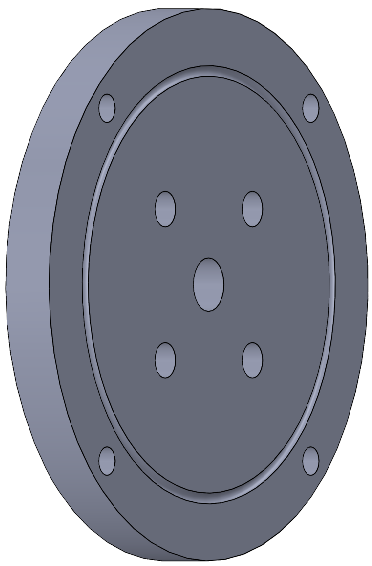
Erstatatning for:

Erstattet av:

Henvisning:

Beregning:





Dato:

Konstr./Tegnet:

Projeksjon:

Målestokk:
1:1,5

NMBU

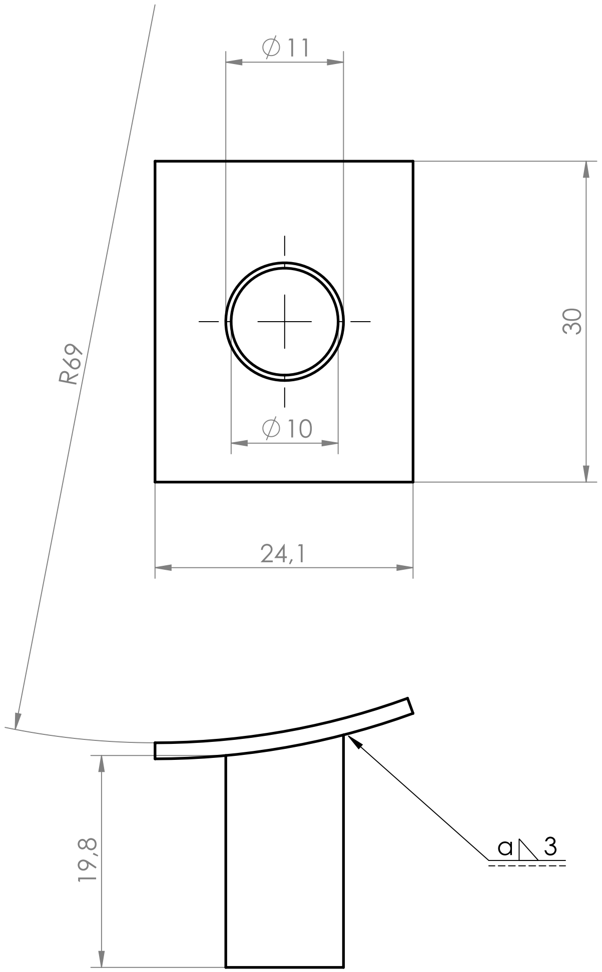
Erstastatning for:

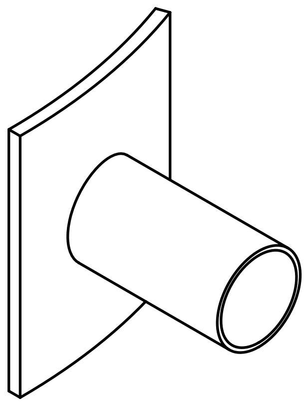
Erstastattet av:

Part 6

Henvisning:

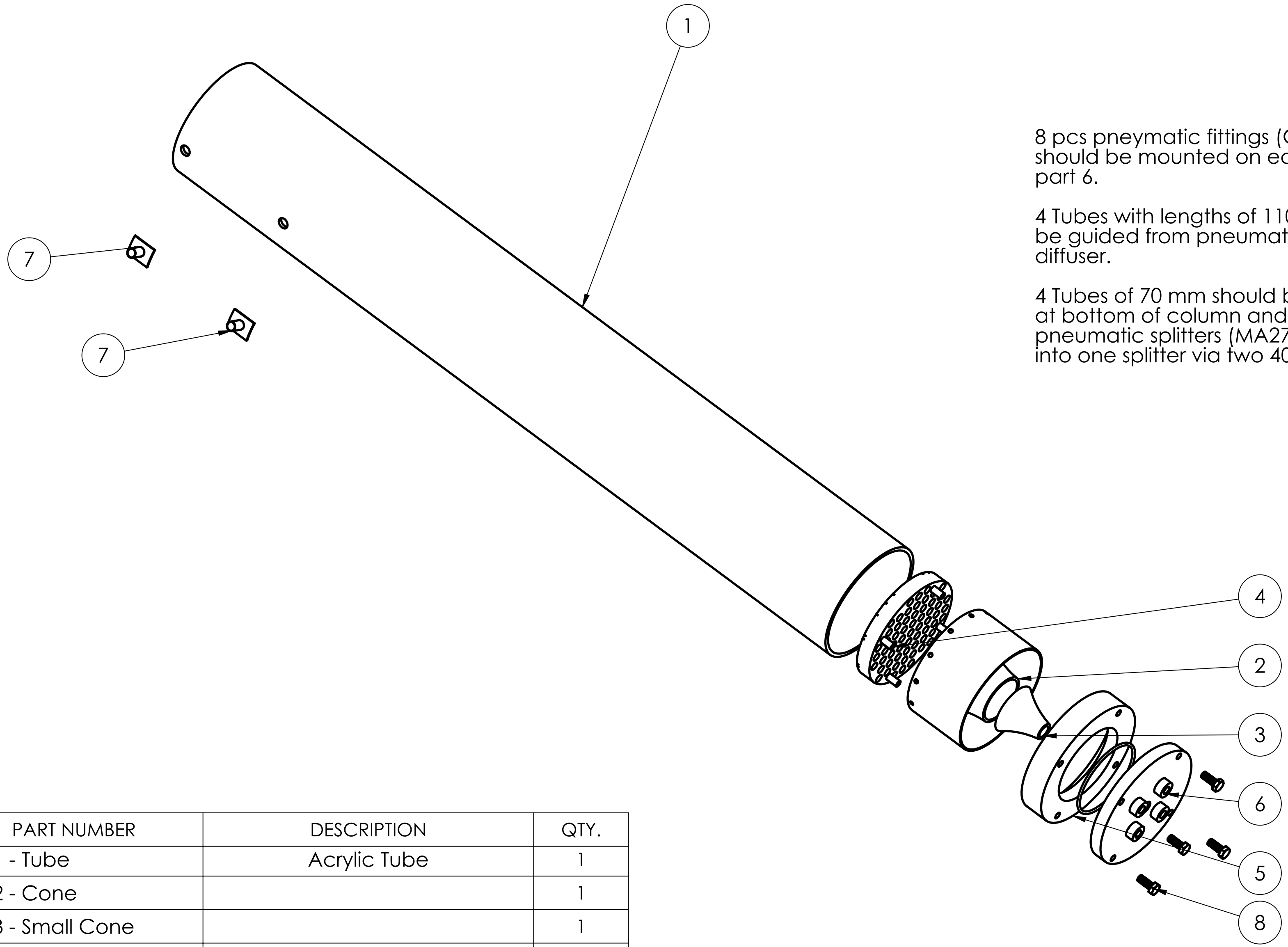
Beregning:





Metal plate welded onto hollow steel tube

Dato:	Konstr./Tegnet:	Projeksjon:	Målestokk:	NMBU	
				Erstastatning for:	Erstastattet av:
Part 7					
Henvisning:	Beregning:				



8 pcs pneymatic fittings (GWS10-8-S) should be mounted on each side of part 6.

4 Tubes with lengths of 110 mm should be guided from pneumatic fittings to air diffuser.

4 Tubes of 70 mm should be mounted at bottom of column and into 2pcs of pneumatic splitters (MA27 10). Further into one splitter via two 40 mm tubes.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Part 1 - Tube	Acrylic Tube	1
2	Part 2 - Cone		1
3	Part 3 - Small Cone		1
4	Part 4 - Diffuser		1
5	Part 5 - Ring	Ring for connecting the tube	1
6	Part 6 - Inlet	Air and water inlet	1
7	Part 7 - Hose connector		2
8	ISO 8676 - M8x1.0 x 20-S	Bolt	4
9	packing	Packing sealing for water	1

Dato:	Konstr./Tegnet:	Projeksjon:	Målestokk:	NMBU
Exploded view				Erstastatning for: / Erstastattet av:
Henvisning:	Beregning:			