Combined automatic system to treat grey water and rainwater

Artur Matusiak

Final thesis for BSc. degree
Faculty of Electrical and Computer Engineering
School of Engineering and Natural Sciences
University of Iceland
Combined rainwater and grey water treatment system

Artur Matusiak

30 ECTS thesis submitted in partial fulfillment of a Baccalaureus Scientiarum degree in Mechatronic technology

Advisors
Þorgeir Þorbjarnarsson
Guðmundur Borgþórsson
Daniel Coaten

Keilir Institute of Technology
University of Iceland
School of Engineering and Natural Sciences
Reykjanesbær, October 2015
Combined rainwater and grey water treatment system

30 ECTS thesis submitted in partial fulfillment of a Baccalaureus Scientiarum degree in Mechatronic technology

Copyright © 2015 Artur Matusiak
All rights reserved

Faculty of Electrical and Computer Engineering
School of Engineering and Natural Sciences
University of Iceland
Grænásbraut 910
235 Reykjanessbær

Sími: 578 4000

Bibliographic information:
Artur Matusiak, 2015, Combined rainwater and grey water treatment system, BSc thesis, Keilir Institute of Technology, University of Iceland, pp. 95.

Printing: Háskólaprent
Reykjanesbær, October 2015
Abstract

During research for the final project idea, some water treatment solutions were found. Throughout time of analysis, it was clear that this field has still many opportunities for improvement. One of an upgrade idea is presented in this document. It combines two systems: rainwater harvesting and grey water recycling in one setup. In addition, gravity feeding is provided to decrease pump’s wear.

It was in high importance to find the best filtration method. According to literature and research reports, membrane bioreactor treatment for greywater was chosen. After contact with manufacturers of the membrane filtrations modules, the C-MEM cartridge filter was selected. Based on specifications for the filter and water usage in the house, a decision over the proper hardware selection was made.

When all of the equipment had been known the control system was designed. By making a prototype of the setup on the bread board, main functions could be checked, for example the main process or cleaning of the filter. Every part of the hardware was indicated by diodes or potentiometer, also text with information was displayed on a LCD screen.

System was designed and it fully meets requirements. Chosen filtration system based on C-MEM cartridge, provides better water quality than expectations from standards. Control system fully connects both of water recycling systems and it is energy efficient. The price of the system is competitive compared to other suppliers in Polish market. Unfortunately, 200 liters of water decrease yearly bills of water of approximately 587 zloty, which means that investment pays off after 30 years. The same system in Germany will pay off after 12 years, so there is an opportunity to sell this equipment.
Úrdráttur


Það var mjög mikilvægt að finna bestu aðferðina til að sía. Samkvæmt faglegu efin og rannsóknarskýrslum var niðurstaðan sú að velja séstaklega útbúna sifu til að sía vatnið. Haft var samband við fyrirtæki sem framleiðir C-MEM hylki og sú tækn valin. Með því að byggja á sérstökum aðferðum sem notaðar hafa verið í húsum var ákvörðun teknum um viðeigandi bunað.

Þegar tekin hafði verið ákvörðun um tækn og hún sannprófuð var á ætlun gerð. Með því að útbúa líkan af uppcætningu var hægt að sannreyna aðalferligi eða hreinsun sínar. Hver hluti bunaðsins inniðið diódur (tvist) og jöfnunarmæli ásamt texta með upplýsingum sem sýndur var á LCD skjá.

Dedication

For future generations...

To my wife Fariba, who supported me all the time and my son Artin for happiness he is giving me every day.
Preface

Nowadays, environment of the planet is in danger. Water supplies in many countries are not sufficient according to the population. People do not realize that they can do something to make a situation better. I am interested in environmental issues, which is why that project came into begin. I wanted to create a system, which is similar to the existing ones, but which is more reliable and affordable for households.

Special thanks for my supervisors, who encouraged me to put more effort into my project documentation. Without their comments, this document would not have a form as it is now. I would also like to thank my wife, who believed in me from the beginning and my sister, who was helping me to correct my English.
Table of Contents

Úrdráttur ......................................................................................................................... vii

List of figures ................................................................................................................... xv

List of Tables .................................................................................................................... xvii

Abbreviations .................................................................................................................. xix

1 Introduction .................................................................................................................. 1

2 Backgrounds ............................................................................................................... 5
  2.1 Types of untreated water ....................................................................................... 5
  2.2 Grey water definition and sources ........................................................................ 5
      2.2.1 Treatment processes ..................................................................................... 6
  2.3 Rainwater harvesting ............................................................................................. 7
  2.4 State of art .............................................................................................................. 8
      2.4.1 Rainwater systems ......................................................................................... 8
      2.4.2 Grey water systems ...................................................................................... 9
  2.5 Filtration Overview .............................................................................................. 10

3 Design and choice of hardware ............................................................................... 13
  3.1 Tanks ..................................................................................................................... 14
      3.1.1 Rainwater tank .............................................................................................. 14
      3.1.2 Grey water tanks ......................................................................................... 16
      3.1.3 Infiltration .................................................................................................... 17
  3.2 Filters ..................................................................................................................... 18
      3.2.1 Filtration overview ....................................................................................... 18
      3.2.2 C-MEM with comparison to other filter ................................................... 19
      3.2.3 C-MEM ....................................................................................................... 21
      3.2.4 Pipe down filter ......................................................................................... 21
  3.3 Pumps ..................................................................................................................... 22
  3.4 Arduino .................................................................................................................. 26
  3.5 Sensors .................................................................................................................. 26
      3.5.1 Floating sensor ............................................................................................ 27
      3.5.2 Flow sensor .................................................................................................. 29
  3.6 Valves ..................................................................................................................... 30
      3.6.1 Reducer ....................................................................................................... 31
  3.7 Blower ................................................................................................................... 32
  3.8 Growth bodies ....................................................................................................... 34

4 System Design and operation ................................................................................... 37
  4.1 Operation modes ................................................................................................... 37
  4.2 Problems during operation ................................................................................... 39
      4.2.1 No electricity ............................................................................................... 39
List of figures

Figure 1 – Sink installed in the flush.................................................................9
Figure 2 – Grey water system under a sink ..................................................10
Figure 3 – Bacteria immobilize carrier..........................................................11
Figure 4 – Percentage of water usage [12]....................................................15
Figure 5 – Filtration differences ..................................................................19
Figure 6 - Clasification of membrane filtration ............................................20
Figure 7 – C-MEM filter cartridge .................................................................21
Figure 8 – Pipe down rain water filter...........................................................22
Figure 9 – Dimension used for specifications ..............................................26
Figure 10 – Floating sensor .........................................................................27
Figure 11 – Main parts of the floating sensor .................................................28
Figure 12 – Flow sensor ...............................................................................29
Figure 13 – Devices and water flow .............................................................37
Figure 14 – Directions of air and back flow water ........................................39
Figure 15 – Flow chart of the system.............................................................42
Figure 16 – Cleaning process flow chart ......................................................43
Figure 17 – Chlorine cleaning process flow chart .........................................44
Figure 18 – Prototype board schematic .......................................................46
Figure 19 – Classic cylindrical tank .............................................................52
Figure 20 – Horizontal tank ........................................................................52
Figure 21 – Key components for Rewatac rainwater system .......................53
Figure 22 – Intewa Rainwater shower system ..............................................54
Figure 23 – Rainwater- Rain director system ..............................................55
Figure 24 – PKm60 specifications ..................................................................63
Figure 25 – SpidAMX 50 specification .................................................................................. 64
Figure 26 – C mem filter specifications .............................................................................. 77
Figure 27 – Plan schedule .................................................................................................... 79
List of Tables

Table 1 – Untreated water ........................................................................................................... 5
Table 2 – Possible grey water contaminants by greywater source ........................................... 5
Table 3 – The characteristic of grey water by different categories ........................................ 6
Table 4 – Common greywater treatment technologies ............................................................... 7
Table 5 – Rain water quality and comparison with drinking water quality. ............................ 8
Table 6 – Selected hardware ................................................................................................... 13
Table 7 – Requirements for rainwater recycle water ................................................................. 14
Table 8 – Specification comparison ....................................................................................... 16
Table 9 – Greywater tank specifications ................................................................................ 17
Table 10 - Infiltration modules specifications ......................................................................... 17
Table 11 – Filters comparison .................................................................................................. 20
Table 12 – Requirements for cleaning filter pump ................................................................. 22
Table 13 – Requirements for transfer pump ........................................................................... 23
Table 14 – Pumps specifications comparison ......................................................................... 25
Table 15 – Energy consumption ............................................................................................. 25
Table 16 – Parameters of a floating sensors .......................................................................... 27
Table 17 – Specifications of flow sensor ................................................................................ 29
Table 18 – 3 and 2 way valve comparison ............................................................................. 31
Table 19 – 5A valve specification .......................................................................................... 31
Table 20 – Reducers specifications ........................................................................................ 32
Table 21 – Blowers comparison ............................................................................................. 34
Table 22 – Time and energy used to fill oxygen in 300 l tank ................................................ 34
Table 23 – Growth bodies .................................................................................................... 35
Table 24 – Components used for prototype board ................................................................. 45
Table 25 – Components list on the circuit and functions

Table 26 – Costs of hardware

Table 27 – Yearly energy cost usage of the system in Poland

Table 28 - Yearly energy cost usage of the system in Germany

Table 29 – Price and components comparison between systems

Table 30 – Project requirements

Table 31 – Arduino specifications
### Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>Biochemical oxygen demand</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical oxygen demand</td>
</tr>
<tr>
<td>TA</td>
<td>Total alkalinity in water content of bicarbonates</td>
</tr>
<tr>
<td>TAC</td>
<td>Total alkalinity in water content carbonates</td>
</tr>
<tr>
<td>TN</td>
<td>Total nitrogen</td>
</tr>
<tr>
<td>TOC</td>
<td>Total organic carbon</td>
</tr>
<tr>
<td>TP</td>
<td>Total phosphorus</td>
</tr>
<tr>
<td>TSS</td>
<td>Total suspended solids</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
</tr>
</tbody>
</table>
1 Introduction

“For six millennia, the human race has been involved in battle to control water resources. Impressive works and facilities have been constructed to harness these resources to the benefit of humankind and society” [1]. Thanks to the water the life on the earth is possible. There is no such substance, which could substitute it. To show that the water is even more important it is believed that water pollution and quality degradation are the cause of 80% of disease1.

Some people do not realize how urgent it is to fight with water pollution every day by trying to save as much water as possible. If people do not change their attitude to the environment now, it is possible that our children will not have enough water to drink. As people see the videos of the earth made from the universe or even on the maps, everyone thinks there is enough water on the earth, three oceans, huge long rivers, lakes, seas etc. Unfortunately, the truth is that 97% of water on the earth is salty and only 3% may be used as drinking water. [2]

Sad truth is that people are polluting our drinking water either for benefits, money, people’s laziness as well as simply ignorance of the problem. Rainwater is polluted by emissions from transport and industries as well as pollutions, which are taken up in the time of surface runoff with all the chemicals, paper, oil, metal reminders, rubbers, vegetation, organic matter and excrements [3]. The rainwater pollution is various, which depends on the city locations, climate, local conditions and nature.

The global crisis develops and the earth is more and more as desert.

“When we pump water for irrigation, some of it percolates back into the ground which is called recharge or return floats, so long as we pump no more than what is recharged we are using the ground water sustainably. The problem is that we are pumping 15 times more water from the ground than it is returning back into it” [1].

What is more, huge companies are building houses next to each other because they want to build as many buildings as they can to earn more with limited water supplies. This also has an effect on the environment. Since there is no much space for the rain water to go into the ground, because of the streets, building etc. all the water goes into the rivers and to the oceans. This causes more clouds but the ground is getting drier and drier. The Earth has arid and semiarid areas, which uses all their supplies only for irrigation. The more dry country is the more water it needs. There are three areas which have lack of water supply: Africa, Middle East and South Asia2. The fact that there are countries which have huge water deficiency is truly disturbing.

There are some solutions, which could reduce water deficiency and help the environment to make its condition. Police and government should put very high punishment on industries which pollute the rivers. People also should reduce water use. Unfortunately, all of those solutions are

1 https://www.foodandwaterwatch.org/
2 http://www.theguardian.com
very difficult and time consuming to adapt in the real life. That is why people started working on systems which could reduce water use into households, companies etc. The systems are created to filter rain and gray water to use it one more time in the household. The installation and materials are still quite expensive for medium-class people. That is why an author has decided to work on the system which would reduce costs and be more affordable for households.

Original research for this project was focused on intelligent house design. This term is used to expressed houses with highly advanced automatic systems like for example electronic door locks opened just by finger print of house householder. There are many solutions which already exist and companies which have strong positions in the Polish and global market. Available solutions are focused on the electrical installations and electricity savings but unfortunately, there is not much done about water solutions. By taking this direction the water treatment topic was found. It can be divided in two main streams:

- Greywater recycling system
- Rainwater harvesting system

Those systems are divided in two other groups:

- Indoor
- Outdoor.

In the Polish and global market there are not ready solutions which connects rainwater and grey water systems together. In this project, author tries to design setup which integrates altogether. Many of the existing systems employ pumps which run continuously and therefore uses a lot of electrical energy. Other systems use pumps which are frequently switched on and off, resulting in pump’s wear. A final system uses two tanks, one in the basement and one on the roof, but this system only takes advantage of rainwater. Fortunately, the author of this report has different ideas.

- The basement tank will store rain water and grey water together.
- A floating sensors will indicate water level in the tanks
- One control system for both treatments
- Two pumps
- One filtration system
- Fully automatic

In Poland most of the systems installed in the houses are rainwater harvesting. The problem is that there are periods when there is no rain. Even though rainwater tanks are big and they can store a lot of water, full tank of water can supply family for around twenty one days and after this time tap water is used. With system presented in this document this problem is solved by grey water coming from the house.

The purpose of this project is to:

- Design control system for combined rainwater and greywater system together,
- Propose hardware which can fulfill requirements,
- Make feasibility study of this setup to check if there is place on the market for this kind of solution.
While grey water and rainwater systems are existing in the market separately there is an opportunity to design system which can connect both of them in one setup for more water recycle and cheaper maintenance.
2 Backgrounds

2.1 Types of untreated water

In Table 1 there is an explanation of different kinds of untreated water. It is important to know what definition of the greywater is and also to see difference between those types of water. There are systems for treatment of black water and dark greywater but setup presented in this document is focusing on greywater.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Other terms in use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greywater</td>
<td>Untreated household wastewater that has not come into contact with sewage</td>
<td>Graywater, gray water, or grey water</td>
</tr>
<tr>
<td>Black water</td>
<td>Wastewater from toilets, bidet, water used to wash diapers (and under some definitions, from kitchens)</td>
<td>Sewage</td>
</tr>
<tr>
<td>Dark greywater</td>
<td>Untreated household wastewater that has not come into contact with sewage, but is from lower-quality sources such as kitchen sinks and dishwashers</td>
<td>(Sometimes considered to be part of black water)</td>
</tr>
</tbody>
</table>

2.2 Grey water definition and sources

Grey water is defined as residual water that does not contain feces, e.g. water from sinks, showers, dish washers or laundry facilities.

In Table 2 there are listed possible contents of grey water depend on the source of water. During design of any filtration system it is important to know what kind of contaminant filter needs to be taken care of. With this information know, the pre-filtration was added to the system.

<table>
<thead>
<tr>
<th>Greywater Source</th>
<th>Possible Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic clothes washer</td>
<td>Suspended solids (dirt, lint), organic material, oil and grease, sodium, nitrates and phosphates (from detergent), increased salinity and pH, bleach</td>
</tr>
<tr>
<td>Automatic dishwasher</td>
<td>Organic material and suspended solids (from food), bacteria, increased salinity and pH, fat, oil and grease, detergent</td>
</tr>
<tr>
<td>Bathtub and shower</td>
<td>Bacteria, hair, organic material and suspended solids (skin, particles, lint), oil and grease, soap and detergent residue</td>
</tr>
<tr>
<td>Sinks, including kitchen</td>
<td>Bacteria, organic matter and suspended solids (food particles), fat, oil and grease, soap and detergent residue</td>
</tr>
</tbody>
</table>
Data shown in Table 3 contains characteristics of grey water from different sources. From those values water needed to be treated to fulfill requirements for grey water stated at UE directive [6]. Filtration setup chosen for this project meets those requirements as the producer of the filters says.

Table 3 – The characteristic of grey water by different categories [7][8]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bathroom</th>
<th>Laundry</th>
<th>Kitchen</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH(-)</td>
<td>6.4-8.1</td>
<td>7.1-10</td>
<td>5.9-7.4</td>
<td>6.3-8.1</td>
</tr>
<tr>
<td>TSS(mg/l)</td>
<td>7-505</td>
<td>68-465</td>
<td>134-1300</td>
<td>25-183</td>
</tr>
<tr>
<td>Turbidity(NTU)</td>
<td>44-375</td>
<td>50-444</td>
<td>298</td>
<td>29-375</td>
</tr>
<tr>
<td>COD(mg/l)</td>
<td>100-633</td>
<td>231-2950</td>
<td>26-2050</td>
<td>100-700</td>
</tr>
<tr>
<td>BOD(mg/l)</td>
<td>50-300</td>
<td>48-472</td>
<td>536-1460</td>
<td>47-466</td>
</tr>
<tr>
<td>TN(mg/l)</td>
<td>3.6-9.14</td>
<td>1.1-40.3</td>
<td>11.4-74</td>
<td>1.7-34.3</td>
</tr>
<tr>
<td>TP(mg/l)</td>
<td>0.11-48.8</td>
<td>0-171</td>
<td>2.9-74</td>
<td>0.11-22.8</td>
</tr>
<tr>
<td>Total coliforms(CFU/100 ml)</td>
<td>10-2,4x10⁷</td>
<td>200,5-7x10⁷</td>
<td>2,4x10⁸</td>
<td>56-8,03 x10⁷</td>
</tr>
<tr>
<td>Fecal coliforms(CFU/100 ml)</td>
<td>0-3,4x10⁵</td>
<td>50-1,4x10³</td>
<td>-</td>
<td>0,1-1,5x10⁸</td>
</tr>
</tbody>
</table>

2.2.1 Treatment processes

In Table 4 there are stated the most popular greywater treatment technologies. The one which was chosen for this project is membrane bioreactor. Like it is shown, this system is very reliable and safe because is able to clean all pathogens.
Table 4 – Common greywater treatment technologies [4]

<table>
<thead>
<tr>
<th>Treatment technique</th>
<th>Description</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disinfection</td>
<td>Chlorine, ozone, or ultraviolet light can all be used to disinfect greywater.</td>
<td>Highly effective in killing bacteria if properly designed and operated, low operator skill requirement.</td>
<td>Chlorine and ozone can create toxic byproducts, ozone and ultraviolet can be adversely affected by variations in organic content of greywater.</td>
</tr>
<tr>
<td>Activated carbon filter</td>
<td>Activated carbon has been treated with oxygen to open up millions of tiny pores between the carbon atoms. This results in highly porous surfaces with areas of 300-2,000 square meters per gram. These filters thus are widely used to adsorb odorous or colored substances from gases or liquids.</td>
<td>Simple operation, activated carbon is particularly good at trapping organic chemicals, as well as inorganic compounds like chlorine.</td>
<td>High capital cost, many other chemicals are not attracted to carbon at all -- sodium, nitrates, etc. This means that an activated carbon filter will only remove certain impurities. It also means that, once all of the bonding sites are filled, an activated carbon filter stops working.</td>
</tr>
<tr>
<td>Sand filter</td>
<td>Beds of sand or in some cases coarse bark or mulch which trap and adsorb contaminants as greywater flows through.</td>
<td>Simple operation, low maintenance, low operation costs.</td>
<td>High capital cost, reduces pathogens but does not eliminate them, subject to clogging and flooding if overloaded.</td>
</tr>
<tr>
<td>Aerobic biological treatment</td>
<td>Air is bubbled to transfer oxygen from the air into the greywater. Bacteria present consume the dissolved oxygen and digest the organic contaminants, reducing the concentration of contaminants.</td>
<td>High degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely.</td>
<td>High capital cost, high operating cost, complex operational requirements, does not remove all pathogens.</td>
</tr>
<tr>
<td>Membrane bioreactor</td>
<td>Uses aerobic biological treatment and filtration together to encourage consumption of organic contaminants and filtration of all pathogens.</td>
<td>Highly effective if designed and operated properly, high degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely.</td>
<td>High capital cost, high operating cost, complex operational requirements.</td>
</tr>
</tbody>
</table>

2.3 Rainwater harvesting

Rainwater harvesting is a process which have been around for 4000 years. In many civilizations we find evidence of the storing rain water. In the ancient Egypt the tanks from 200 to 2000m³ were used to store rain water and some are still working today. [9]

System proposed in this document connects two different water sources, the rain water qualification is shown in Table 5. People who gets this data from research [10] drawn conclusion that water from rainwater is not suitable for potable usage but they have used only mechanical filtration with activated carbon.
Table 5 – Rain water quality and comparison with drinking water quality. [10]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>min</th>
<th>max</th>
<th>Drinking water</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>-</td>
<td>5,6</td>
<td>10,4</td>
<td>6,5 to 9</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>8,3</td>
<td>22,4</td>
<td>25</td>
</tr>
<tr>
<td>Conductivity</td>
<td>µS/cm</td>
<td>15,8</td>
<td>235</td>
<td>180-1000</td>
</tr>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0,5</td>
<td>6,1</td>
<td>2</td>
</tr>
<tr>
<td>Color</td>
<td>mg pt/L</td>
<td>&lt;5</td>
<td>36</td>
<td>15</td>
</tr>
<tr>
<td>TOC</td>
<td>mg/l</td>
<td>1,1</td>
<td>5,1</td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td>mmol/l</td>
<td>0,1</td>
<td>0,6</td>
<td></td>
</tr>
<tr>
<td>TA</td>
<td>mmol/l</td>
<td>&lt;0,2</td>
<td>0,5</td>
<td></td>
</tr>
<tr>
<td>TAC</td>
<td>mmol/l</td>
<td>&lt;0,4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cl⁻</td>
<td>mg/l</td>
<td>0,6</td>
<td>4</td>
<td>250</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>mg/l</td>
<td>0,9</td>
<td>3</td>
<td>250</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>mg/l</td>
<td>1,5</td>
<td>7,8</td>
<td>50</td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td>mg/l</td>
<td>&lt;0,1</td>
<td>0,5</td>
<td></td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>mg/l</td>
<td>0,1</td>
<td>0,7</td>
<td></td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>mg/l</td>
<td>1,5</td>
<td>18,7</td>
<td></td>
</tr>
<tr>
<td>Na⁺</td>
<td>mg/l</td>
<td>0,3</td>
<td>2,3</td>
<td>200</td>
</tr>
<tr>
<td>K⁺</td>
<td>mg/l</td>
<td>0,3</td>
<td>4,9</td>
<td></td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>mg/l</td>
<td>&lt;0,1</td>
<td>1,5</td>
<td>0,1</td>
</tr>
</tbody>
</table>

2.4 State of art

2.4.1 Rainwater systems

There are few ways of using rainwater and below there are explained most of them.

In the small roof water collection systems water from the roof is flowing via gutter into the ground storage. In Poland, especially in the villages, the barrels were used for storage.

Larger systems occur for educational institutions, stadiums, airports, and other facilities. In those systems the underground tanks are used and stored water is used for non-portable purposes because a price for filtering system is expensive.
On top of a high-rise building the storage tanks are placed for collecting rain water. Because the weight of storages can increase during rainfall the roofs need to be specially designed.

Land surface catchments is define as: “Rainwater harvesting using ground or land surface catchment areas can be a simple way of collecting rainwater. Compared to rooftop catchment techniques, ground catchment techniques provide more opportunity for collecting water from a larger surface area. By retaining the flows (including flood flows) of small creeks and streams in small storage reservoirs (on surface or underground) created by low cost (e.g., earthen) dams, this technology can meet water demands during dry periods. There is a possibility of high rates of water loss due to infiltration into the ground, and because of the often marginal quality of the water collected, this technique is mainly suitable for storing water for agricultural purposes.”

2.4.2 Grey water systems

One example of grey water usage is shown on the Figure 1. Water coming from a hand wash is going to toilet cistern, instead of sewer.

![Figure 1 – Sink installed in the flush](http://considerthethought.blogspot.com/2011/11/toilets-in-japan.html)

System below shown in Figure 2 is more complicated than the previous one. The cistern is instaled below the sink and it is connected with the toilet tank by a hose. When there is no water in the toilet storage the water from below of sink is trasfered through a filter to the toilet.

---


2.5 Filtration Overview

Three main methods were pointed in the literature: physical treatment, chemical treatment and biological treatment [11]. The C-mem cartridge filter chosen for this project connects physical and biological treatment so only those are going to be defined.

One of example for physical treatment is made by soil and membrane filtration followed by disinfection step. Because the system worked without biological treatment, the bacteria and viruses regrow on the membrane and in the pipe system causing membrane fouling and also lowering quality of the water. Based on that, physical treatment is not sufficient alone [11].

Biological treatment bacteria naturally existing in the water are used to take away organic contaminations from greywater. Oxygen is added to the water to allow aerobic bacteria to do their job. Bacteria settle on bacteria immobilize carrier, which is shown in Figure 3.

---

5 http://inhabitat.com
Figure 3 – Bacteria immobilize carrier

6 https://www.mrc.co.jp/english
3 Design and choice of hardware

In every project the requirements should be described in details. In this chapter choice of hardware is shown based on specifications stated in Appendix B.

Firstly, an amount of rain water from the roof and daily usage of water in family house was checked. Based on those information proper size of tanks was chosen. Secondly, according to water demand the filtration was selected so recycle water could fulfill requirements from the EU and WHO Thirdly two pumps were added to the system. The first one was to transfer water from rainwater or greywater tank to the roof top. The second one to create backflow to clean the filter. Finally, correct valves were found to control water flow, blower for aeration and bacteria immobilizer carrier for the bacteria bed. Suppliers were tried to be selected from Poland, but some of them were chosen from other countries.

In Table 6 there are shown selected hardware needed for this project.

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainwater tank 3000 l</td>
<td>1</td>
</tr>
<tr>
<td>Greywater tank 300 l</td>
<td>2</td>
</tr>
<tr>
<td>Infiltration module</td>
<td>1</td>
</tr>
<tr>
<td>Transfer pump</td>
<td>1</td>
</tr>
<tr>
<td>Cleaning pump</td>
<td>1</td>
</tr>
<tr>
<td>3-way valve</td>
<td>1</td>
</tr>
<tr>
<td>2-way valve</td>
<td>1</td>
</tr>
<tr>
<td>2-way valve with 5A supply</td>
<td>1</td>
</tr>
<tr>
<td>Reducer</td>
<td>1</td>
</tr>
<tr>
<td>Non return valve</td>
<td>1</td>
</tr>
<tr>
<td>Arduino</td>
<td>1</td>
</tr>
<tr>
<td>Sensors</td>
<td>3</td>
</tr>
</tbody>
</table>
3.1 Tanks

The system combines two kinds of water recycles system: grey water and rainwater. It was decided that the one 3000 liters tank will be used for rain water storage and two 300 liters tank for grey water.

3.1.1 Rainwater tank

To correctly choose rainwater tank calculations were done according to the information provided in Table 7.

Table 7 – Requirements for rainwater recycle water

<table>
<thead>
<tr>
<th>Location of the building</th>
<th>Poland, Lodz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surface of the roof</td>
<td>200 m²</td>
</tr>
<tr>
<td>2. Type of the building</td>
<td>Family house</td>
</tr>
<tr>
<td>3. Material of the roof</td>
<td>Ceramic roof tiles – run off rainwater coefficient =0.9</td>
</tr>
<tr>
<td>4. Inclination of the roof</td>
<td>Incline</td>
</tr>
<tr>
<td>5. Number of family members</td>
<td>4</td>
</tr>
<tr>
<td>6. Number of toilets</td>
<td>2</td>
</tr>
<tr>
<td>7. Number of washing machines</td>
<td>1</td>
</tr>
<tr>
<td>9. Number of sinks</td>
<td>4</td>
</tr>
<tr>
<td>10. Size of washing surface</td>
<td>50 m² - balcony</td>
</tr>
<tr>
<td>11. Size of the garden</td>
<td>300m²</td>
</tr>
</tbody>
</table>

There are three factors which determine volume of water flowing from the roof:

1. \( \mu \) - Run off coefficient – it depends on material of the roof
2. A - Surface of the roof
3. R – Rainfall – in Lodz family town of the author, 600 mm per m² per year

\[
R \times A \times \mu = 600 \times 200 \times 0.9 = 108000 \text{ Liter}
\]

The Data provided in Figure 4 [12] shows 6 months usage of water in the house of four person family.
For toilet flushing 86.66 liters per day x 365 days of the year = 31630 liter per year
Washing machine 3 liters per day x 365 days of the year = 1100 liter per year
Shower 55.04 liters per day x 365 days of the year = 21000 liter per year
Sink 18.6 liters per day x 365 days of the year = 6789 liter per year
Which means that the family needs 67371 liters of water per year
With these information we can now calculate the water capacity of rainwater tank.

\[ x = 108000 \text{ – volume of rainwater from the roof} \]
\[ y = 67371 \text{ – yearly family usage of water} \]
\[ \rho = \text{not raining period coefficient} \]

\[ \frac{x + y}{2} \times \rho \]

\[ \frac{108000 + 67371}{2} \times \frac{21}{365} = 5044 \text{ liters (1) [13]} \]

Estimated size of the tank is supposed to have 5000 liters. Based on the article in Water Science & Technology [14] combine systems give greater efficiency with smaller water storages. The equation (1) is provided to calculate the rainwater tank capacity. In this project equation is not valid because there are two systems combined. Therefore formula (2) was given which does not include \( y \) parameter – yearly family water demand.

\[ \frac{108000}{2} \times \frac{21}{365} = 3682 \text{ liter (2)} \]

As it is stated in this calculation and availability of cisterns with standard sizes, 3000 liters tank was selected
Qualifications of tanks are very similar as it is shown in Table 8. Two parameters which differs between them is price and guaranty. Three layer tank provides high resistance to mechanical damages. Manufacturer of the tank provides also free adjustment of the tank based on client’s needs, for example additional inlets or change of their positions, which is why 3 layer tank was chosen.

Table 8 – Specification comparison

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Graf</th>
<th>One layer</th>
<th>3 layers tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (m³)</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Inlet (mm)</td>
<td>110 or 160</td>
<td>110 or 160</td>
<td>110</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>750</td>
<td>1650</td>
<td>1200</td>
</tr>
<tr>
<td>Height to outlet (mm)</td>
<td>N/A</td>
<td>N/A</td>
<td>1000</td>
</tr>
<tr>
<td>Outlet (mm)</td>
<td>110 or 160</td>
<td>110 or 160</td>
<td>110 or 160</td>
</tr>
<tr>
<td>Material</td>
<td>Polyethylene</td>
<td>One layer of Polyethylene</td>
<td>3 layers of Polyethylene</td>
</tr>
<tr>
<td>Guaranty</td>
<td>15 years</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Price (pln)</td>
<td>5000</td>
<td>2848</td>
<td>3575</td>
</tr>
</tbody>
</table>

3.1.2 Grey water tanks

In the first design rainwater and grey water is supposed to be stored in one 5000 liters tank, treated there and transferred to the roof cistern. Unfortunately, aeration of the large capacity tank is very expensive and as it is shown in chapter 5 of this document, could take 20% of actual savings.

In the second attempt, different approach was chosen. The grey water is transported to the 300 liters tank where physical and biological filtration occurs. Then cleaned water is sent to the roof tank with the same volume.

Those tanks were selected from the same company as the previous one because it is easier to manage deliveries and get better price of the product when it is ordered from one supplier. Specification for the tank can be found in Table 9.
Table 9 – Greywater tank specifications

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (m³)</td>
<td>0,3</td>
</tr>
<tr>
<td>Inlet (&quot;)</td>
<td>¾</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>1040</td>
</tr>
<tr>
<td>Ø (mm)</td>
<td>655</td>
</tr>
<tr>
<td>Material</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>Price (pln)</td>
<td>620</td>
</tr>
</tbody>
</table>

3.1.3 Infiltration

This part of the system will be used to infiltrate overflowed rainwater from the rainwater tank to the ground. System already has 3000 l water storage so the smallest volumes of infiltration were chosen for consideration. Chosen modules are shown in Table 10.

Table 10 - Infiltration modules specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEODEK type A⁷</td>
<td>GRAF Infiltration tunnel⁸</td>
</tr>
<tr>
<td>Height (m)</td>
<td>0,6</td>
</tr>
<tr>
<td>Width (m)</td>
<td>0,3</td>
</tr>
<tr>
<td>Length (m)</td>
<td>1,2</td>
</tr>
<tr>
<td>Volume (l)</td>
<td>230</td>
</tr>
<tr>
<td>Price (pln)</td>
<td>168,61</td>
</tr>
<tr>
<td>GRAF Infiltration tunnel⁸</td>
<td>0,51</td>
</tr>
<tr>
<td>Width (m)</td>
<td>0,8</td>
</tr>
<tr>
<td>Length (m)</td>
<td>1,16</td>
</tr>
<tr>
<td>Volume (l)</td>
<td>300</td>
</tr>
<tr>
<td>Price (pln)</td>
<td>243,54</td>
</tr>
<tr>
<td>REWATEC KLAR-BOX⁹</td>
<td>0,6</td>
</tr>
<tr>
<td>Width (m)</td>
<td>0,32</td>
</tr>
<tr>
<td>Length (m)</td>
<td>1,2</td>
</tr>
<tr>
<td>Volume (l)</td>
<td>230</td>
</tr>
<tr>
<td>Price (pln)</td>
<td>252,15</td>
</tr>
</tbody>
</table>

Modules needs to be chosen based on the ground. In the specifications from Graf, it looks that it can be installed in the variety of grounds whereas others need specific ones. That is why the Graf module has been chosen for this project.

---

⁷ http://www.gea-2h.com
⁸ http://www.graf-water.com
⁹ http://www.rewatec.de
3.2 Filters

The most important parts of the system are filters. Without them the whole system could not exist. The WHO and the EU specify the quality of the water used for reuse. Filters used for water treatment in this project meet those requirements. In the setup shown in Figure 13 two of them are installed.

A down pipe filter is used to clean rainwater from the big particles like leaves, small pieces of wood, etc. and it protects pipes from occlusions. It has to be done so they will not block the main filter or decay at the bottom of the lower storage tank.

The filter, which can be called “the heart of the system” has a difficult task. It needs to provide water, which fulfills specifications of the EU directive. It cannot contain any bacteria, viruses, chemicals, etc. It took a few weeks to find a proper filter. In the end C-MEM has been chosen for a few reasons:

1. The price is relatively low
2. It has a ten years guarantee
3. It can be cleaned automatically
4. It is a flow filter.

3.2.1 Filtration overview

According to research, [15] two stage filtration is available. Firstly, mechanical filtration up to 20 µm clears water from contamination. Secondly, disinfection step is provided usually by UV lamp.

Physical process based on ultrafiltration provides better quality of water than in the example before. Nevertheless, study proved that MBR systems by combining the activated sludge process with membrane separation provide high quality of water. [7].

Membrane filtration can be divided in to two group’s dead end: filtration and cross flow filtration.

Dead end filtration is when flow of the water is parallel to the fibers contained in a filter. Cross flow filtration is when permeate is perpendicular to feed stream [16]. Difference between them is shown in Figure 5.
During the research submerged and not submerged filters were found. Ami membranes, CSM, Pentair x-flow, Hydracap from Hydranautica are examples of not submerged modules. Submerged filtration takes less space, there is no need of additional circulation in side of the bioreactor and operation of the system is very effective, which is why only submerged filters were taken to consideration [17]. Another advantage is that air from submerged filters is transferred to the bioreactor so biological process continues.

### 3.2.2 C-MEM with comparison to other filter

In Table 11, there are compared three submerged modules which were found during the research. The manufacturers in the documentation of each particular filter implies that water quality exceeds the UE directive demand. Therefore four other specifications were chosen to select proper filter.

System is supposed to take small amount of space so, small size of the filter is needed. Pore size is also important requirement because of quality water provided. In Figure 6, there is shown classification of membrane filtration and that C-MEM is in a group of ultrafiltration filters. Flux is a parameter which needs to be taken to consideration so it can fulfill requirements. Cleaning method is important so the system does not need to be cleaned manually.

In Table 11, values of parameters were shown. Water flow in the house does not exceed a 200 liters per day so small flux size, compared to other filters, is not an issue. It is important to add that according to the information from manufacturer of C-MEM cartridge, it can be used in situation when periodically there is no water in the tank. The other modules if they dry out, it can damage structure of the fibers. Based on this information and fact that C-MEM module is the smallest one it was decided to use it for this project.

---

10 http://www.spectrumlabs.com
Table 11 – Filters comparison

<table>
<thead>
<tr>
<th></th>
<th>C-mem</th>
<th>ZeeWeed</th>
<th>Sterapore 5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (mm)</td>
<td>410 x 164</td>
<td>2,198 x 844 x 49</td>
<td>1015 x 600 x 30</td>
</tr>
<tr>
<td>Pore size(µm)</td>
<td>&lt;0,211</td>
<td>0,4</td>
<td>0,4</td>
</tr>
<tr>
<td>Flux (liters/h)</td>
<td>30-600</td>
<td>100 - 400</td>
<td>100 - 400</td>
</tr>
<tr>
<td>Cleaning method</td>
<td>Back wash connect with air scour</td>
<td>Continuous air scour, air and water backwash</td>
<td>Continuous air scour, air and water backwash</td>
</tr>
</tbody>
</table>

Figure 6 - Classification of membrane filtration12

11 http://sfcu.at
12 http://onlinembr.info/
3.2.3 C-MEM

“The characteristic of the C-MEM™ process is the use of submerged organic hollow fiber membranes. The hollow fiber are wound around a carrier cartridge are arranged in bundles. The cartridge gives the hollow fibers the required strength and permits the introduction of high pressure air scouring for cleaning. In this system there is only one cartridge but it can be combined in modules”\(^\text{13}\). By suction from the pump, water is going throughout the filter and leaving all impurities inside of it. Later on when cleaning process starts the filter is being cleaned.

![Figure 7 – C-MEM filter cartridge](http://sfcu.at)

There was not found any research about water quality provided by C-MEM. However, Intewa Company has several systems based on this filter and according to them it provides water quality required by EU [6, pp. 48-49]. In this document water quality demand to operate is shown and used after treatment.

3.2.4 Pipe down filter

Operating method of the pipe down filter is very simple and it is shown in Figure 8. When it is raining, water with particles is floating through the net which is inclined relative to the bottom of the filter.

- Low maintenance due to optimised self-cleaning
- Suitable for roof areas up to 200 m²
- Slim design- only 16 mm distance between downpipe and outside wall
- Turntable filter body for flexible connection
- Reliably filters contaminations out of the rainwater
- Fills the rainwater tank and prevents full rainwater storage tank from overflowing
- Can be easily switched from summer to winter use by turning the adjusting collar\(^\text{15}\)

\(^\text{13}\) http://sfcu.at

\(^\text{14}\) http://sfcu.at

\(^\text{15}\) http://www.graf-water.com
3.3 Pumps

In the system, there are two pumps connected in parallel like it is shown in Table 13. They have different functions: the first one needs to provide water for cleaning the filter, the second one transfer water to the roof cistern. The pressure needed for both processes are calculated from data shown in Table 12 and Table 13 and Figure 9.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vertical length between bottom of the underground tank and pumps</td>
<td>2.2m</td>
</tr>
<tr>
<td>2. Depth set of suction pipe</td>
<td>0.4m</td>
</tr>
</tbody>
</table>

1mH₂O = 0.1bar [18]

\[
h_{1H_2O} \times 0.1\text{bar}
\]

2.2 \times 0.1 = 0.22bar (1)

By following this 0.22 bar is needed to operate for cleaning process.

---

\[\text{Figure 8 – Pipe down rain water filter}^{16}\]

16 http://www.graf-water.com
Table 13 – Requirements for transfer pump

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Horizontal length between pump and the furthest water inlet</td>
<td>13.5 m</td>
</tr>
<tr>
<td>2. Vertical length between pump and the further water inlet</td>
<td>4 m</td>
</tr>
<tr>
<td>3. Vertical length between bottom of the underground tank and pumps</td>
<td>2.2 m</td>
</tr>
</tbody>
</table>

\[ 1 \text{mH}_2\text{O} = 0.1 \text{bar} \] [18]

\[ (h3 \ast H_2O + h1 \ast H_2O) \ast 0.1 \text{bar} \]

\[ 4 \ast 0.1 + 2.2 \ast 0.1 = 0.62 \text{bar} \] (2)

By following, 0.62 bar is needed to transport water to roof top tank.

In Table 14, there is shown parameter comparison between the different pumps. All of them meet specification provided in the project. In the system there are two pumps shown in the Figure 13.

With the information shown in Table 14 correct choice of the transfer pump was made.

All of the parameters provided meet specifications, so only energy consumption was taken to consideration. For the system, it is necessary to transfer 200 liters of treated water to the roof cistern. In Table 15, there are shown times, which each pump needs to transport 200 liters of water to the roof tank and yearly energy consumption, by assuming that pump will work 2 times a day.

To calculate time to transfer 200 liters of water three parameters are needed:

P=0.62 bar – pressure need to transport water to the roof tank

Q – flow rate at 0.62 bar

V=200l

Value Q is taken from specifications of each pump.

It known that:

\[ 1 \text{ m}^3/\text{h} = 0.28 \text{ l/s} \]

So, by taking \( Q = 1.65 \text{ m}^3/\text{h} \) from QB60 pump specification and changing it to l/s from equation below the time transfer can be calculated.

\[ Q=1.65 \text{ m}^3/\text{h}=0.45\text{ l/s} \]
By following equation 3, times were added to Table 15.

To calculate energy consumption in a year:

\[ M = \text{max power of motor} \]

\[ D = 730 - \text{number of usage} - \text{approximately 2 times a day each day of the year} \]

\[ T/3600 = \text{time of one usage in “h” unit} \]

\[ M \times D \times T \quad (4) \]

By taking equation 4 and data from Table 14 and Table 15 for QB60 the calculation can be made:

\[ 0.37 \times 730 \times 444/3600 = 33.01 \text{kWh} \]

By following equation 4 energy consumption values were added to the Table 15

With this data, two pumps are considered being the most efficient PKm60 and SpidAMX 50. It is clear that the second pump needs half time to send 200 liters of water compare to the first one. It is important for the user of the system to do not wait too long for water. That is why SpidAMX50 was chosen for this project.

By using the same data, pump for cleaning the filter can be chosen. In the specification sheet provided from the filter manufacturer filter needs to be cleaned with water pressure not exceeding 2.5 bar. In that case by comparing values from Table 14 and Table 15, the PKm60 was chosen for this project because of small energy demand and small pressure provided.
### Table 14 – Pumps specifications comparison

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QB60&lt;sup&gt;17&lt;/sup&gt;</td>
</tr>
<tr>
<td>Power supply (V/Hz)</td>
<td>230/50Hz</td>
</tr>
<tr>
<td>Suction length (m)</td>
<td>7</td>
</tr>
<tr>
<td>Lift - (H_{\text{max}}) (m)</td>
<td>30</td>
</tr>
<tr>
<td>Flow rate (Q_{\text{max}}) (l/min)</td>
<td>32</td>
</tr>
<tr>
<td>Max power of motor (kW)</td>
<td>0.37</td>
</tr>
</tbody>
</table>

### Table 15 – Energy consumption

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QB60</td>
</tr>
<tr>
<td>Flow at 0,62 bar (m³/h)</td>
<td>1,65</td>
</tr>
<tr>
<td>Time (s)</td>
<td>444</td>
</tr>
<tr>
<td>Energy used (kWh)</td>
<td>33,01</td>
</tr>
</tbody>
</table>

<sup>17</sup> http://malec-pompy.pl  
<sup>18</sup> http://malec-pompy.pl  
<sup>19</sup> www.lenntech.com
During process of design and choice of pumps submersible, pumps were taken to consideration. For easier maintenance in eventual break down, it was decided not to use this kind of pumps.

### 3.4 Arduino

“The Arduino Duemilanove is a microcontroller board based on the ATmega168. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.”

Specification are shown in Appendix E  Arduino specifications

System described in this project does not exist anywhere else. It was decided to base it on Arduino because the system is in prototype level. Arduino is a platform of many users and it is easy to use, so the main focus could be put on to the design.

### 3.5 Sensors

Main function of sensors used in this project is to check water level in both tanks. It was considered to choose optical switches, but their price is too high. One piece costs 135\$ and for

---

20 [https://www.arduino.cc](https://www.arduino.cc)
needs of the project 7 of them were needed\textsuperscript{21}. There are also conductive sensors available, but they need a transducer to operate, so the price is still not satisfying. Therefore cheaper solution was found: Floating sensors.

### 3.5.1 Floating sensor

Floating sensors give out analog signal and they can be supplied by 12VDC and connected directly to the microcontroller via voltage divider. The specifications are shown in Table 16. The next advantage is that it is enough to use two of them, whereas with conductive sensors it would be necessary to have one sensor in each level where the measurement is required. What is more they are available in 0-20 or 4 - 20 mA setups depending on the requirements. One of the examples of the floating sensor is in Figure 10.

![Floating sensor](https://www.oequest.com/cat/1434)

**Figure 10 – Floating sensor\textsuperscript{22}**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (m)</td>
<td>2</td>
</tr>
<tr>
<td>Output(mA)</td>
<td>4-20 or 0-20</td>
</tr>
<tr>
<td>Recurrence (cm)</td>
<td>1</td>
</tr>
<tr>
<td>Pressure (bar)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

---

\textsuperscript{21} [https://www.oequest.com/cat/1434]

\textsuperscript{22} [http://www.eiewin.com.pl]
In the Figure 11, there is shown how the sensor is built. It contains float build from polypropylene with magnet inside. Terminal with taper thread and rail with reed relay which turn on resistors and also circuits which process signal from rail to 4-20mA.

Figure 11 – Main parts of the floating sensor

---

23 www.eiewin.com.pl
3.5.2 Flow sensor

Sensor viewed in the Figure 12 is added to the setup to react quickly for eventual overflow of the system. It is supplied by 5 volts so it can be directly connected to the microcontroller. There were taken to consideration two of them with different diameter. Comparison can be seen in Table 17

![Flow sensor](http://www.seeedstudio.com)

Figure 12 – Flow sensor

In the table below red color represent parameters which differ between sensors. First of all 1” is the same as in the pumps, so additional adjustment is not needed. The second parameter is flow rate range. If client requests, it can be added to the system calculation of how much water is going through overflow, so it can be seen how reliable the setup is. Third one is water pressure: both of them meets requirements because the water pressure will be 0, 62 bar Based on this information the 1” sensor has been chosen.

Table 17 – Specifications of flow sensor

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Inflow G3/4”</th>
<th>Inflow G 1”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini. Working Voltage (V)</td>
<td>DC 4.5</td>
<td>DC 4.5</td>
</tr>
<tr>
<td>Max. Working Current(mA)</td>
<td>15mA (DC 5V)</td>
<td>15mA (DC 5V)</td>
</tr>
<tr>
<td>Working Voltage(V)</td>
<td>DC 5~24</td>
<td>DC 5~24</td>
</tr>
<tr>
<td>Flow Rate Range(l/min)</td>
<td>0~60</td>
<td>2~100</td>
</tr>
<tr>
<td>Load Capacity(mA)</td>
<td>≤10 (DC 5V)</td>
<td>≤10 (DC 5V)</td>
</tr>
<tr>
<td>Operating Temperature(°C)</td>
<td>≤80</td>
<td>≤80</td>
</tr>
<tr>
<td>Liquid Temperature(°C)</td>
<td>≤120</td>
<td>≤120</td>
</tr>
<tr>
<td>Operating Humidity(RH)</td>
<td>35%~90%</td>
<td>35%~90%</td>
</tr>
<tr>
<td>Water Pressure(MPa)</td>
<td>≤2.0</td>
<td>≤1.75</td>
</tr>
</tbody>
</table>

---

24 http://www.seeedstudio.com
3.6 Valves

During the design process it was decided to use as few valves as possible. The more elements the system contains, the more possible failure may occurred. In the end, two valves were chosen.

Polish standards classified water in to 5 different classes. Greywater and rain water are classified class 5. This class of water requires air gap between the highest level of water in the tank and inflow of tap water [19]. Regulation from Ministry of Infrastructure explains that the recycle water system cannot be connected in any point with tap water. To achieve this standard air gap is used [20]. That air gap needs to be 80mm from the level of water to inflow valve. There is another possibility to make this happen. An anti-pollution valve can be used. Unfortunately, they cannot be installed in the setup because they are not available with solenoid.

In the end 3 solenoids valves were chosen:

1. 3 way solenoid valve
2. Back up solenoid valve for the tap water
3. 2 way solenoid valve to open rainwater flow

Three-way valve, specifications shown in Table 18, controls water flow pumped out from the lower tank. Depending on the situation, the position can change, so water can go to sewage or upper tank. The system is built and connected in a way that even without electricity this valve do not need to operate. In other words, when electricity is on, the position of the valve can be controlled. In case of lack of power, water cannot be pumped out, because pump needs electricity, so this valve does not operate. Parameters of the valves are almost the same so, the cheaper A80 has been chosen.

Two way valve used for control water inflow from the rainwater tank has the same parameters as the previous one because difference lays only with number of ways of flow the choice is again valve with A80 motor.
Table 18 – 3 and 2 way valve comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ferro25</th>
<th>A8026</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of diameter(“)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rated Voltage(V)</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>Position change time(s)</td>
<td>5</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Protection class</td>
<td>IP67</td>
<td>IP65</td>
</tr>
<tr>
<td>Price(pln)</td>
<td>430</td>
<td>250</td>
</tr>
</tbody>
</table>

The other one is a two-way valve TF25-B2-A27. It has a 5v-supplied solenoid so it can be operated even without electricity by microprocessor, which is crucial to make system user as friendly as possible. In the Table 19, there are specifications for this valve28

Table 19 – 5A valve specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of diameter(inch)</td>
<td>1</td>
</tr>
<tr>
<td>Rated Voltage(VDC)</td>
<td>5,</td>
</tr>
<tr>
<td>Open/close time (s)</td>
<td>5</td>
</tr>
<tr>
<td>Protection class</td>
<td>IP67</td>
</tr>
</tbody>
</table>

3.6.1 Reducer

In the specifications for C-MEM filter the max transmembrane pressure used for backwash was supposed not to exceed 2.5 bar. The pump pKM 60 which will be used for this purpose gives max 3 bar of pressure which exceeds needed value. That is why reducer needs to be used.

Based on data from Table 20 Eurobrass reducer was chosen. It has higher temperature handle and the price is more attractive.

25 http://ferro.pl
26 http://washservice.pl
27 http://www.china-electricvalves.com
28 http://www.globalsources.com/si
### 3.7 Blower

Blower in this setup has two tasks. First is to help with cleaning process of the filter. By blowing the air in the other direction than water, it creates bubbles, so small particles can be removed from the membrane. The second one is to put oxygen to the tank so the bad odors will not occur. The most important parameter which needs to be taken into consideration is the air flow\(^1\). In the research about a fouling control authors point air flow as the most important parameter in air scouring. [21]. In the data sheet of the C-mem filter any specification about pressure during air scouring is not mentioned.

\[
\rho_{\text{air}} = 1.492 \text{g/l}
\]

In the air is 20% of oxygen

\[
\rho_{\text{air}} \times 0.2 = 0.2984 \text{g/l } \text{O}_2 \text{ in the air}=298.4 \text{mg/l}
\]

Daily grey water income = 200l [12]

COD – Carbon degradation = 187.5 mg/l\(^2\)

N – Nitrification = 10mg/l

3*N – factor of safety = 30 mg/l

\(^1\)http://wiki.intewa.net/index.php/Wasseraufbereitung_und_Grauwassernutzung/en#cite_ref-isa_0-1

\(^2\)http://wiki.intewa.net/index.php/Wasseraufbereitung_und_Grauwassernutzung/en#cite_note-isa-0
V= volume of greywater tank = 300 Liters

To calculate required oxygen amount

\[ \text{COD} + 3 \times N = 220 \, \text{mg/l} \]

To calculate amount of air which needs to be blown to the tank

\[ 220 \times V = 66000 \, \text{mg} \]

\[ \frac{66000 \, \text{mg}}{298.4 \, \text{mg/l} \, \text{O}_2} = 221.4 \, \text{lO}_2 \]

221.4 lO₂ supposed to be blown to the greywater tank for biological process.

In Table 21 there are specifications for three different kinds of blower. This data is used to calculate time and energy consumption for each blower. In Table 22 are shown values of those calculations.

\[ \text{VO}_2 = 221.4 \, \text{l} \]

AF= air flow

\[ \text{AF}_{\text{intewa}} = 85 \, \text{l/min} \]

To calculate time needed to supply enough oxygen

\[ \frac{\text{VO}_2}{\text{AF}_{\text{intewa}}} = 156 \, \text{s} \]

Now to estimate energy consumption in a year:

\[ P_{\text{intewa}} = 100 \, \text{W} \]

D=number of usage 1460 in a year by assuming 4 times a day system will clean the filter

\[ T_{\text{intewa}} = 156 \, \text{s} \]

\[ P \times D \times T / 3600 = 6.3 \, \text{kWh} \]

6.3 kWh the blower will use each year.

Based on this information Intewa blower was chosen. It takes two times less to fill enough oxygen to the tank compare to the others, what is more, it consumes less energy.
### Table 21 – Blowers comparison

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intewa&lt;sup&gt;33&lt;/sup&gt;</td>
</tr>
<tr>
<td>Supply voltage (V)</td>
<td>230</td>
</tr>
<tr>
<td>Frequency</td>
<td>50</td>
</tr>
<tr>
<td>Pressure (bar)</td>
<td>0,18</td>
</tr>
<tr>
<td>Air flow l/min</td>
<td>85</td>
</tr>
<tr>
<td>Power (W)</td>
<td>100</td>
</tr>
<tr>
<td>Weight</td>
<td>9.4</td>
</tr>
</tbody>
</table>

### Table 22 – Time and energy used to fill oxygen in 300 l tank

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intewa&lt;sup&gt;33&lt;/sup&gt;</td>
</tr>
<tr>
<td>Time (s)</td>
<td>156</td>
</tr>
<tr>
<td>Energy used (kWh)</td>
<td>6,3</td>
</tr>
</tbody>
</table>

### 3.8 Growth bodies

Growth bodies are placed into the lower tank of the system to become a place where bacteria which are taken from the filtration will settle. In the Table 17, there are shown specifications for growth bodies. To explain a choice, the calculations were made.

**COD = 187.5 mg/l**

**Daily grey water income = 200 l/day**

**Daily pollution load = COD * 200 l/day = 37500 mg/day = 37, 5 g/day = 0,0375 kg/day**

Required substrates are 0,0375 kg/day

<sup>33</sup> [http://shop.intewa.net](http://shop.intewa.net)

<sup>34</sup> [http://hipblow-usa.com](http://hipblow-usa.com)
“A surface load of < 0.004 kg COD/m²*d is to be maintained in small wastewater treatment plants to ensure proper operation with safety factors”\textsuperscript{35}

\[
0.0375 / 0.004 = 9.375 \text{m}^2
\]

The lower tank, where the growth bodies will be placed, has 300 liters of capacity. By looking at specifications from Table 23, it is enough to place 3l of growth bodies. From the same table the Mitsubishi immobilizers were chosen, because of the bigger surface.

Table 23 – Growth bodies

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Intewa\textsuperscript{36}</th>
<th>Mitsubishi\textsuperscript{37}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (mm)</td>
<td>36</td>
<td>6 in - 10 out</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>30</td>
<td>N/A</td>
</tr>
<tr>
<td>Geometric surface(m²/m³)</td>
<td>320</td>
<td>9000</td>
</tr>
<tr>
<td>Density range: (g/l cm³)</td>
<td>0.95 - 1.10</td>
<td>0.95</td>
</tr>
<tr>
<td>Packaging unit (l)</td>
<td>30</td>
<td>N/A</td>
</tr>
</tbody>
</table>

\begin{footnotesize}
\textsuperscript{35} http://wiki.intewa.net
\textsuperscript{36} http://shop.intewa.net
\textsuperscript{37} http://mrc.co.jpBackup
\end{footnotesize}


4 System Design and operation

System consists of the devices which have to fulfill certain functions so the whole setup can work properly. Their specifications are listed and explained in Chapter 3 of this document. A reader can find below what are the roles of each particular hardware in the configuration. In the further subchapters the Figure 13 will be used to explain the process and how system uses them.

4.1 Operation modes

There are two tanks for rainwater and grey water. In the storages there is a floating sensor. Depending on the water level, signal from the detector is sent to the microprocessor after water
reaches certain position. The same is happening in the upper tank but the sensor shows there only if the tank is full or empty. This water level checks up is of high importance, because with those information processor can control water flow in the system.

Water in the upper tank supplies toilets and washing machines. To make the system easier to maintain, water from town also can flow into the top cistern, so there is only one pipe line required. In other words, instead of providing water from the town directly to a washing machine or a toilet by different system of pipes, water flows to the tank and from there goes where it’s needed.

When system is turned on the first time, water from the town needs to supply upper tank because there is no water yet in the lower tank. After top cistern is full, the backup valve will be closed to avoid overflow. Next, there can be two situations:

1. All tanks are empty
2. Lower tank has water and upper tank is empty

If the first situation happens, water from town will fill the top tank. In the second position, pump will go on and will pump water until upper cistern is full. This process will continue until the system will be on or negative circumstances occur.

If the second situation occur water from the rainwater or grey water tank will be transferred until upper cistern fills or water in the lower tank finishes.

Producer of the C-MEM filter requires cleaning of the filter. To do this automatically there is a need of two devices: blower and pump which produce back flow of water. It is enough to clear the filter in the household once in every 12h. Water from the top tank is going to be pumped for 30 seconds and in the same time the blower will put air inside of the cartridge. According to specifications air inflow has 1¼” dimension and it is connected with blower via blower pipes. After this time both devices will be off until the next cleaning process. The directions are explained in Figure 14.
4.2 Problems during operation

There can be listed few problems which may happen during the operation:

1. No electricity
2. Broken sensors
3. Broken pump
4. Broken valve or solenoid

The system was designed to manage unpredicted situations.

4.2.1 No electricity

It is possible that during operation of the system power will go off. In that case, Microcontroller will detect change in voltage and will start using battery supply. The floating sensors also will be unable, so 5v flow detector will go on to check when water from upper tank will start overflowing. Immediately when it happens, backup valves turn off.

In the situation of electricity failure water from the system will be used only to flush toilets. Upper tank contains 200 liters of water which is enough for 32 flushes. Nowadays, toilets cisterns has capacity around 6 liters. The user can flush a toilet with 3 or 6 liters of water.

6 liters of water * 32 flushes = 192 liters of water.

38 Data sheet_C-MEM cartridges 2014.pdf
Before it will be used, electricity should be back. In a situation that current is not back yet and upper tank is empty, user can open backup valve manually, and the system will close it when cistern will be full.

### 4.2.2 Broken sensors

Every device can be broken and it can happen to sensors too. This situation also was predicted during the plan of the system. It needs to be clear that broken sensor will give 0A on the output or it will give current which is out of scope above 22mA.\(^{39}\)

Firstly it can be considered failure of the water level detector in greywater and rainwater tank. There can be two extremes:

- No water
- Too much water.

To solve the first problem the floating sensor will be installed in a way that every reading below 50 liters will be considered as a failure of the sensor so system will operate as there is no water in the bottom tank.

In the second situation flow sensor installed above the floating detector will send signal to the microcontroller. With this information system will give an alarm that floating sensor is broken and it will also remove 100 liters of water to the sewage by using a timer.

Secondly the upper tank detector failure can be taken into consideration. Again two extremes can happen:

- No water
- Too much water.

If the sensor breaks it sends 0A or 22mA value which is out of scope. This information will turn on an alarm to inform about broken sensor. If there will be no current the system behaves as there is no water in the upper storage and water will be transferred to the moment when water starts overflow. In this situation flow detector will find out what is happening and immediately turns off pump and turns on an alarm.

It can happen that there is too much water in the upper tank but this situation is explained above. Each overflow will be detected by flow sensor and setup will respond to it.

### 4.3 Main Process

Main process is explained in the flow chart shown in the Figure 15. It is started with checkup of the water level in the tanks and position of the backup valve. Very important is the reading

\(^{39}\) http://www.eiewin.com.pl
from the sensor in the greywater tank. When the system is started first time there is a possibility that there is no water in this storage. If so, water from town supplies upper tank until enough water is in the recycled cistern. In case that some of sensors break, there is a timer added to protect system from overflow. In the overflow pipe of the upper cistern a digital flow meter will be installed so it can detect broken level sensor.

After water in the greywater tank reaches proper level, pump will start to work to transport water to the upper storage. Pump will be on until roof cistern is full. Afterwards it will be off to the moment when upper tank will need water again. It may happen that the grey water tank and the upper tank will be full. The software is prepared for this kind of situation. There is the 3-way valve in the system so, in those conditions it will change position and send water directly to the sewage until 50 liters of water will be pumped out. If greywater and roof tank are empty, then rainwater valve will open and rainwater will fill in the upper cistern.
Figure 15 – Flow chart of the system.
4.4 Cleaning process

The cleaning process is required for the best operation of the C-MEM filter. Below in the Figure 16 there is an explanation how this procedure is executed by the software. When the setup starts working a 12 hour timer turns on. Nothing will happen until this amount of time passes. After that it will be checked if the upper tank is full. If it is, the cleaning process will start and it will continue for 30 seconds. After this time, timer restarts, the pump and the blower turn off until the next 12 hours. It is important to state that cleaning will not start until the upper tank is full, to protect the pump from dry work.

Figure 16 – Cleaning process flow chart
4.5 Chlorine cleaning process

C-MEM filter needs to be cleaned by chlorine or citric acid as it is explained in the specifications of the filter, shown in appendix F, to work on high performance during use. It is supposed to be done every 6 months. At this time qualified plumber will check maintenance of the system and add specified unit of chlorine to the system. Below, in the Figure 17, there is an explanation of how the process will proceed.

![Chlorine cleaning process flow chart](image)

**Figure 17 – Chlorine cleaning process flow chart**

After two buttons are pressed, process will start and tanks will be empty. This means that first level of water in tanks will be checked and pump will do job to transfer water from storages to sewer. When it happens water with chlorine will fill upper tank. Nothing happens until upper...
tank will be full of water. At this moment, back flow pump will pump water through the filter to the lower cistern. The second pump will turn on when the lower tank will be full. At this moment first pump will be off. After water will flow through the filter, back flow pump will be off. This process will be repeated for 30 minutes, after this time, lower cistern empties and system come back to the normal process.

4.6 Prototype board and simulation

For the purpose of this project prototype board for simulation was created. It contains two 10kΩ potentiometers which are indicating floating sensors. By manipulating them it is possible to simulate water levels in tanks. Because readings from the tanks are the most important information which the whole system is based on, processes can be simulated. To create safety features two buttons were implemented. Because cleaning process firstly emptying both tanks, to start that feature two buttons at the same time need to be pressed so it will not happen by coincidence.

4.6.1 Implemented components

In Table 24, there are listed components used to create prototype board. Specifications for LCD display are in appendix.

<table>
<thead>
<tr>
<th>Component name</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino Uno</td>
<td>ATmega328 microchip</td>
</tr>
<tr>
<td>LCD 2x16</td>
<td>controller HD44780</td>
</tr>
<tr>
<td>Cable communication</td>
<td>USB</td>
</tr>
<tr>
<td>Potentiometer</td>
<td>10 kΩ</td>
</tr>
<tr>
<td>Potentiometer</td>
<td>20kΩ</td>
</tr>
<tr>
<td>Resistors</td>
<td>220Ω</td>
</tr>
<tr>
<td>Resistor</td>
<td>5kΩ</td>
</tr>
<tr>
<td>Diodes</td>
<td>Different colors</td>
</tr>
<tr>
<td>Breadboards</td>
<td></td>
</tr>
<tr>
<td>Switches</td>
<td></td>
</tr>
<tr>
<td>Wires</td>
<td></td>
</tr>
</tbody>
</table>
4.6.2 Bread board schema

To simulate the system behave the circuit was created shown on Figure 18. Arduino gives power 5v to each of components. The potentiometers are connected to A0 and A1 pins which are able to read analog inputs. The diodes D1 and D2 are connected to pins A4 and A5 but in this case those pins are working as digital ones. The other diodes are connected to digital pins 6, 7, 8, 10, 13. There is one resistor R8 which has 5kΩ and it is connected to V0 pin in the LCD. Its function is to keep contrast on the display. LCD pins D7, D6, D5, D4, are connected to pins 2, 3, 4, 5 in the Arduino directly. The purpose of this connection is to make possible data exchange between the screen and microcontroller.

![Figure 18 – Prototype board schematic](image)

In Table 25 there are listed components and their functions in the simulation.
Table 25 – Components list on the circuit and functions

<table>
<thead>
<tr>
<th>Component name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode D1</td>
<td>Indication of back up valve</td>
</tr>
<tr>
<td>Diode D2</td>
<td>Indication of Blower</td>
</tr>
<tr>
<td>Diode D3</td>
<td>Indication of back flow pump</td>
</tr>
<tr>
<td>Diode D4</td>
<td>Indication of 3 – way valve position</td>
</tr>
<tr>
<td>Diode D5</td>
<td>Indication of pump up pomp</td>
</tr>
<tr>
<td>Diode D6</td>
<td>Indication of upper tank water level</td>
</tr>
<tr>
<td>Diode D7</td>
<td>Indication of lower tank water level</td>
</tr>
<tr>
<td>Diode D8</td>
<td>Indication of Rainwater valve</td>
</tr>
<tr>
<td>Switch 1</td>
<td>Shows status of tanks</td>
</tr>
<tr>
<td>Switch 2</td>
<td>System is ready for maintenance</td>
</tr>
<tr>
<td>Potentiometer 1</td>
<td>Indicates reading from the floating sensor instal in lower tank</td>
</tr>
<tr>
<td>Potentiometer 2</td>
<td>Indicates reading from the floating sensor instal in upper tank</td>
</tr>
</tbody>
</table>

4.7 Implementation

There are two possibilities to apply this system in a building. First is to implement such a system during the process of building. Second is to install it in an existing one. The difference is that the second one is more expensive because of changing in the pipe system. The law states that recycling water setup needs to be separate from the fresh water pipes.

The system is going to be fully automated, so it is very comfortable solution for the user. Maintenance of the system done by the user will be limited to clean a growth bodies. Each system will be designed for the special needs of the client. The design will vary by a few factors such as:

- Size of the roof – Bigger the roof bigger the storage tanks
• Height of the building – More powerful pump needs to be used for higher building
• Amount of sinks toilets showers etc.
Main control system will not be change and it will contain:

• Microchip base control system with 2x16 LCD
• Pumps
• Valves
• Floating sensors
• Tanks
• Filtering system – filtering system depend on the client’s needs.

For the special needs system can be applied with additional features such as:

• Control system based on a PLC with HMI display
• Remote access to a control panel of the system via internet.
• Special 24 h assistance for maintains of the system
5 Feasibility study

5.1 Cost Analysis

5.1.1 Cost of chosen hardware

Most of the prices in this chapter are going to be presented in USD for better understanding costs of the hardware. There can be some slightly differences between real prices and prices changed to USD because most of suppliers were chosen from Poland where currency is PLN. Below, in Table 26, there are costs analyzes of the system components.

Table 26 – Costs of hardware\(^{40}\)

<table>
<thead>
<tr>
<th>Hardware name</th>
<th>Price(pln)</th>
<th>Amount</th>
<th>Cost(pln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating sensor</td>
<td>450</td>
<td>3</td>
<td>1350</td>
</tr>
<tr>
<td>Flow sensor</td>
<td>111</td>
<td>1</td>
<td>111</td>
</tr>
<tr>
<td>Pump SpidAmx</td>
<td>588</td>
<td>1</td>
<td>588</td>
</tr>
<tr>
<td>Pump PKm 60</td>
<td>450</td>
<td>1</td>
<td>450</td>
</tr>
<tr>
<td>Valves</td>
<td>250</td>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>Upper tank</td>
<td>620</td>
<td>1</td>
<td>620</td>
</tr>
<tr>
<td>Grey water tank</td>
<td>620</td>
<td>1</td>
<td>620</td>
</tr>
<tr>
<td>Lower tank</td>
<td>3575</td>
<td>1</td>
<td>3575</td>
</tr>
<tr>
<td>C-MEM filter</td>
<td>2817</td>
<td>1</td>
<td>2817</td>
</tr>
<tr>
<td>Pipe down filter</td>
<td>286</td>
<td>1</td>
<td>286</td>
</tr>
<tr>
<td>Battery</td>
<td>75</td>
<td>1</td>
<td>75</td>
</tr>
<tr>
<td>Growth bodies</td>
<td>143</td>
<td>1</td>
<td>143</td>
</tr>
<tr>
<td>Control system</td>
<td>350</td>
<td>1</td>
<td>350</td>
</tr>
</tbody>
</table>

SUM before tax 11485
SUM after tax 14126.55

\(^{40}\) Exchange made in landsbanki.is at 13.09.2015
5.1.2 Energy consumption and costs

Each year the system can save, by assuming a 200 liters of water usage every day, 73m$^3$ of water a year. Price of 1m$^3$ Lodz is 4 pln and 4 pln for sewage which gives 8 zloty per m$^3$. With simple calculation

$$73 \times 8 = 584 \text{ pln}$$

In Table 27 is shown energy usage of the system. So by taking to consideration energy usage:

$$584 - 33.75 = 550.25$$

Cost of the system before tax is 11485 pln

$$\frac{11485}{555} = 20$$

Investment in the system will pay off after 20 years.

Unfortunately, in those calculations the maintenance of the system is not included.

As it is shown in Table 26, c-mem filter costs 2817 pln and it needs to be changed at least every 10 years. Unfortunately, this will increase the time of pay off twice, and still not every of maintenance is included. Pumps or solenoid valve may be broken. With this in mind approximately pay off time is 50 years.

Table 27 – Yearly energy cost usage of the system in Poland

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Consumption (kWh)</th>
<th>Price For kWh (pln)</th>
<th>Price(Pln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer pump</td>
<td>34,12</td>
<td>0,52$^{41}$</td>
<td>17,74</td>
</tr>
<tr>
<td>Cleaning filter pump</td>
<td>24,5</td>
<td></td>
<td>12,74</td>
</tr>
<tr>
<td>Blower</td>
<td>6,3</td>
<td></td>
<td>3,27</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>33,75</td>
</tr>
</tbody>
</table>

The same research was done for Gemany where water is more expensive.

$^{41}$ http://www.cenapradu.strefa.pl/
In Germany, 16,8 pln\textsuperscript{42,43} cost water and waste water together. By using similar calculations as before and data from Table 28, 1226.4 pln can be saved each year on a water bill.

It means that this investment in Gemany will pay off after 12 years. At this time only once the filter needs to be changed, so with all other costs approximately 15 years is needed to pay back.

Table 28 - Yearly energy cost usage of the system in Germany

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Consumption (kWh)</th>
<th>Price For kWh (pln)</th>
<th>Price(Pln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer pump</td>
<td>34,12</td>
<td>1,2\textsuperscript{44}</td>
<td>41</td>
</tr>
<tr>
<td>Cleaning filter pump</td>
<td>24,5</td>
<td></td>
<td>29,4</td>
</tr>
<tr>
<td>Blower</td>
<td>6,3</td>
<td></td>
<td>7,6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>78</strong></td>
<td></td>
</tr>
</tbody>
</table>

5.1.3 Competitors

There are few companies which are strong in Polish water solution market and they will be presented below.

1. Rewatec\textsuperscript{45}

Rewatec is a German company which has mostly rainwater systems. In a website, there can be found two setups.

- BlueLine II – tank shape is shown in Figure 19

\textsuperscript{42} https://www.landsbankinn.is/

\textsuperscript{43} http://www.spangdahlem.af.mil/library/factsheets/factsheet.asp?id=21623

\textsuperscript{44} http://www.germanenergyblog.de/

\textsuperscript{45} "http://www.rewatec.de/
Figure 19 – Classic cylindrical tank\textsuperscript{46}

- F-LINE - tank shape is shown in Figure 20

Figure 20 – Horizontal tank\textsuperscript{47}

In Figure 21 there are listed key components of the system.

\textsuperscript{46} http://www.rewatec.de/

\textsuperscript{47} http://www.rewatec.de/index.php?cat=41
Those systems are working in a similar way difference lays between tanks. Cost of the cheapest on is approximately 1500$.

2. Intewa

Intewa is a German company which has variety of systems for grey and rainwater recycling. Their grey water system consists of few components listed below:

- AQUALOOP- pre-filter
- AQUALOOP- growth bodies
- AQUALOOP- membranstation with system control
- AQUALOOP- membranes
- AQUALOOP- blowers

---

48 Blueline-diver-use-guide.pdf
49 "http://www.intewa.de/en/products/aqualoop/,"
There are viewed on Figure 22

![Diagram of Intewa Rainwater shower system]

1. PURAIN filter DN100 with skimmer and non-return valve
2. PLURAFIT inlet calmer DN100
3. Submersible Pump up to 130 Liter/min, Hmax 6 m
4. 10 m HORIZON suction hose 1”
5. Wall bushing DN 100
6. Floating switch incl. Plug
7. AQUALOOP Membran
8. AQUALOOP membrane station and control unit
9. 2x AQUALOOP Tank 350 L separate with the lid
10. Floating suction with coarse filter 1”
11. 3 m SDS suction hose 1”
12. RAINMASTER Favorit 20 speed control
13. Expansion vessel 5 litre

Figure 22 – Intewa Rainwater shower system

Approximately cost of one system is: 6000$

3. Rainwater Harvesting

Rainwater Harvesting is a company placed in the United Kingdom they are specialized in rainwater harvesting systems. Depend on tank volume the price for the cheapest system is 3000$. Components of this system are viewed in the Figure 23.

---

50 pricelist_products_03_2015_01.pdf

51 "http://www.rainwaterharvesting.co.uk"
Figure 23 – Rainwater- Rain director system

52 Rain-director-install.pdf
In Table 29, there are shown prices and ways of how systems work. Even though presented system connects two systems, still price of the setup is competitive. The next advantage over competitors is gravity feeding, which protects pump from quick wear, and saves money on electricity.

Table 29 – Price and components comparison between systems

<table>
<thead>
<tr>
<th>Pump</th>
<th>tank</th>
<th>Control system</th>
<th>Water transfer</th>
<th>Price (pln)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rewatec Rainwater harvesting</strong></td>
<td>Submersible</td>
<td>1</td>
<td>Floating switch controls pump</td>
<td>5540</td>
</tr>
<tr>
<td><strong>Intewa rain water</strong></td>
<td>Submersible</td>
<td>3</td>
<td>Control Unit</td>
<td>22162</td>
</tr>
<tr>
<td><strong>Rainwater Harvesting</strong></td>
<td>Submersible</td>
<td>2</td>
<td>Control Unit</td>
<td>11000</td>
</tr>
<tr>
<td><strong>Propose system grey and rainwater</strong></td>
<td>Peripheral</td>
<td>2</td>
<td>Control Unit</td>
<td>14126</td>
</tr>
</tbody>
</table>

### 5.1.4 Certifications

By following companies, which are selling water recycling systems in Poland important information were found. Setup described in this document contains components which have certifications. Nevertheless system as a whole needs to have certification from Instytut Techniki Budowlanej\(^{54}\). By contacting accreditation department the price for such document were given. Of course the real price could not be achieved because system does not exist yet but the prices starts from 2777$ up to 9000$

Poland is a member of European Union and because the components of this system will be ordered from EU countries there is no need for duties documentations. Another important fact is that certifications given by European Union are easily accredited by Polish institutions.

---

\(^{53}\) Exchange made in landsbanki.is at 13.09.2015

\(^{54}\) http://www.itb.pl/aprobaty/aprobaty-techniczne-15
6 Future developments

The future developments are listed below. To see progress in the project, it is necessary to:

- transfer existing setup from Arduino board to microcontroller,
- create electric diagrams and build electric circuit to control valves and pumps via microcontroller,
- design way of taking the impurities from the lower tank,
- build small scale model for better understanding the system behave,
- additional function for the time when users are not at home to circulate water in the system,
- additional valve may be needed in the system to distinguish between grey water transfer and rainwater transfer,
- design of a filter fixing,
7 Conclusions

Firstly, it is good to mention that feasibility study shows that the product is competitive with solutions existing on the Polish market. Thanks to the different approach and filtration system based on the C-mem module, the price of the system is concurrence. Unfortunately, for 200 liters of water usage per day, in Poland pay back for the system is very long, around 50 years. The situation looks different in Germany, where this investment will be back after 15 years.

Secondly, it was good decision to build prototype board for simulation. Simulations made on the prototype board shows that the software works well.

Design control system meets the requirements and it helps to keep efficiency of the whole setup. Water transferred only once or twice a day decreasing pump wear and increase energy efficiency.

Hardware choice was done with specifications for each particular part of the system and it looks that this process has been done correctly. It includes good prices from the suppliers as well as energy efficiency.
8 References


[19] "PN-EN 1717 Ochrona przed wtórnym zanieczyszczeniem wody w instalacjach wodociągowych i ogólne wymagania dotyczące urządzeń zapobiegających zanieczyszczeniu przez przepływ zwrotny".


[22] "PN-ENV 1046:2007 Systemy przewodów rurowych z tworzyw sztucznych -- Systemy poza konstrukcjami budynków do przesyłania wody lub ścieków -- Praktyka instalowania pod ziemią i nad ziemią".

Appendix A  Pumps specifications

Figure 24 – PKm60 specifications\textsuperscript{55}

\textsuperscript{55} http://malec-pompy.pl
Figure 25 – SpidAMX 50 specification\textsuperscript{56}

\textsuperscript{56} http://www.lenntech.com
## Appendix B Requirements

**Table 30 – Project requirements**

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Requirements for this particular project</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Location of the building</td>
<td>Poland Lodz</td>
</tr>
<tr>
<td>2. Surface of the roof</td>
<td>200 m²</td>
</tr>
<tr>
<td>3. Type of the building</td>
<td>Family house</td>
</tr>
<tr>
<td>4. Material of the roof</td>
<td>Ceramic roof tiles</td>
</tr>
<tr>
<td>5. Inclination of the roof</td>
<td>Incline</td>
</tr>
<tr>
<td>6. Load of surface above tank</td>
<td>Car and pedestrian</td>
</tr>
<tr>
<td>7. Overflow connection from the tank</td>
<td>Sewage</td>
</tr>
<tr>
<td>8. Type of the clay up to depth of the tank</td>
<td>Medium sand</td>
</tr>
<tr>
<td>9. Earth water level</td>
<td>Above tank</td>
</tr>
<tr>
<td>10. Purposes of the usage of water</td>
<td>Garden and House</td>
</tr>
</tbody>
</table>

### Suction pipe line

<table>
<thead>
<tr>
<th>11. Horizontal length between underground tank and pumps</th>
<th>a =3m</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. Vertical length between bottom of the underground tank and pumps</td>
<td>h1=2.2m</td>
</tr>
<tr>
<td>13. Depth set of suction pipe</td>
<td>h2=0.4m</td>
</tr>
<tr>
<td>14. Material of pipes</td>
<td>Plastic isolated</td>
</tr>
<tr>
<td>15. Suction pipe dimension</td>
<td>1 ″</td>
</tr>
</tbody>
</table>

### Pressing pipe line

<p>| 16. Horizontal length between pump and the furthest water inlet | b=13.5m |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Vertical length between pump and the furthest water inlet</td>
<td>h3=4m</td>
</tr>
<tr>
<td>18. Pressing pipe dimension</td>
<td>1˝</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Additional information</strong></td>
<td></td>
</tr>
<tr>
<td>19. Number of family members</td>
<td>4</td>
</tr>
<tr>
<td>20. Number of toilets</td>
<td>2</td>
</tr>
<tr>
<td>21. Number of washing machines</td>
<td>1</td>
</tr>
<tr>
<td>19. Number of sinks</td>
<td>4</td>
</tr>
<tr>
<td>20. Number of valves</td>
<td>2 valves - ¾˝</td>
</tr>
<tr>
<td>21. Size of washing surface</td>
<td>50 m²</td>
</tr>
<tr>
<td>22. Size of the garden</td>
<td>300m²</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fully automatic</td>
</tr>
<tr>
<td></td>
<td>Gravity feeding</td>
</tr>
<tr>
<td></td>
<td>Cheap</td>
</tr>
</tbody>
</table>
Hello Roland.

My name is Artur Matusiak.

According to our conversation earlier today I would like to ask you few questions.

1. What are the dimensions of inlets?

   1 ¼” top and bottom

2. Can the filter be cleaned just by back-flow of the clean water without using air?

   Yes, but this is only applicable for low polluted water, like rain water. For grey water a combined cleaning of backwash and air is recommended.

3. Grey water contains water from washing machines - are the chemicals contain in the waste water can damage the membranes?

   The materials which are used for the cartridge are highly resistant against low and high pH, as well as oxidative chemicals. In our experience there should be no problem with grey water from washing machines.

   However, in order to confirm officially we would need the names of the chemicals used so that we can recheck the material database.

4. For how long approximately the filter can be used?

   Lifetime is up to 10 years depending on operation and raw water.

5. Is there any guaranty for the cartridge?

   2 years.
6. Around 100 liters of water needs to be pump out each time it is needed. Is it necessary to use vacuum pump? Can I use just regular one?

We would suggest a small clear water tank with a capacity of 100 L where the treated water will be collected. For the treatment system it will be better to treat the water more equally and not in short intervals.

A suitable pump would be included in the Intewa package.

Regards Artur Matusiak
Appendix D  Code

Main process

```c
void MainProcess()
{
    sensorValue1 = analogRead(analogInPin0);
    outputValue1 = map(sensorValue1, 0, 1023, 0, 100);
    sensorValue2 = analogRead(analogInPin1);
    outputValue2 = map(sensorValue2, 0, 1023, 0, 100);
    if(outputValue1>95 && outputValue2>95)
    {
        digitalWrite(8,HIGH);
        digitalWrite(7,LOW);
        digitalWrite(A5,LOW);
        digitalWrite(9,LOW);
    }
    else if ((outputValue1<80 && outputValue1>50) && outputValue2>95)
    {
        digitalWrite(8,LOW);
        digitalWrite(7,LOW);
        digitalWrite(A5,LOW);
        digitalWrite(9,LOW);
    }
    else if ((outputValue1<80 && outputValue1>50) && outputValue2<20)
    {
        digitalWrite(7,HIGH);
        digitalWrite(8,HIGH);
        digitalWrite(A5,LOW);
        digitalWrite(9,LOW);
    }
    else if ((outputValue1<80 && outputValue1>50) && outputValue2<5)
    {
        digitalWrite(8,HIGH);
        digitalWrite(7,HIGH);
        digitalWrite(A5,LOW);
        digitalWrite(9,LOW);
    }
    else if (outputValue1<50 && outputValue2<5)
    {
        digitalWrite(A5,HIGH);
        digitalWrite(8,LOW);
        digitalWrite(9,HIGH);
    }
    else if (outputValue1<50 && outputValue2>55)
    {
        digitalWrite(A5,LOW);
        digitalWrite(8,LOW);
        digitalWrite(9,LOW);
    }
}
```
Chlorine cleaning process

```c
void ChlorineCleaningProcess()
{
    sensorValue1 = analogRead(analogInPin0);
    outputValue1 = map(sensorValue1, 0, 1023, 0, 100);
    sensorValue2 = analogRead(analogInPin1);
    outputValue2 = map(sensorValue2, 0, 1023, 0, 100);

    // emptying tanks
    if (outputValue1 > 95 && outputValue2 > 95)
    {
        digitalWrite(6, HIGH);
        digitalWrite(7, LOW);
        digitalWrite(A5, LOW);
        digitalWrite(6, LOW);
    }
    else if (outputValue1 <= 80 && outputValue2 > 95)
    {
        digitalWrite(0, HIGH);
        digitalWrite(7, LOW);
        digitalWrite(6, HIGH);
    }
    else if (outputValue1 <= 80 && outputValue2 > 5)
    {
        digitalWrite(0, HIGH);
        digitalWrite(7, LOW);
        digitalWrite(6, LOW);
    }
    else if (outputValue1 <= 5 && outputValue2 < 5)
    {
        digitalWrite(0, LOW);
        digitalWrite(7, LOW);
        digitalWrite(6, LOW);
        digitalWrite(A5, LOW);
    }
}
```
Sensor indicators

```cpp
void sensor1() // basement tank water level
{
    sensorValue1 = analogRead(analogInPin0);
    outputValue1 = map(sensorValue1, 0, 1023, 0, 100);

    if(outputValue1<10)
        digitalWrite(12, LOW);

    if(outputValue1>90)
        digitalWrite(13, HIGH);
}

void sensor2() // roof tank water level
{
    sensorValue2= analogRead(analogInPin1);
    outputValue2= map(sensorValue2, 0, 1023, 0, 100);

    if(outputValue2<10)
        digitalWrite(10, LOW);

    if(outputValue2>90)
        digitalWrite(10, HIGH);
}
```
Buttons code implementation

```c
int button1( int &SwitchCase)
{
    int buttonState1 = 0;
    int buttonState2 = 0;
    // read the state of the pushbutton value:
    buttonState1 = digitalRead(buttonPin1);
    buttonState2 = digitalRead(buttonPin2);
    // check if the pushbutton is pressed.
    // if it is, the buttonState is HIGH:
    if (buttonState1 == LOW && buttonState2 == HIGH) {
        delay(40);
        std::string s1;
        // turn LED on:
        digitalWrite(ledPin1, s1);
        while(buttonState1 == LOW && buttonState2==HIGH)
        {
            buttonState2 = digitalRead(buttonPin2);
            buttonState1 = digitalRead(buttonPin1);
        }
        delay(40);
        return SwiichCase=1;
    }
}

int button2( int &SwitchCase)
{
    int buttonState2 = 0;
    int buttonState1=0;
    // read the state of the pushbutton value:
    buttonState2 = digitalRead(buttonPin2);
    buttonState1 = digitalRead(buttonPin1);
    // check if the pushbutton is pressed.
    // if it is, the buttonState is HIGH:
    if (buttonState2 == LOW && buttonState1==HIGH) {
        delay(40);
        std::string s2;
        // turn LED on:
        digitalWrite(ledPin2, s2);
        while(buttonState2 == LOW && buttonState1==HIGH)
        {[
            buttonState1 = digitalRead(buttonPin1);
            buttonState2 = digitalRead(buttonPin2);
        }
        delay(40);
        led.clear();
        return SwitchCase = 2;
    }
}

int TwoButtonsPressed( int &SwitchCase)
{
    int buttonState1 = 0;
    int buttonState2 = 0;
    buttonState1 = digitalRead(buttonPin1);
    buttonState2 = digitalRead(buttonPin2);
    if (buttonState2 == LOW && buttonState1==LOW)
        return SwitchCase=3;
```
void setup() {
  lcd.begin(16, 2);
  lcd.print("Final Project!");
  Serial.begin(9600);
  pinMode(ledPin1, OUTPUT);
  // initialize the pushbutton pin as an input:
  pinMode(buttonPin1, INPUT_PULLUP);
  pinMode(ledPin2, OUTPUT);
  pinMode(buttonPin2, INPUT_PULLUP);
  pinMode(A5, OUTPUT);
  pinMode(A4, OUTPUT);
}

void loop() {
  delay(40);
  lcd.clear();
  sensor1();
  sensor2();
  button1(SwitchCase);
  button2(SwitchCase);
  TwoButtonsPressed(SwitchCase);

  switch(SwitchCase) {
    case 0:
      MainProcess();
      lcd.print("Final Project!");
      break;

    case 1:
      lcd.print("Water level1: ");
      lcd.print(sensorValue1/10);
      lcd.setCursor(0, 1);
      lcd.print("Water level2: ");
      lcd.print(sensorValue2/10);
      MainProcess();
      break;

    case 2:
      lcd.print("Final Project!");
      break;

    case 3:
      ChlorineCleaningProcess();
      lcd.print("chlorination");
      break;
  }
}
Appendix E  Arduino specifications

Table 31 – Arduino specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>ATmega328</td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>5V</td>
</tr>
<tr>
<td>Input Voltage (recommended)</td>
<td>7-12V</td>
</tr>
<tr>
<td>Input Voltage (limits)</td>
<td>6-20V</td>
</tr>
<tr>
<td>Digital I/O Pins</td>
<td>14 (of which 6 provide PWM output)</td>
</tr>
<tr>
<td>Analog Input Pins</td>
<td>6</td>
</tr>
<tr>
<td>DC Current per I/O Pin</td>
<td>40 mA</td>
</tr>
<tr>
<td>DC Current for 3.3V Pin</td>
<td>50 mA</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>32 KB (ATmega328) of which 0.5 KB used by bootloader</td>
</tr>
<tr>
<td>SRAM</td>
<td>2 KB (ATmega328)</td>
</tr>
<tr>
<td>EEPROM</td>
<td>1 KB (ATmega328)</td>
</tr>
<tr>
<td>Clock Speed</td>
<td>16 MHz</td>
</tr>
<tr>
<td>Length</td>
<td>68.6 mm</td>
</tr>
<tr>
<td>Width</td>
<td>53.4 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>25 g</td>
</tr>
</tbody>
</table>
Appendix F – C–mem filter specifications

Submerged Hollow Fibre Filtration Cartridges for Water and Wastewater Treatment

<table>
<thead>
<tr>
<th>VERSION</th>
<th>PRODUCT DESCRIPTION</th>
<th>April 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C-MEM hollow fibre:</td>
<td>PE (110-440 µ, 740 mm +/- 15 mm, 1600 - 2000 fibres)</td>
</tr>
<tr>
<td></td>
<td>Membrane Chemistry:</td>
<td>PE reinforced / PP reinforced / U-PVC / ABS</td>
</tr>
<tr>
<td></td>
<td>Housing Shell / End Caps:</td>
<td>U-PVC / SS 1.4301 (304)</td>
</tr>
<tr>
<td></td>
<td>Permeate Collection Tube:</td>
<td>Proprietary epoxy compound</td>
</tr>
<tr>
<td></td>
<td>Potting Material:</td>
<td>Hollow fibre</td>
</tr>
<tr>
<td></td>
<td>Membrane Construction:</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Antifouling:</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Pre-Wetting:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRODUCT SPECIFICATION</th>
<th>C-MEM Model</th>
<th>Flow Range (l/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 m³</td>
<td>15 – 300</td>
<td></td>
</tr>
<tr>
<td>6 m³</td>
<td>30 – 600</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPERATING &amp; DESIGN INFORMATION</th>
<th>Maximum Pressure (water): 3 bar 40°C</th>
<th>Temperature Range: 0°C to 40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Production Transmembrane Pressure:</td>
<td>0.7 bar</td>
<td></td>
</tr>
<tr>
<td>Maximum Backflush Transmembrane Pressure:</td>
<td>2.5 bar</td>
<td></td>
</tr>
<tr>
<td>Maximum Free Chlorine @ 25°C (77°F) or lower:</td>
<td>5000 ppm @ 8.5 pH during intermittent chemical backwash</td>
<td></td>
</tr>
<tr>
<td>Maximum Total Chlorine Contact:</td>
<td>1.0 Nlc ppm – hrs cumulative</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRODUCT DIMENSIONS</th>
<th>Model</th>
<th>Fiber Diameter (ID)</th>
<th>Membrane Area [mm²]</th>
<th>D (mm)</th>
<th>H (mm)</th>
<th>Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C-MEM</td>
<td>0.41 – 0.44 mm</td>
<td></td>
<td>164</td>
<td>410</td>
<td>1 ½”</td>
</tr>
</tbody>
</table>

Figure 26 – C mem filter specifications
Appendix G – Report Plan Schedule

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Control system</td>
<td>Thu 1.1.15</td>
<td>Sun 19.4.15</td>
<td>100%</td>
<td>0%</td>
<td>109 days</td>
</tr>
<tr>
<td>start</td>
<td>Thu 1.1.15</td>
<td>Fri 2.1.15</td>
<td>100%</td>
<td>0%</td>
<td>1 day</td>
</tr>
<tr>
<td>flow chart</td>
<td>Thu 1.1.15</td>
<td>Sun 29.3.15</td>
<td>100%</td>
<td>0%</td>
<td>8 days</td>
</tr>
<tr>
<td>programing</td>
<td>Sat 3.1.15</td>
<td>Sun 19.4.15</td>
<td>100%</td>
<td>0%</td>
<td>61 days</td>
</tr>
<tr>
<td>bread board prototype</td>
<td>Sat 3.1.15</td>
<td>Mon 2.3.15</td>
<td>100%</td>
<td>0%</td>
<td>14 days</td>
</tr>
<tr>
<td>testing</td>
<td>Thu 12.2.15</td>
<td>Tue 3.3.15</td>
<td>100%</td>
<td>0%</td>
<td>20 days</td>
</tr>
<tr>
<td>Design</td>
<td>Sun 29.3.15</td>
<td>Thu 24.9.15</td>
<td>100%</td>
<td>0%</td>
<td>144 days</td>
</tr>
<tr>
<td>choice of hardware</td>
<td>Sun 29.3.15</td>
<td>Fri 10.4.15</td>
<td>100%</td>
<td>0%</td>
<td>13 days</td>
</tr>
<tr>
<td>drawings</td>
<td>Sun 29.3.15</td>
<td>Thu 10.9.15</td>
<td>100%</td>
<td>0%</td>
<td>71 days</td>
</tr>
<tr>
<td>prototype model building</td>
<td>Sun 29.3.15</td>
<td>Sat 18.4.15</td>
<td>100%</td>
<td>0%</td>
<td>21 days</td>
</tr>
<tr>
<td>documentation</td>
<td>Sun 29.3.15</td>
<td>Thu 24.9.15</td>
<td>100%</td>
<td>0%</td>
<td>144 days</td>
</tr>
<tr>
<td>finish</td>
<td>Thu 24.5.15</td>
<td>Thu 24.9.15</td>
<td>100%</td>
<td>0%</td>
<td>1 day</td>
</tr>
</tbody>
</table>

Figure 27 Plan schedule