Appendix A: Water Quality

1. Water Contamination

Water contamination can happen in very different ways and at different moments in the Water-Journey. Developing a solution that can tackle all these situations is a challenging a hard to fulfil functionality.

Before the water reaches the water taps, the water is treated by the AAWAS and often safe to drink. Contamination of the water is not only become a health issue, but is also a waste of resources spent by the AAWAS. Preventing recontamination is therefore a valuable approach to keeping the water safe for consumption. Within prevention two different approaches can be taken; impeding and informing.

Impeding (recontamination)

Even for the most important tool used in the journey, the water container, there is an ongoing discussion, between experts, on the design of storage containers. Some say that containers with a narrow opening (such as the jerrycans have) reduce the risk of contamination. Others say that preventing contamination is not possible, and using a container with a wide opening is easier to clean (reducing the risk of using a contaminated container). Wide-opening containers require a utensil to retrieve the water, however, 62% of the people do not use utensils with a handle. This means that dirty hands come into contact with the water, thereby contaminating it (Adane et al., 2017).

Not having clear guidelines determining as to what a container should comply to impede (re)contamination makes it impossible to design a solution for this approach without first having to perform extensive field research.

As illustrated by the many steps in the water journey, a technical solution to impede contamination has to cover many scenarios. Each step has its own challenges making it hard to design a solution that works is all those situations.

Informing & Incentivising

Informing people about water contamination and educating them on their hygiene can have substantial effects (Preventing Recontamination, 2019). It is important to realise that people do already take precautions to prevent contamination of the water. They use separate containers for drinking water, they usually rinse the containers with soap once every (other) week, and so on. However, this is not enough to ensure safe drinking water (O. de Gruijter, 2021 & Adane et al., 2017).

The efficacy of this approach is heavily dependent on the users themselves, and how well they perform certain tasks (such as washing hands). Informing people on how to do these things is only the first step, actually executing these correctly afterwards is subject to the users'. That means that this approach doesn't maintain control of the outcome throughout the process, and the effectiveness depends on people's responsibility.

2. WHO Guidelines

The WHO uses two parameters to determine the safety of water; the E. coli CFU concentration and the risk score of the water source tested. These two combined give the likeliness of the water being contaminated and the level of contamination. In the table below you can see how these relate to each other.

World Health Organization (WHO) Guidelines for Drinking Water Quality, Table 5.4, Fourth Edition, 2017

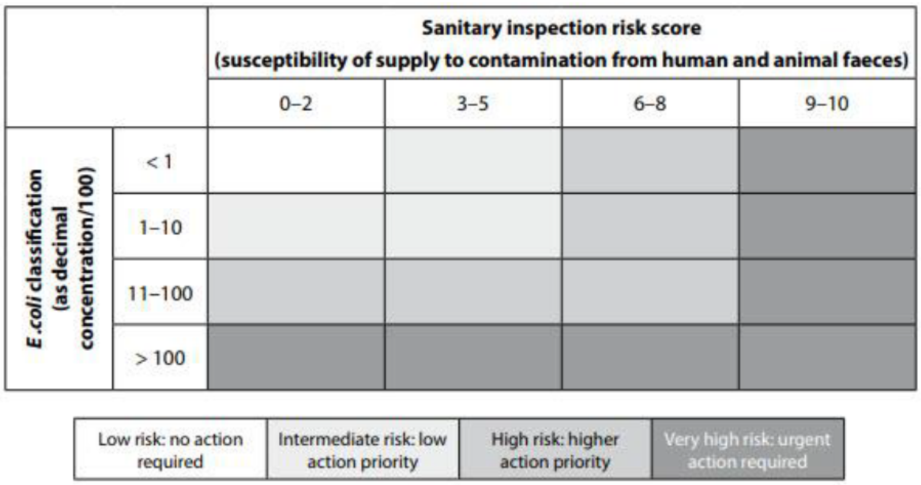


TABLE A3-3 — Content of Toxic and/or Disease-causing Substances in Drinking Water

Substance or characteristic[1]	**Maximum permissible level**
Barium (Ba) mg/L	0.7
Total mercury (Hg) mg/L	0.001
Cadmium (Cd) mg/L	0.003
Arsenic (As) mg/L	0.01
Cyanide (CN) mg/L	0.07
Nitrate (NO_3) mg/L	3
Lead (Pb) mg/L	0.01
Boron (B) mg/L	0.3
Selenium (Se) mg/L	0.01
Fluoride (F) mg/L	1.5
Chromium (Cr) mg/L	0.05

[1]For other parameters, see CES-58, Ethiopian Standards Agency 2013.

Bacteriological requirements: when tested the bacteriological requirements of treated drinking water must not exceed the levels shown in Table A3-4.

TABLE A3-4 — Bacteriological levels

Organism	**Maximum permissible level**
Total viable organisms, colonies per mL	Must not be detectable
Fecal streptococci per 100 mL	Must not be detectable
Coliform organisms, number per 100 mL	Must not be detectable
E. coli, number per 100 mL	Must not be detectable

3. AAWAS Guidelines

The AAWAS not only handles the organic contamination of the water but also looks at the other physical and chemical concentrations in the water. In the tables below, all the permissible levels for different types of contaminants in the water are mentioned.

TABLE A3-1 — Physical Characteristics of Drinking Water

Characteristics	Maximum permissible level
Odor	Unobjectionable
Taste	Unobjectionable
Turbidity, NTU	5
Color, TCU	15

Chemical requirements (CES-58):

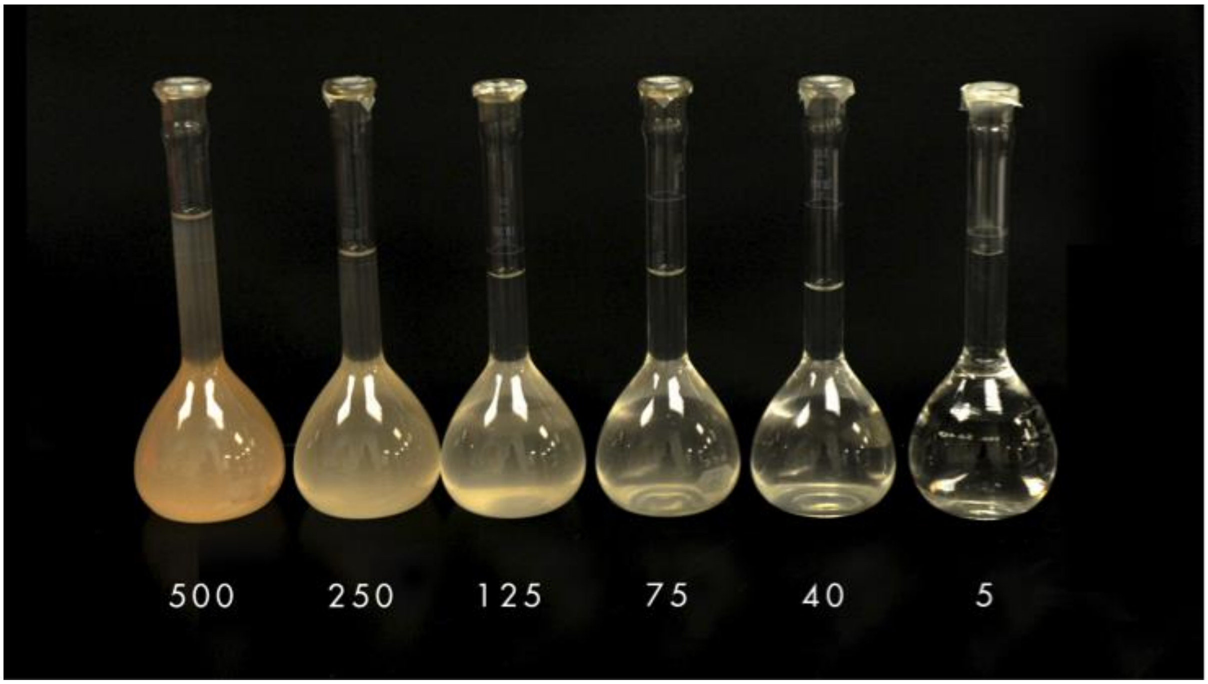
Palatability properties: characteristics that affect the palatability of water must conform to the levels specified in Table A3-2.

TABLE A3-2 — Characteristics that Affect the Palatability of Drinking Water

Substance or characteristic	Maximum permissible level
Total hardness ($CaCO_3$)	300
Total dissolved solids mg/Ll	1,000
Total Iron (Fe) mg/L	0.3
Manganese (Mn) mg/L	0.5
Ammonia (NH_3+NH_4+) mg/L	1.5
Residual free chlorine mg/L	0.5
Magnesium (Mg) mg/L	50
Calcium (Ca) mg/L	75
Copper (Cu) mg/L	2
Zinc (Zn) mg/L	5
Sulfate (SO_4) mg/L	250
Chloride (Cl) mg/L	250
Total alkalinity ($CaCO_3$) mg/L	200
Sodium (Na) mg/L	200
Potassium(k) mg/L	1.5
pH value, units	6.5 to 8.5 (permissible range)
Aluminum (Al) mg/L	0.2

NTU

The Nephelometric Turbidity Unit is an indicator of the water's turbidity, which indicates the cleanliness of the water. Research found that the more turbid the water is, the more likely it contains pathogens. It also means that the water will contain more particles, making it sometimes harder for water treatment methods to work efficiently, such as clogging up filters. In the case of piped water, this does not represent an essential factor since almost all piped water has an NTU value of 5 or less, which is considered clear; see the figure for an example of this.



Appendix B: Peri-urban households

Most people in the peri-urban context live in relatively simple houses that consist of not more than 1 or 2 rooms (Issa, 2021). These are typically hand-built with a basic structure and materials. In figures 9 and 11, examples of these houses are shown.

These homes house families of 3 to 4 people (Bureau of Finance and Economic Development, 2013). Having no more than two rooms at their disposal, these rooms have to fulfil different functions at different times of the day. This means that furniture and objects need to be quickly movable to accommodate new functions of the room. In these homes usually, the parents live with two children, which are between 5-and 10 years of age.

Around 50% of the households of Addis Ababa live under the poverty line determined by the UN, less than $2/day. Most of the population (in Addis Ababa) works in the informal sector, responsible for approximately 60% of the economy (UN-Habitat, 2011). People working in this sector have a median income per household of around $100/month (Alemayehu, 2008).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Appendix D: Water Treatment Methods

1. Existing Methods

1.1 Sedimentation

Sedimentation is the process wherein the turbidity of the water is let sink to the bottom of the container easing the process of filtration and improving the overall water quality. This method however does not remove alle turbidity or pathogens. It is however a very cheap and simple method to improve water quality. There are different solutions that rely on this same principle.

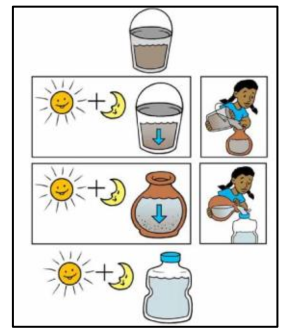

Figure 1The process of pot setting

1.1.1 Pot Setting

This method relies on preferably multiple containers in which the water is stored for a longer period of time, to allow the turbidity to settle. Each day the water is poured from one container to the other (while ensuring not to pour the sediment). Doing this with multiple containers will ensure a better process and quality of water (see figure 1).

1.1.2 Coagulation & Flocculation

Coagulation & flocculation relies on the same principle of pot setting, only using some substances to speed up the process and improve its effect. Powder contained in a satchel will bind most of the turbidity in the water making it sink faster. This process takes around 30min for a jerrycan (much faster than with pot setting), a second advantage is that all the sedimentation is bound together by the added substance making it easier to remove from the water. In many cases, the coagulant is mixed with a disinfectant ensuring that all pathogens are killed or inactivated making the water even safer to drink. Adding the disinfectant also improves the timespan the water can be stored safely.

1.2 Disinfection

As already shortly discussed, disinfection is a method that specifically targets pathogens in the water. An important factor to consider is that turbid water is harder to disinfect than clear water, all the particles in the water make it harder for the disinfectant to effectively target the pathogens.

1.2.1 Chlorine

Disinfection is achieved most of the time through chlorine. It is easy to use and widely available in most countries (OpenWASH, 2016). After adding the chlorine, it takes around 30 minutes before the water is safely drinkable, but also ensures protection against recontamination in the short term (Bipin Dangol (ENPHO) & Dorothee Spuhler (GMBH), n.d.). It is effective against algal growth, bacteria and viruses. Almost all pathogenic bacteria are as effectively treatable with chlorine as E. Coli. Viruses on the other hand have shown to be more resistant to chlorination.

Figure 2 Liquid chlorine disinfection

A guideline for requirement of the disinfected water set up by the WHO says; virus-free water can be obtained from a faecal polluted source water if the following requirements are met:

- Turbidity lower than 1NTU
- pH lower than 8
- Add chlorine 30minutes before drinking
- If at least 0.5mg/L residual free chlorine can be achieved after 30min

Protozoa are even more resistant to chlorine that viruses and therefore chlorination is not considered an effective mean against protozoa. To properly address this chlorination should be combined with other water treatment solutions (*Effectiveness on Pathogens, CDC*, 2021).

A second disadvantage of chlorination as a disinfection method is the chemical taste the water gets, it is considered unpleasant and therefore other methods are often considered preferrable if the water is not treated after disinfection (van Dooren, 2021).

1.2.2 SODIS

Is a method that relies on the UV-light from the sun to sterilize the water. Water is collected in clear plastic bottles with a max. volume of around 2L to ensure maximum efficiency. However, it still takes around 6 hours on a sunny day and 2 days with cloudy weather (Pooi & Ng, 2018). An advantage of this method is that it requires no actual effort and is free of costs (assuming one has plastic bottles) (CDC, 2012).

Figure 3 The process of SODIS, exposing water to UV-light from the sun

1.2.3 Boiling

Boiling of the water for disinfection is a widely practiced method in all different communities. It is important to consider that the water needs to be boiled with a rolling boil to ensure effective pathogen inactivation (WHO, 2007). A rolling boil is that state of boiling wherein the water is vigorous and lots of bubbles come up. The main disadvantage of boiling however is the need for fuel (wood, gas, gasoline) which often makes this method, in the long term, more expensive than others (Bipin Dangol (ENPHO) & Dorothee Spuhler (GMBH), n.d.).

These methods however do not improve the taste and odour properties of the water, and in the case of chlorine make it even worse. Therefore, these solutions are mostly seen in bottom of the pyramid (BoP) households and communities, as soon as people have a little more to spend, they switch to different water treatment solutions.

1.3 Filtration

1.3.1 Biosand Filtration

Biosand filtration (BSF) relies on the sample principle of sand filters but has a higher faucet than the sand layer. This makes it possible to grow biofilm of microbes around the sand that effectively removes microorganisms, colloids and other contaminants. In fully operational filters there is up to a 98% removal rate of E. Coli. Building such a BSF requires some knowledge but can be done with locally sourced materials. Although water filtered by the BSF does not meet the WHO standards it improves the water quality and reduces the risks of diseases such as diarrhoea (Jenkins & Tiwari, 2010).

Figure 4 Biosand filter section view

1.3.2 Ceramic Filter

A second filtration method that is used in SSA, is filtration through ceramic filters coated with silver. The purifying element in these filters it the ceramic filter (often called a candle). These candles are slightly porous and thereby filter out particles, if the pores are sufficiently small, they can also remove pathogens. Often these candles are impregnated with silver to kill microorganisms (Whitby, 2020). Since the pores on these ceramic candles are small, even when they are not developed for pathogen filtering, they can clog up pretty quickly and therefore are not suitable for turbid water (WELL, 1999).

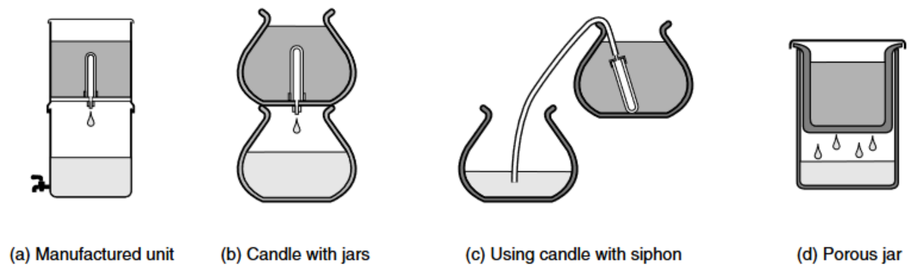

Figure 5. Ceramic filters

Figure 5 Various types of ceramic filters

1.3.3 Cloth Filtration

One of the most basic methods and not suitable to be used as a standalone solution. It is often used in combination with coagulants or sedimentation to remove the particles more easily from the water when it is poured into a clean container.

Figure 6 Cloth Filtration

2. Alternative Methods

Besides the just discussed methods, there are many other to treat water. Currently most of these other methods are not used in the context of SSA. Most of the methods that will be discussed here are commonly used in more developed societies.

2.1 Reverse Osmosis

This method relies on semi-porous membranes that only lets the water molecules pass. The osmosis process which would naturally occur is countered and reversed through pressure, the concentrated water (with pathogens, minerals, chemical, etc.) is pushed through the membrane under pressure. This membrane only lets water molecules pass. For a household solution however, this is not a very effective system. Because of the relatively low pressure that can be achieved in comparison to professional plants. In research from the NDSU (1991), it is shown that reverse osmosis only recovers between 5-15% of water entering the system. Since 1991 there have obviously been many technological advances in this area but even now, still 45-60% of water is discarded (Wikipedia contributors, 2021).

2.2 Filtration

An advantage of filters over many other methods is that the water output will always have the same quality, no matter the feed quality. Thereby also removing the need for chemicals.

2.2.1 Activated Carbon (AC)

Active carbon filters are mostly used in water filters to improve the waters sensory qualities, such as odour, taste and colour. In addition, it also removes some toxics such as chlorine (Norwicki, 2016). Activated carbon is a very porous material, this gives it a large surface area to remove contaminants. These contaminants are removed from the water through adsorption, wherein the contaminates stick to the surface area of the activated carbon.

There are two different types of activated carbon filtration methods possible: GAC and PAC filets. GAC-filters are activated carbon filters that contain granules that are loosely held together by a container or cartridge. PAC-filters have smaller particles and stands for powdered activated carbon, often these are compressed in a certain shape (also known as blocks) and consists of many smaller particles. They have very similar properties but differ on some minor application details. PAC-filters have better properties than GAC filters when it comes down to filtering contaminants due to the smaller particle size, often 5 to 20 times smaller (*The Difference Between Granular Activated Carbon and Activated Carbon Block Water Filters*, 2018). If these carbon blocks are properly designed, they are able to trap contaminates up to 3 microns in size (Mukherjee, 2018). These types of filters need to be frequently changed, within 6 months to 1 year (Campbell, 2021). This is when these are used in western countries to filter tap water. When considering the context of peri-urban Addis Ababa water sources the lifespan might even be shorter.

GAC filters, due to the loosely placed particles, make it possible to maintain a much higher flow rate of the water throughout the filter. The water finds the path of the least resistance and therefore also passes between the granules and thus does not optimally use the filtration capacities. In addition, there is a higher chance of microbial growth in this type of filters (Mukherjee, 2018). An advantage GAC has over PAC is that these filters can easily be regenerated and therefore last longer (Soni et al., 2020).

AC filters can be used for dichlorination of water. GAC used for dichlorination is not suitable for reactivation as it becomes weak in this service and breaks down during reactivation. (Brandt et al., 2017)

2.2.2 Particle Filters

Particle filters can be classified into 3 categories: microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF). These stand for different pore sizes of the filters, determining what can and cannot pass the filter (see figure 7). It should be noted though, that MF doesn't work against certain bacteria and that not all viruses are blocked by UF (CDC, 2020).

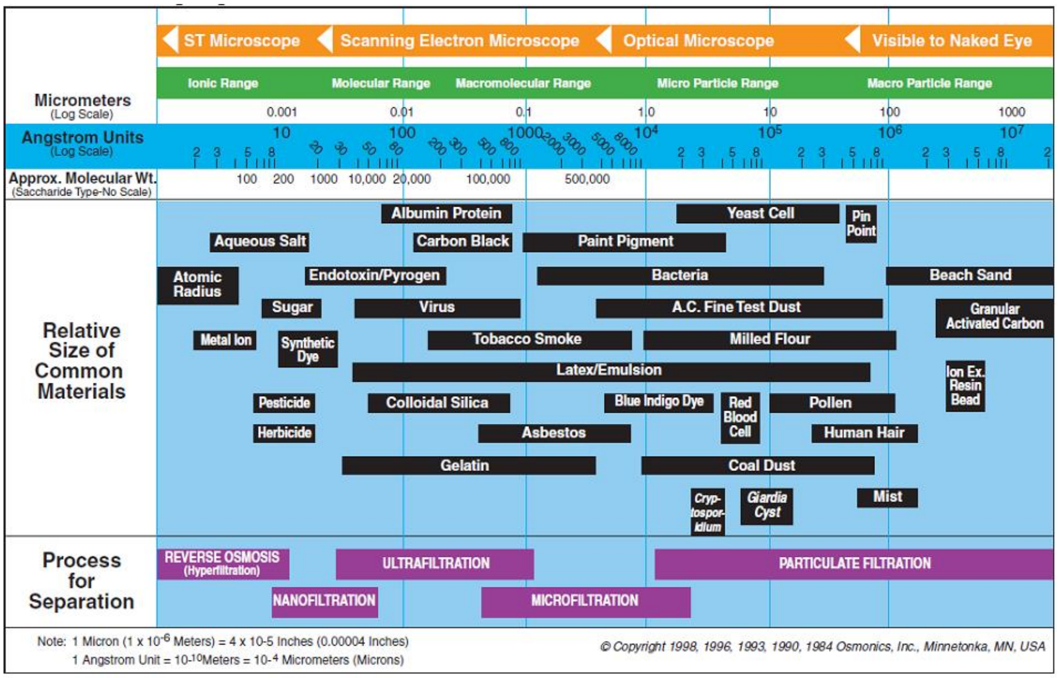

Figure 7 Contaminants of water and their size compared to filtration types

Microfiltration (MF)

MF is mostly used as a pre-treatment before other water treatment methods are used. The pores in these membranes have a size that varies between 0.1 to 1 micron and can filter out mostly sediments, algae and protozoa. It only removes the larger bacteria and doesn't stop viruses, minerals or chemicals. The advantage on the other hand is that a higher water flow speed can be achieved (CDC, 2020).

Ultrafiltration (UF)

The filtration process with UF membranes, differently than with MF, relies on an external pressure or difference in concentration for the filtration through the semi-permeable membrane. These smaller pore sizes, ranging from 0.01 to 0.1 micron, can remove besides the MF capabilities also small bacteria and most viruses (CDC, 2020).

These smaller pore sizes also mean that longevity of membranes is strongly reduced, and more frequent and extensive cleaning is needed (CDC, 2020).

Nanofiltration (NF)

Similar to MF and UF, nanofiltration has even smaller pores, with sizes between 0.001 to 0.01 micron its pores are just slightly bigger than those of membranes used in reverse osmosis. Therefore, it is effective against all viruses and even some chemicals. Just as with UF, NF has the disadvantage of needing frequent maintenance and replacement and therefore it is quite expensive.

Hollow fibre filters (HF)

This type of filtration method relies on the same principles of MF, UF and NF because it works with a semi-porous membrane with different sizes of pores. The difference lies in how the membrane is shaped and positioned. HF-filters use many straw-like tubes called, the fibres, which are 1mm thick and have very small pores ranging from 0.1 till 0.02 micron (Mazloum, 2004).

The bores of HF-filters are often bent to form a loop, see figure below. Hereby the open ends of the bores (the ends are fixed within a resin to ensure no flow of water in between the bores, this can be seen on the left side of the filter in the figure below). Products using HF-filters can be designed in two different ways considering the waterflow through the filter, outside-in or inside-out. This means that the waterflow can either come from the 'looped' side (outside-in) of the fibre or the open-ended fibre (inside-out). Working with an outside-in flow is often preferable when working with water containing larger particles, this method prevents any particles from getting stuck inside of the hollow fibres and thereby reducing the functionality of the membrane (Ing, 2021). Working with an outside-in flow filter also has the advantages of a bigger surface area and higher permeability and makes it possible to backflush the filter (Outbackwater, 2021). Just like with UF, HF-filters also require some form of external pressure to function and actually filter the water.

2.2.3 Cleaning of filters

The main disadvantage of working with filters, is the lifespan of filters. These have to be replaced quite often, every six months or so. A way to prolong the life of the filter is cleaning it, which is often done through the process of backwashing. The principle of backwashing is simple, with clean water you rinse the filter by reversing the flow of the water, that way the particles that have accumulated on one side of the filter are flushed out and the performance of the filter is improved. Water treatment filters that can be backwashed include rapid sand filters, pressure filters and granular activated carbon (GAC) filters (Rouf, 2015). The frequency of the backwashing differs for each filter type, in general AC filters should be backwashed every week while sand filter every 3 days, this however applies for water purification plants and not necessarily household solutions.

2.3 Electrolysis

Electrolysis is used as a step previous to disinfection of the water, by adding salt (NaCl) to water (H2O). Two electrodes, powered by a low voltage source, are inserted into the water and start a reaction which results in sodium hypochlorite (NaOCl) (*Electrochemistry Encyclopedia - Brine Electrolysis*, 2015)[1]. This can then be used to disinfect the water and the same principles as with chlorine disinfection apply. The advantage of using this process is the independent ability to produce chlorine and therefore not depending on the availability of the chlorine. Thereby production of chlorine by electrolysis is much

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[1] Electrochemistry Encyclopedia - Brine electrolysis. (2015, August). The Electrochemical Society. Retrieved October 26, 2021, from https://knowledge.electrochem.org/encycl/art-b01-brine.htm

cheaper than buying the chloride (Brandt et al., 2017). Sodium Hypochlorite also has some deodorising properties that might improve the overall water taste/smell.

The disadvantage of this process is that it requires electrical current to actually work and produce the chlorine.

2.4 UV-C light

UV-light has different wavelengths, ranging between 100 to 400 nm. UV-C which has a range between 200 and 280nm is considered the most effective against pathogens because it is effectively absorbed by the DNA or RNA and thereby making it impossible for the microbe to copy the DNA or RNA, rendering it inactive. Viruses are the most resistant of pathogens to UV-C light (Brandt et al., 2017). These lamps have a lifetime of approximately 5000-10000 hours and can disinfect a litre of water within 90 seconds. UV-lamps are not energy efficient with most of the energy converted into heat.

Advantages	Disadvantages
• Short contact time	• Higher power consumption
• Minimal space requirements	• May require uninterruptible power supply and standby power source
• No transportation, storage or handling of hazardous chemicals	• Effectiveness reduced by suspended solids, colour, soluble organic matter and turbidity
• No significant formation of toxic disinfection by-products[1]	• Risk of microbial reactivation by light and dark repair mechanisms
• Simple equipment; easy to operate and maintain	• No disinfectant residual
• Good reliability	• Need for periodic replacement of lamps
• Effective against *Giardia* and *Cryptosporidium*	• High UV doses required for inactivation of Adenovirus Types 40 and 41
• Performance not affected by pH of water	

2.5 Ozonation

Ozone is a powerful disinfection agent and only requires a few minutes to fully disinfect the water (between 4-10minutes, with dosages of 1-3mg/L). It is also known to be more effective against viruses and cysts than chlorine. Thereby it also improves the possibility to remove organic material during coagulation, obviously if done priorly. In small capacity facilities, ozone is made by having air pass through a UV-light. It needs to be created shortly prior to using due to its unstable nature and the short half-life time (0.5-5min in water). This short half-life is also the reason it can't work as a long-term disinfectant. Another advantage ozone has over chlorine is the fact that it does not react with ammonia, therefore making it extremely suitable for water bodies with high ammonia levels which otherwise would require high doses of chlorine (Brandt et al., 2017).

The hardest part of implementing ozone as a disinfecting agent lie in transferring it into the water, this often requires complex machines of processes in which the ozone is combined with air and added to the water in the form of bubbles. This is quite suitable for large facilities but not for small household applications.

2.6 Iodine

Iodine is used as an alternative for chlorine in the water purification process. It can be used in tablet or crystallised form, whereas the crystals are more potent but also need more care with dosage. Iodination (disinfection by iodine) takes around 15 minutes at 25°C while around 3°C this process takes up to half an hour (Kahn & Visscher, 1974). An important factor to consider is that iodine is three times less effective against E. coli than chlorine (Koski et al., 1965). There are many contradicting research papers regarding the safety and side effects of the chronic use of iodine and its dosage. The WHO (1996) states that research conducted for 5 years among people consuming water with a dosage of 1mg/L (approximately 0.03 mg/kg of body weight per day of iodine did not have any side effects.

Next to iodine tablets, that work in approximately the same manner as chlorine tablets iodine comes also in crystals and in a liquid solution. The liquid solution requires adding a few drops to the water to treat it, it turns the water in a slightly orangish colour. The use of crystals reduces the price, and it can easily be used for large volumes of water. In addition, they have an unlimited shelf life if not exposed to air or water. To use iodine crystals, 4 to 8 grams of it should be collected in a 30mL container that is filled with water. After shaking for 30 to 60 seconds 2mL of this solution is to be added to 1L of to be treated water. These same crystals can be used again and again for over 1000 times before the need to replace them (Kahn & Visscher, 1974).

Iodine has some disadvantages, one of these is that iodine reacts with many different materials, which is inconvenient for storage. It is known that both glass and PTFE (also known as Teflon) are suited for the storage of iodine (Ritter, 2002). Secondly, just as chlorine also iodine affects the taste of water. This change in taste and smell can be countered by adding vitamin C, important remark here is that this should only be added after the water has already been purified by the iodine (Goras, 2014).

Appendix E: Water Treatment Products

1. MadiDrop

The MadiDrop is a block made from ceramic material coated with silver-ions. These silver ions are gradually released into the water and are absorbed by organic material into the cell, this process disables the organism, and it dies. This process however is quite slow, the MadiDrop needs to be placed in the container with water for at least 12 hours when you want to purify around 20L. In addition, the quality of the water should already be quite good since it doesn't filter out any particles and works better when the water is clear. The good thing about this product is its simplicity and longevity. It is virtually impossible to break it to an extend that it doesn't function anymore, even when chopped into smaller pieces it will maintain its functionality. Furthermore, it is designed to be able to function for around 12 months is used daily to purify 20L. However, the company that makes these blocks states that it is effective against bacteria, viruses and protozoa but doesn't guarantee anything, so as to reliability this is doubtful.

Figure 9 The MadiDrop

Figure 8 Manual for MadiDrop

2. PUR

PUR is a sachet containing a flocculant and disinfectant combination, which renders it highly effective to purify highly turbid water. The flocculant binds all the particles in the water and makes them sink to the bottom in around 10minutes, after that it takes approximately another 20minutes for the disinfectant, chlorine, to kill all pathogens. After that the water should be poured in another container and made sure to filter out all the sediment. This could be done with a simple cloth since all the sediment has bonded together. This solution is widely used in the context of BoP and rural areas as a solution to treat water of very bad quality. It leaves the water with chlorine like taste and smell and therefore isn't really liked by its users.

Figure 10 PUR, a coagulant and disinfectant developed by P&G

3. Potable Aqua: Pure

Is a product that uses electrolysis to purify water. The first step is by making abrine solution, so by having water with a high salt concentration. Through this solution then a current is run to transform the salt into chlorine, which can then be used for water disinfection. The device works very simple, a designated compartment is filled with the brine solution after which the user selects the amount of water it wants to disinfect. The device then starts to process the brine into chlorine in the right concentration for the selected volume. On one battery charge the device can process 150L and in the total lifespan up to 60.000 litres. In addition, it has a solar panel that with 2 hours of sunlight can process enough chlorine to disinfect 1litre of water.

Figure 11 Potable Aqua: Pure filled with brine

4. Katadyn Micropur Antichlorine

This product ensures that water that has chlorine taste is returned to taste as normal as possible. It does this only partially, there is always a little bit of taste and odour of chlorine left. It is also important to consider that this product should be added to the water only after the 30minutes for the chlorine to work as disinfectant have passed, otherwise the disinfecting process might not have successfully killed all pathogens. The Micropur is added in a dosage of approximately 3 drops per litre and takes around 3 minutes to remove the chlorine. The advantage this product offers compared to the costs and effort seems bit too shallow for it to be appreciated. With a different setup, for example by automating the process, it might be more interesting. By adding this product however, the chlorine from the water is removed and thus the water also loses its protection for prolonged storage.

Figure 12 Katadyn Micropur antichlorine

5. Steripen Aqua

Prefilter

Before using the Steripen Aqua, ore any Steripen or UV-C light for that matter, it is necessary that the water has a certain level of cleanliness to ensure all the pathogens are killed. Particles in the water might otherwise block the UV-C rays and affect its performance. This prefilter has a filter level up to 40micron, which apparently is good enough to ensure that the water is clear enough for UV-C radiation. However, when filtering what with such a filter it doesn't look drinkable, it still has a different colour and particles floating around. This filter isn't designed to be easily backwashable, is has a lot of edges and parts where dirt can get stuck.

UV-C lamp

The UV-C lamp is quite bulky for the actual working components of the product. Approximately 70% of the product is composed of battery storage and around 15% is the lamp itself. It has a simple operating procedure, with the on/off switch you can easily choose whether to purify 0.5L or 1L. It won't light up the UV-C light until it is in contact with the water. Within 90 seconds it is done with purifying 1L of water. A good feature of this product is that it gives feedback to the user whether or not the process was successful. The lamp automatically turns of after 90 seconds to tell the user the water is safe to drink, but if anything in those 90 seconds goes wrong the lamp has built in LEDs that tell the user what the problem is. In total the Steripen Aqua is capable of disinfecting 3000L.

6. LifeStraw

The Lifestraw is a water filter designed for emergency and outdoor situations. It is designed in such a way that the user can sip directly from the water source as through a normal straw. The filter used is a hollow fibre filter with pore sizes of 0.2micron, capable of filtering out 99.999% of all bacteria and protozoa. It doesn't require too much effort for a person to operate but the water volume flow is quite low when drinking directly through it. If such a filter would be used without suction it would require a pump which is capable of generating quite some pressure, otherwise the water won't flow through it. However, when wondering how hygienic and safe it is to use there are some doubts. Since you have to place your mouth directly onto the filter it is quite easily possible this mouthpiece is contaminated since it might in some ways have been in contact with the contaminated water.

The backwashing mechanism for this filter is really easy, just blow air in the opposite direction through the filter. In total the filter should be capable of filtering 4000L of water, depending on water quality.

7. Aquatabs

These tablets are used as a last resort in water purification, and as an easy fix in case of emergency, they are not recommended to be used on long term. The active agent in these tablets is chlorine which slowly dissolves into the water. Using these tablets is really simple and doesn't require much explanation, one tablet purifies 1L of water and should be used at least 30 minutes prior to drinking, to ensure al pathogens are killed. The effectiveness is greatly influenced by the turbidity of the water, the more turbid the less effective and more time the chlorine needs to kill all pathogens. Since each tablet can only be used once it isn't the cheapest solution either even though the tablets themselves are really cheap.

8. Test Results

On the next pages, the test results for various parameters for many different types of water treatment products are synthesised into a table to be able to compare results. The green marks the parameters that score above average, orange is average-below average, and the red slots are the parameters where the product scored far below average.

<u>Water Flow Rate</u>

An essential factor in adopting solutions from a user's perspective is the achievable flow rate, the amount of water the solution can provide in litres/minute.

There is a big difference between the treatment and dispensing flow rates. The first is about how many litres of water can be treated per minute; the second is about how much water per minute the solution can dispense to the user. The difference herein lies that a solution that takes a lot of time (+1 hour) to treat the water can still (once it has treated the water) dispense it at a high flow rate. In the end, it may be a favourable solution in respect to a solution that can dispense and treat simultaneously but very slowly. The main factor herein is the willingness of the user to wait for the required container to fill.

Waiting for 30 minutes for the water treatment to take place and then tap water at 2L/min might be favourable compared to tap water at 0.5L/min immediately.

Tests with different products and flow speeds from the tap have shown that a flow rate of approximately 1.5L/min is the minimum dispense flow rate that is still deemed acceptable, no matter the flow rate of treatment.

This flow speed is suitable for filling glass and bottles; larger volumes may require higher flow speeds. An overview of all the test results can be found in Appendix B. Ideally, the flow rate should be as high as possible.

Product	Flow Rate (L/min)	Notes
Steripen	0.75	
Lifestraw	1.5-2	Depends how fast and much the user wants to drink
Aquatabs	1L/30min/pill	One pill can disinfect a L of water within 30minutes. Adding more pills means a larger volume of water can be disinfected
MadiDrop	-	Treats 20L/12hours, after 12 hours those 20L are safe to drink
AquaPure	1L/30min	As with the Aquatabs it depends on the dose, each cycle requires to wait 30minutes for the chlorine to take effect
Jerry	2	Uses a pump to push water through filter
Tap on Jerrycan	3	Just a simple tap mounted at bottom of jerrycan
Faucet – max flow rate	6	Max flow rate from faucet at Quooker BV
Faucet – comfortable glass filling	4	The desired flow rate to normally fill a glass
Faucet – minimum acceptable flow	1.5	Personal opinion of what I would deem the minimum flow rate to fill a glass

	Lifestraw	Steripen Katadyn	Steripen Prefilter	Coffee filter	Paper towel (5 layers)
Effective Against					
Bacteria					
Viruses					
Protozoa					
Sediment					
Working Principle					
Disinfection					
Filtration	0.2 micron		40micron	20micron	20micron
Water Improvement					
Taste					
Colour/Turbidity					
Smell					
Operating Requirements					
Waterpressure					
Electricity					
Turbidity level					
Capacities					
Litres in total	4000L	3000L	/	1-2L	1-2L
Litres/minute	Pressure dependent	0.75L	0.75L	0.3L	0.1L
Reduction of NTU	<5		17	6	<5
Backwash necessary					
Economics/Repairability					
Price tot.	25	45	12.95	0.0001	0.0001
Price/Litre	0.006 eu/L	0.015 eu/L	/	0.0001	0.0001
Ruggedness					
Ease of repair					
Repairability cost					
Context					
Applicability					
Ease of use					

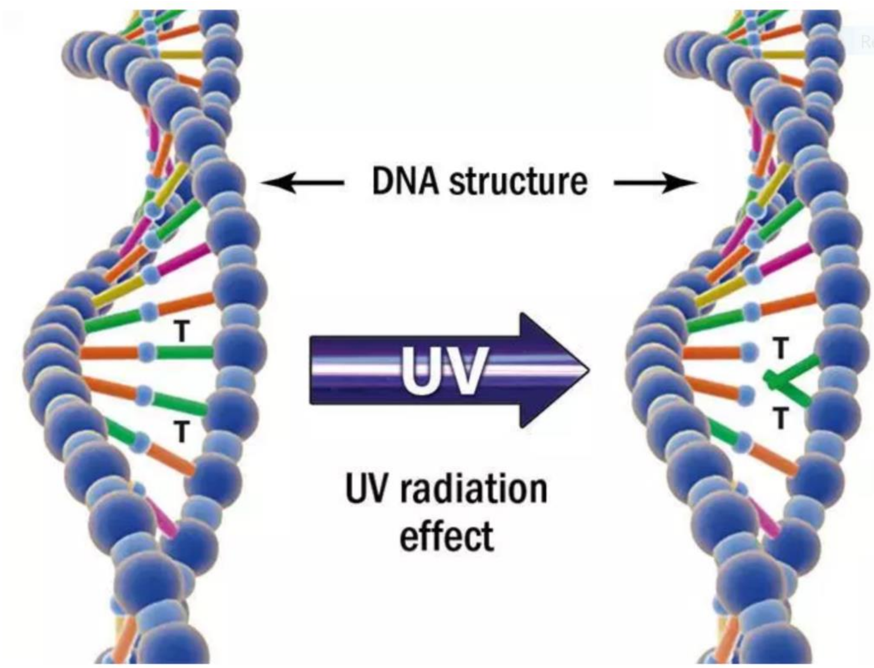
MadiDrop	Microfiber Cloth	Sedimentation	Boiling	Aquatabs	Potable Aqua	Flocculation
	20micron					
7300	/	/	/	1L (per pill)	60000	/
20L/12 hours	0.1L		/	1L*pills/30minute	3L (30minute wait)	10minute wait
	<5					
15	1	/	/	/	95eu	/
0.002	/	/	/	0.1	0.0016	/
				/		/
/		/	/	/		/
/		/	/	/		/

Appendix F: UV-C Theory

1. Health Hazards

Besides being dangerous to unicellular organisms, UV-C can cause serious damage to all living organisms. For humans this means that exposure can cause severe skin burns and permanent damage to the eyes. This can further develop, if exposed for too long, into skin cancer and photokeratitis (permanent damage to the corneas) (Welch et al., 2018). This can easily be prevented by wearing covering clothing and goggles designed to absorb all the UV rays. It has been determined that the threshold for photokeratitis is at a dose 50mJ/cm^2 UV-C radiation (United States - Bureau of Radiological Health, Division of Biological Effects, 2022).

However, when designing for the consumer in the context of this project that is not something that can be expected. However, UV-C is absorbed by most materials and therefore only an openly accessible LED that emits UV-C is dangerous. If the LED is contained inside a casing it will not cause any harm.



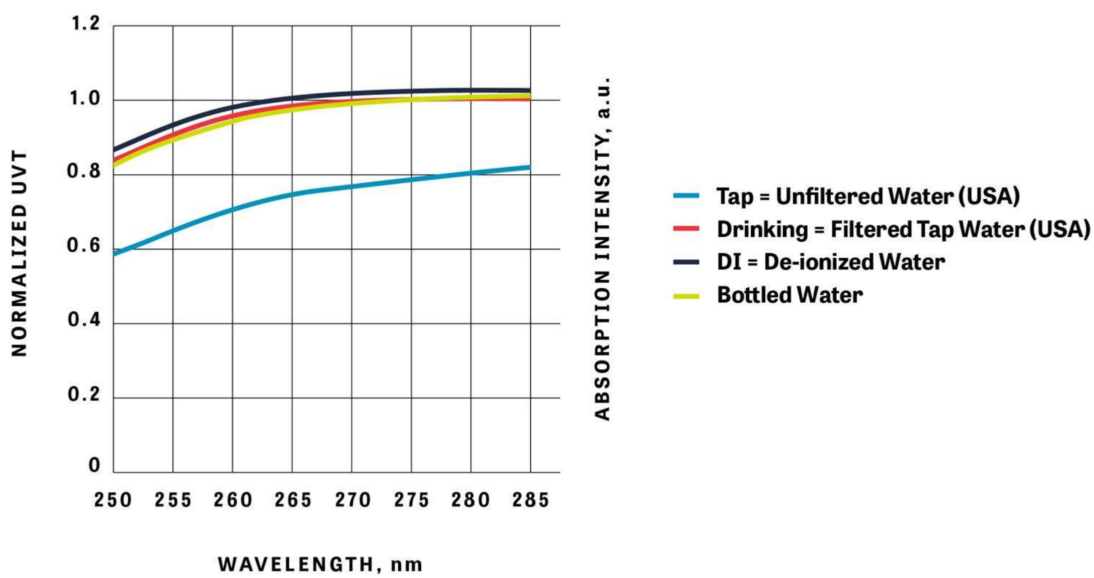
2. UV Transmittance

One of the main points of concern for me was the UV transmittance (UVT). The transmittance can greatly influence the delivered UV-dose.

UV-C Absorbance by water

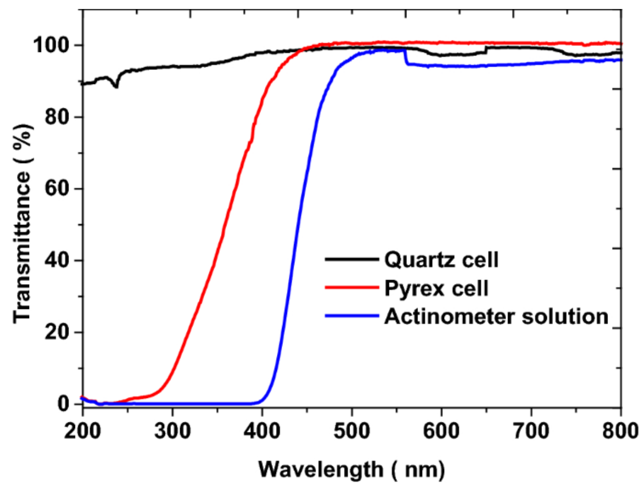
Water doesn't absorb much in the UV-C spectrum (200-300nm). At the ideal wavelength, 265nm, the absorption is 0.4 (1/m). Meaning that up to a meter of depth only 4% of the UV-C intensity is absorbed. What isn't absorbed is transmitted, that means that the transmittance is around 96% (for distilled water) for each meter of water.

The radiation transmittance is mostly influenced by the quality of the water that needs to be disinfected. Water is considered optically clean when it reaches a NTU value of 5 or lower. This however does not mean that there aren't any particles in the water that can block the irradiation of pathogens. In general, the UV-transmittance (UVT) in tap water is around 75% (at 265nm) (Bilton & Kahn, 2018). When looking at the impact the water quality has on the UVT, we can see in the figure on the next page that there is a big difference between tap water and bottled water.



UV-C Absorbance Quartz

Obviously, the LED cannot be in direct contact with water, therefore as a separation layer between the water and the LED a quartz glass is used. Quartz is used in almost all UV-C water treatment products as it is one of the few materials with a very low UV-C absorbance and reflectivity. Its transmittance at 265nm is around 92% (QSIL, 2021).



3. Effective UV-C irradiance

Besides the UVT there are several other factors that can influence the delivered those to the pathogens. Some of these can be adjusted by design other are fixed, based on components.

Reactor Design

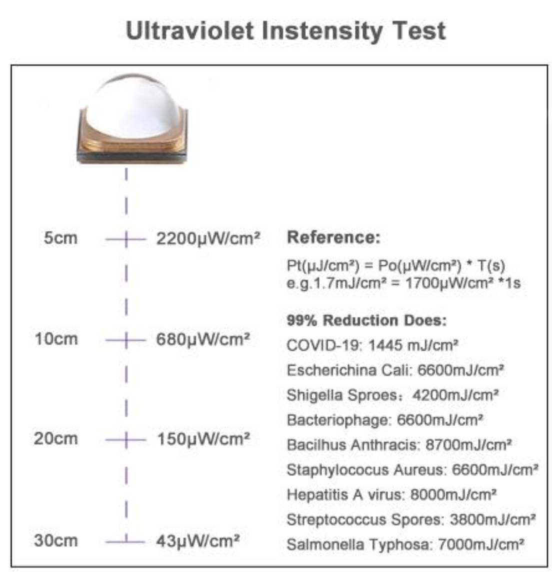
Firstly, the reactor design largely influences the time of exposure of pathogens to UV-C. As can be seen in the equation for the UV dose this makes a major difference. Longer exposure times to UV-C drastically increase the delivered UV-C dose. This can be achieved by influencing the flow speed of the water but also by optimizing the delivery of the UV-C by the LED.

Secondly, the material of the reactor can have a major impact on the UV dose delivered and the design of the system. There are 3 materials widely used for UV-C reactors, (e-)PTFE, aluminium, and stainless steel. These materials have different qualities in reflecting UV-C, but this reflection can increase the achieved UV dose on pathogens when using a properly developed reactor. In the table, the different levels of reflectivity for each type of material are mentioned (Kaplan University & Crystal IS, 2016).

Material	Reflectivity
e-PTFE	95%
PTFE	90%
Aluminium	80%
Aluminium Foil	73%
Stainless Steel (variations)	20-28%

Irradiation Distance

The intensity (mW/cm^2) is the amount of UV-C delivered to a certain area. The intensity is greatly influence by the distance to the source, as can be seen in the figure on the right. Here an example of an LED intensity compared to the distance, a factor 5 increase in distance leads to almost a factor 11 reduction in intensity. Therefore, when developing a UV-C product it can be most interesting to develop it in such a way that the treated surface is as close as possible to the LED. This will greatly reduce the necessary LEDs to deliver a sufficient dose to kill pathogens.



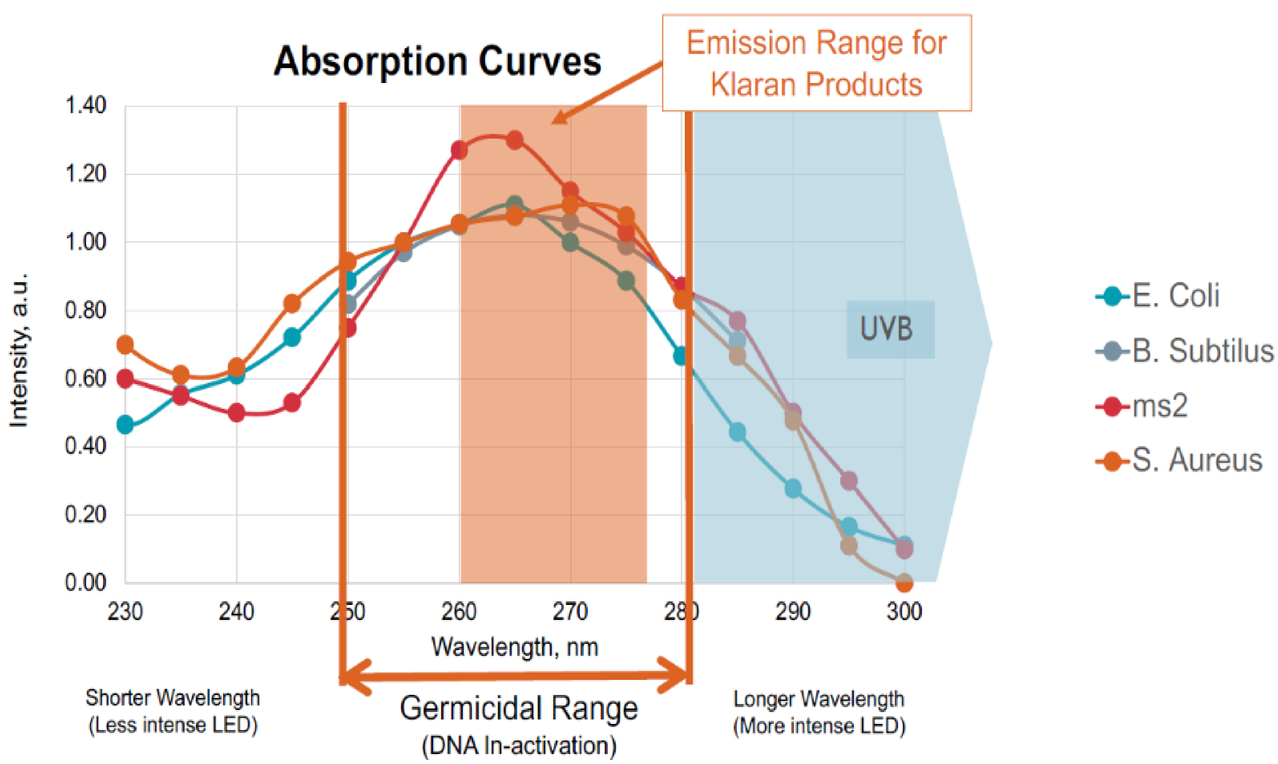
4. Required UV-C Dose

Having clarified the different factors that influence the UV-dose it is important to determine what the necessary UV-dose is to achieve a log 3 reduction of all the most predominant pathogens.

In general UV-C systems for water treatment are categorised into two classes, A and B. Class A systems have a minimum irradiation of 40mJ/cm^2 and are used for water sources of which the quality is unknown. Class B systems have a minimal UV-C irradiance of 16mJ/cm^2 and are used as a supplemental treatment for water that has already been deemed of acceptable quality.

Pathogen specific UV-dose

Each pathogen differs, and therefore requires specific wavelengths of UV radiation for optimal and efficient disinfection. For pathogens the maximum absorption happens between 260nm and 270nm (Bilton & Kahn, 2018). A study conducted Vermeulen et al. (2007) determined that for E. coli, the optimum wavelength for inactivation is approximately 265nm, see figure FIXME.



In this context, the water quality is unknown and thus we should be inclined to develop a class A system. Developing such a system, however, cost a lot more, due to the need for more LEDs or more powerful ones. Since the context is also price sensitive I identified the necessary UV-dose necessary to kill all previously identified pathogens to develop a system that is capable of dealing with the most predominant pathogens while at the same time maintaining the minimum requirement. Thus, developing a very cost-effective solution that can still have a lot of positive impacts. These results have been collected in the table below.

Unfortunately, there hasn't been done any research into the log reduction of the Hartmannella and acanthamoeba protozoa as to their sensitivity to UV-C irradiation. Since both these are protozoa, which are very susceptible to UV-C, and are common hosts for the legionella bacteria the assumption is made that both will require the same UV-dose as the legionella bacteria, 6.9mJ/cm^2.

Pathogen	UV-dose (mJ/cm^2) for Log 2 Reduction	UV-dose (mJ/cm^2) for Log 3 Reduction	Source
Legionella	5	6.9	Wilson et al. 1992
E. Coli	8	10.5	Tosa Hirata 1999
Streptococci	8.8	9.9	Chang et al. 1985
Proteus	NA	7*	Outback Water 2022
Pseudomonas	NA	11*	Outback Water 2022
Klebsiella Terrigena	6.7	8.9	Wilson et al. 1992
Acinetobacter (Baumannii)	1.8	3.3	Templeton et al. 2009
Cryptosporidium	<5	5.2	Craik et al. 2001
Hartmannella (host for legionella)	See Legionella	See Legionella	
Acanthamoeba (host for legionella)	See Legionella	See Legionella	

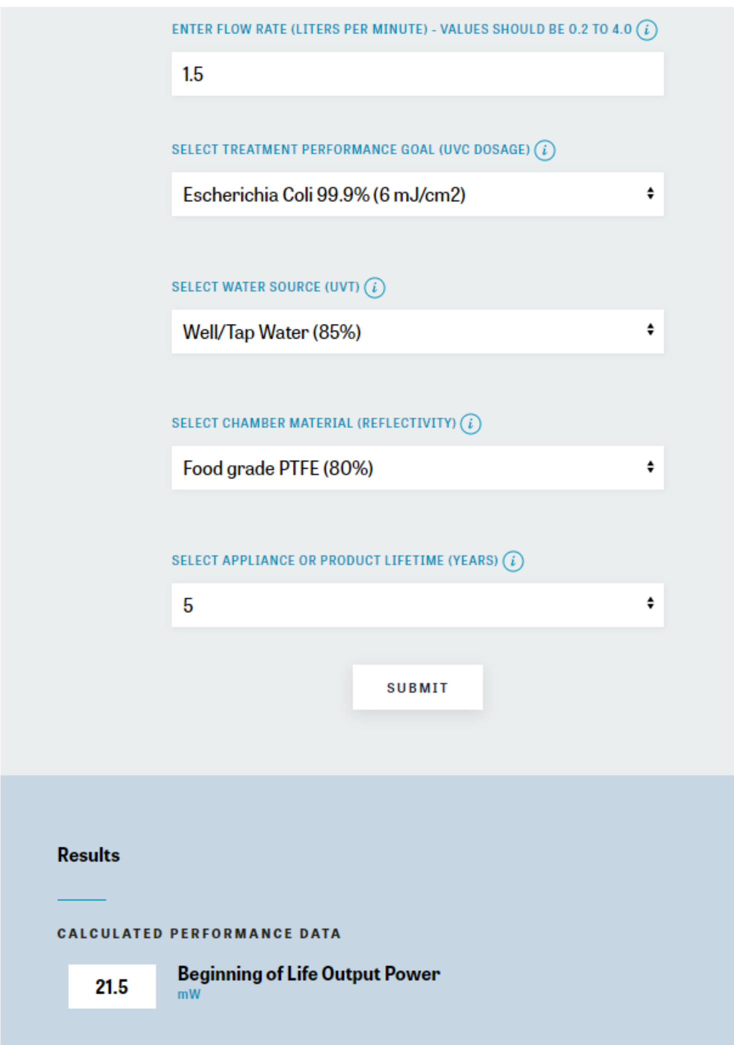
*For Pseudomonas and Proteus only values for log 4 reduction have been found

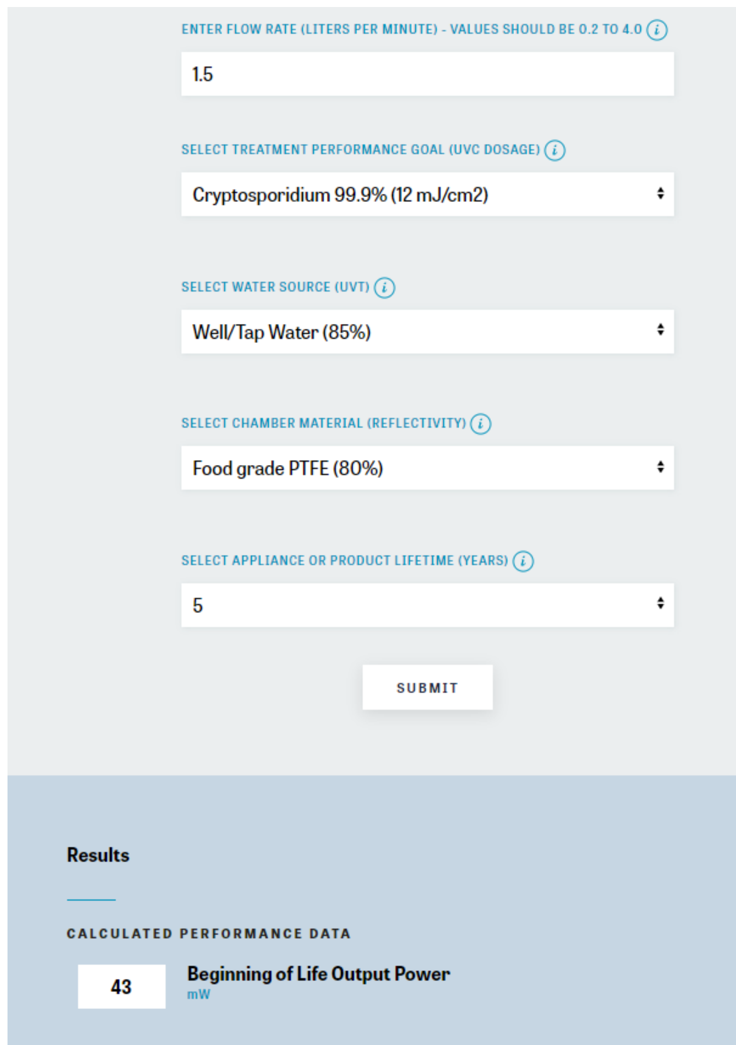
Klaran Water Disinfection ROI Calculator

The Klaran Water Disinfection ROI Calculator is a tool developed by the company Crystal IS. They are a manufacturer of UV-C LEDs and UV-C water disinfection systems.

The design of a UV-C disinfection product is quite complex and to be able to corroborate expectations the product should always be tested. This tool can only help give an indication of what is required from the LEDs.

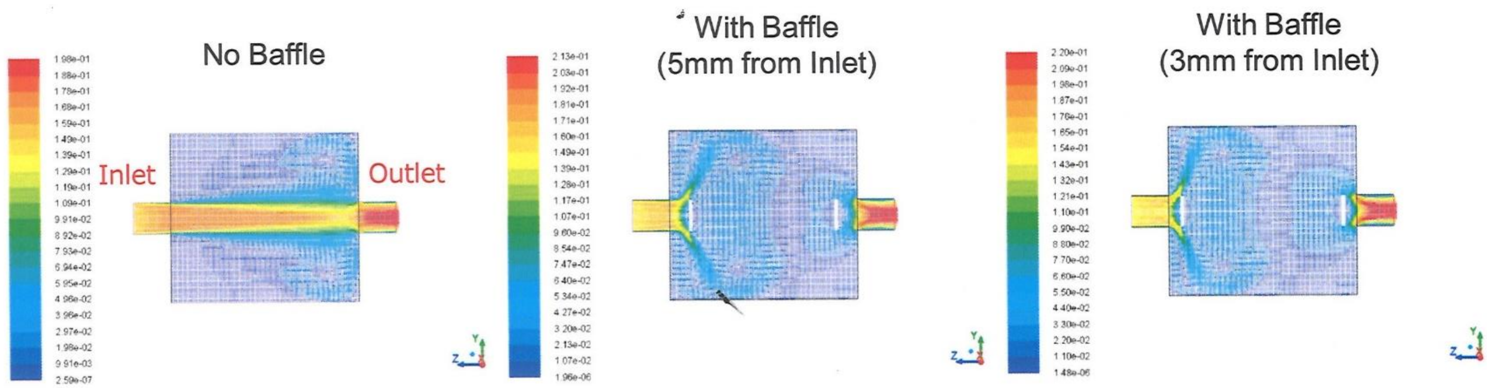
The estimation is that for a 6 mJ/cm^2 UV-C dose the minimal mW output should be 21.5 mW, whereas for a 12 mJ/cm^2 the output needs to be 43 mW. Taking the average of these two values gives that the UV-C output should minimally be 32.25 mW. See the figures below for all the values of parameters and the example of the calculator tool.



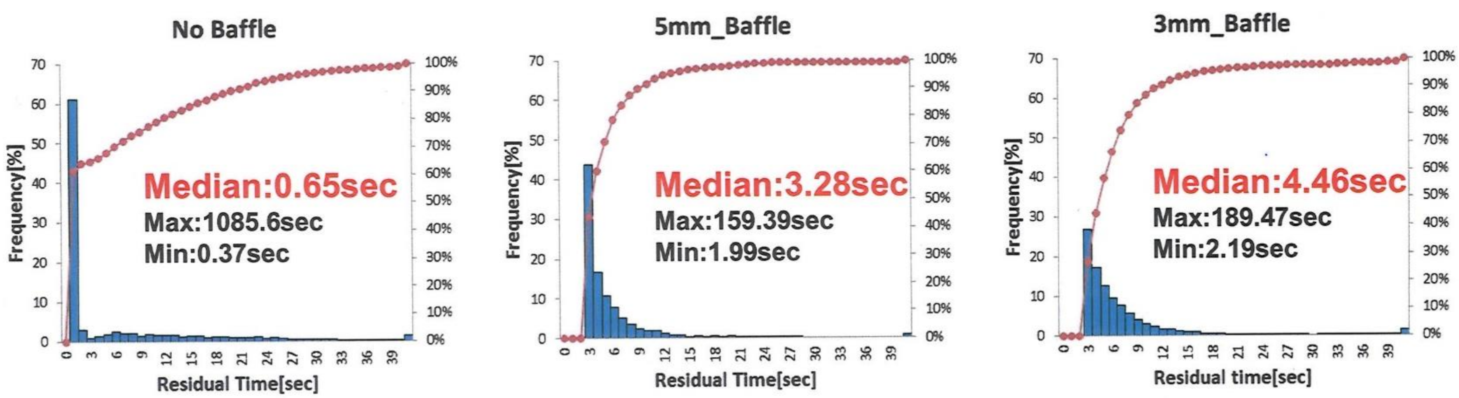


5. Water Flow

The graphs below show the impact of the placement of a baffle just after the water inlet of the reactor. The baffle slows the water flow down and makes sure that everywhere in the reactor the water has the same speed.



Distribution of Residual time



Appendix G: UV-C Product Analysis

1. Healter Bottle Cap

The Healter is an aftermarket bottle cap that can be mounted to several water bottles with an inner tread. The goal of this product is to keep the water inside the bottles safe for consumption over longer periods of time and reduces the chance of bad smells and mould forming.

It has one UV-C LED at the bottom of the cap that can be turned on by the capacitive button on top of the cap or by quickly flipping the cap when mounted on the bottle.

Price: € 19.17

On top of the cap there is an RGB LED to indicate what the cap is doing. This works very well and is very intuitive. This prevents the user from actually see the UV-C LED to check if the cap is turned on or off, avoiding explosion to UV-C radiation.

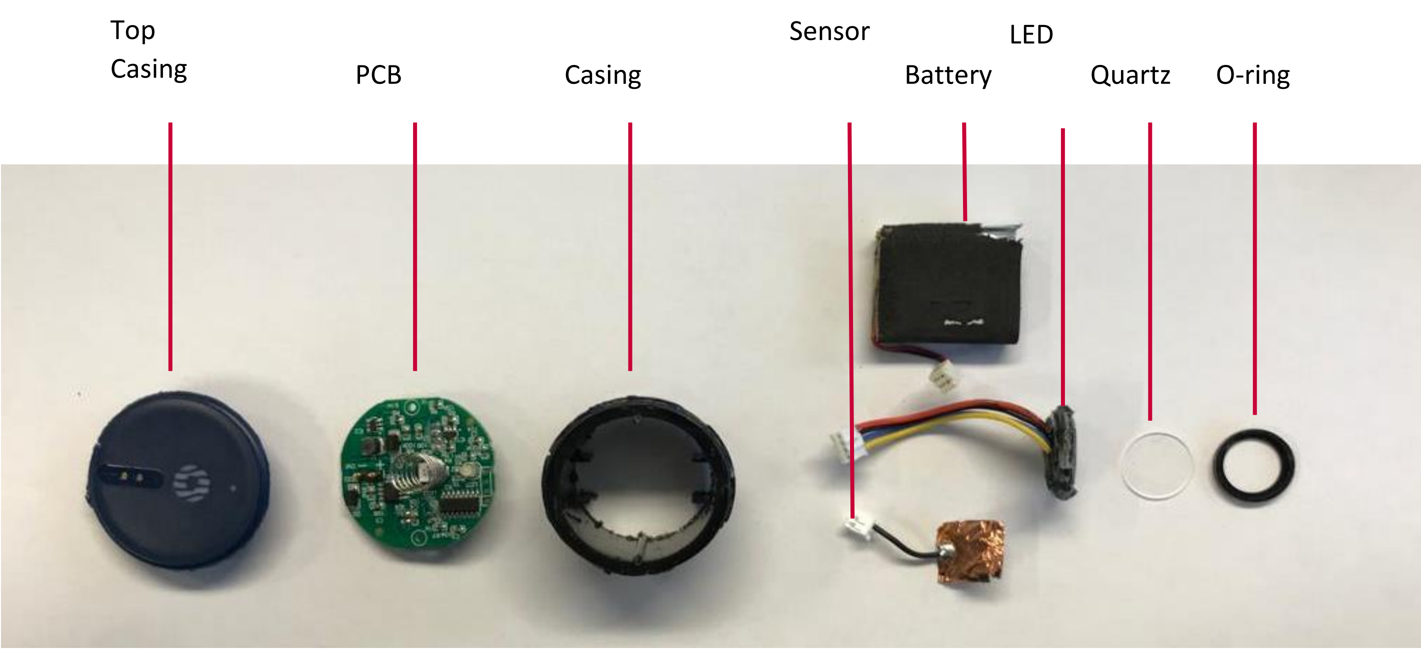
The cap has several modes:

- The first is just simply turning on the light and it will stay on for 3min to disinfect the water
- The second mode delivers 30 seconds of UV-C radiation every hour and keep doing this for as long the cap is in the bottle

The battery can last up to a month when using the second mode. Charging happens through a watertight magnetic connector on top of the cap.

To safely manage the cap and not run the risk of the user exposing himself to UV-C there is abuilt-in sensor. This sensor registers whether or not the cap if mounted on the bottle though applied pressure on the sides.

In the figure below all the components of this product are shown. Maybe apart from the sensor these are the minimum required components to develop a functioning UV-C disinfection system. The o-ring and quart glass are necessary to protect the LED from the water while still being able to irradiate the water.



3. Philips Sanitation Box

This sanitation box by Philips is designed to sanitise all types of small personal effect, such as watches, phones, wallets and keys. Inside there are four UV-C LEDs on one side that disinfect the content.

Price: € 34.99

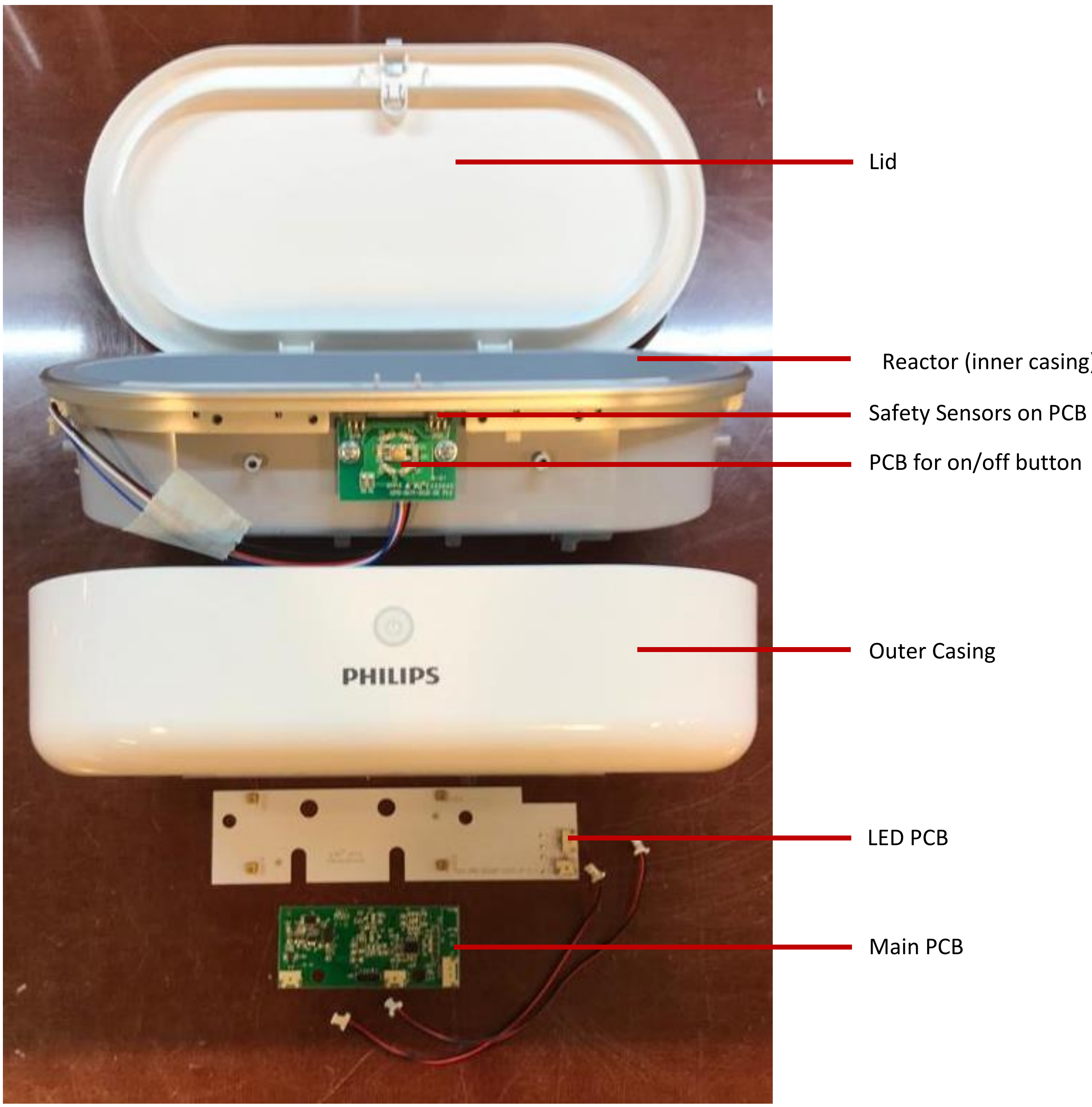
The design for the disinfection of this box isn't optimal. Since all 4 LEDs are placed on the same side, the opposing side of the product inside (wallet, phone, etc.) isn't really illuminated and therefore probably isn't effectively disinfected. This improbably also the reason that each disinfection cycle lasts for 8 minutes (much longer than the other tested product).

This device has just a single mode, on or off. By pushing the start button on the front, the 8-minute cycle starts, It can be stopped by pushing a second time on the button or by opening the lid. This product as well has a sensor to register whether or not the lid is closed, and the LEDs can safely be turned on. The sensor is placed right above the on/off button where two pins from the lid push through.

As can be seen in the picture in the top right of this page, the on/off button turns blue when the cycle is in progress.

Safety Sensors

Implementation of the LEDs in this product was easier since there was no need to protect them from water, therefore no quartz or O-ring are necessary. However, electronically this product is more complex. There are three PCBs that control everything and operate together. The PCB containing the LEDs is made from aluminium to ensure maximum heat dispersion, since these are four powerful 1W LEDs they generate a lot of heat.



4. Steripen Aqua

The Steripen Aqua is a UV-C disinfection product that uses a mercury lamp instead of a UV-C LED. Mostly used by backpackers and people in the outdoor to disinfect water from different sources. Mercury lamps are much more delicate due to the shape and the quartz glass cover. Dropping such a device would often lead to it being broken. Furthermore, mercury lamps have a much shorter lifetime than LEDs, where leds can last up to 10.000, this mercury lamp works only for 3000 hours.

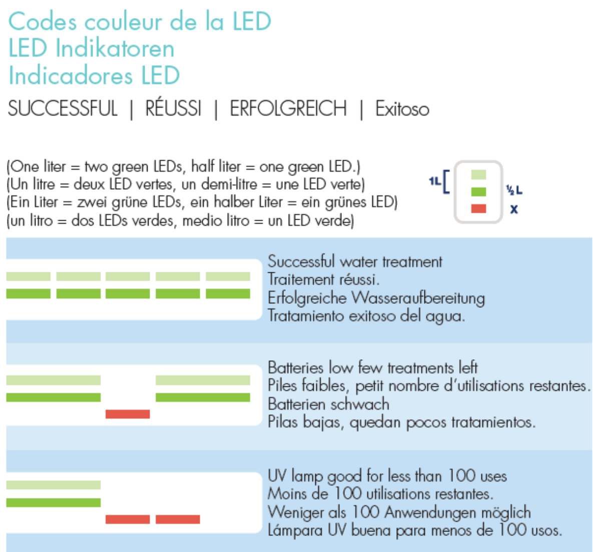
Price: € 45.00

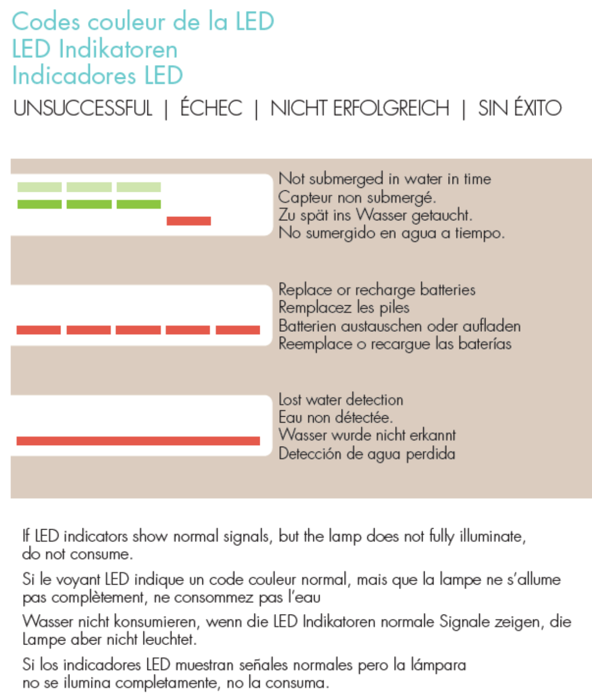
It has two disinfection modes, 0.5L or 1L. The difference between the two is the time the lamp is turned on. For 0.5L the lamp is turned on for 48 seconds, while for 1L this is 90 seconds. The selection of the mode is done by clicking once or twice on the button. A RGB LED will indicate which modus is selected.

The Steripen uses 4 AA batteries which can treat up to a 150L. This much less than would be possible with UV-C LEDs, with the same amount of power it would easily be possible to treat up to 500L. Furthermore, the batteries are drained quite fast even when not in use, after not being used for 2 months the batteries of the device where empty (and before that a maximum of 10L had been treated).

The use of a mercury lamp and AA batteries make that the device is also much bigger than for example the Healter cap discussed before. In the picture on the right, you can see the difference in size of the two products. The Healter cap is less than half the size of the Steripen Aqua.

The RGB LED also has different patterns to indicate, battery levels, success of treatment, etc. See the figure below for some more detail.





To ensure the user is not exposed to UV-C light also this device has sensors (number 4 in the figure). These sensors register if the device is submerged in the water, if that's the case the lamp can be turned on otherwise the RGB Led will become red.

For the rest the setup and components are quite similar to those of the Healter cap, discussed difference aside.

5. Klaran WS Series

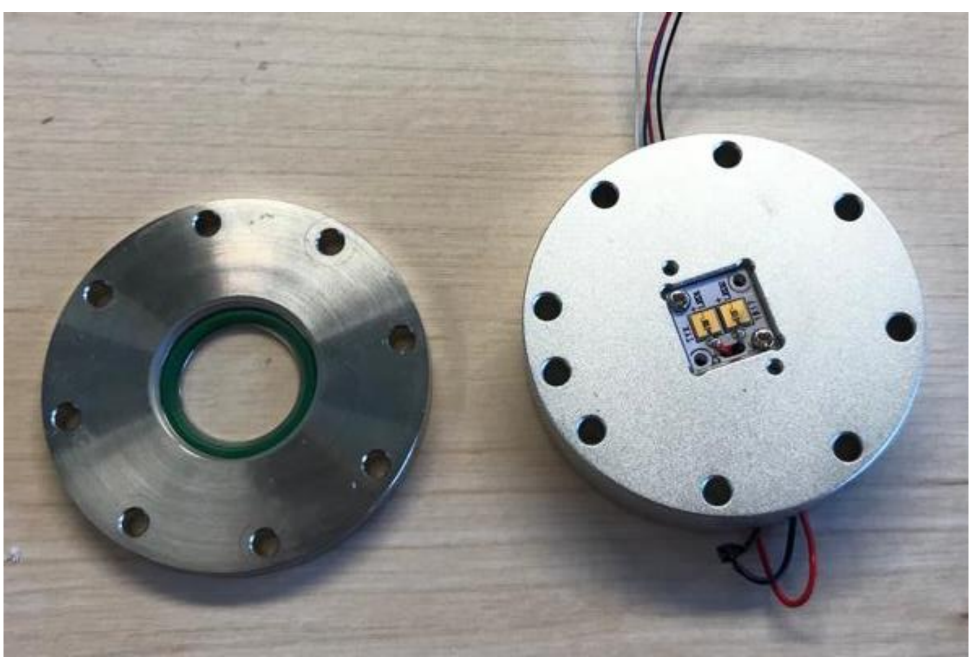
The Klaran is a retrofittable water purifier that can be connected to the main water supply to the faucet. It can achieve flow rates up to 3L/minute which is almost the maximum flow rate for faucets without any water treatment system.

Price: Unknown

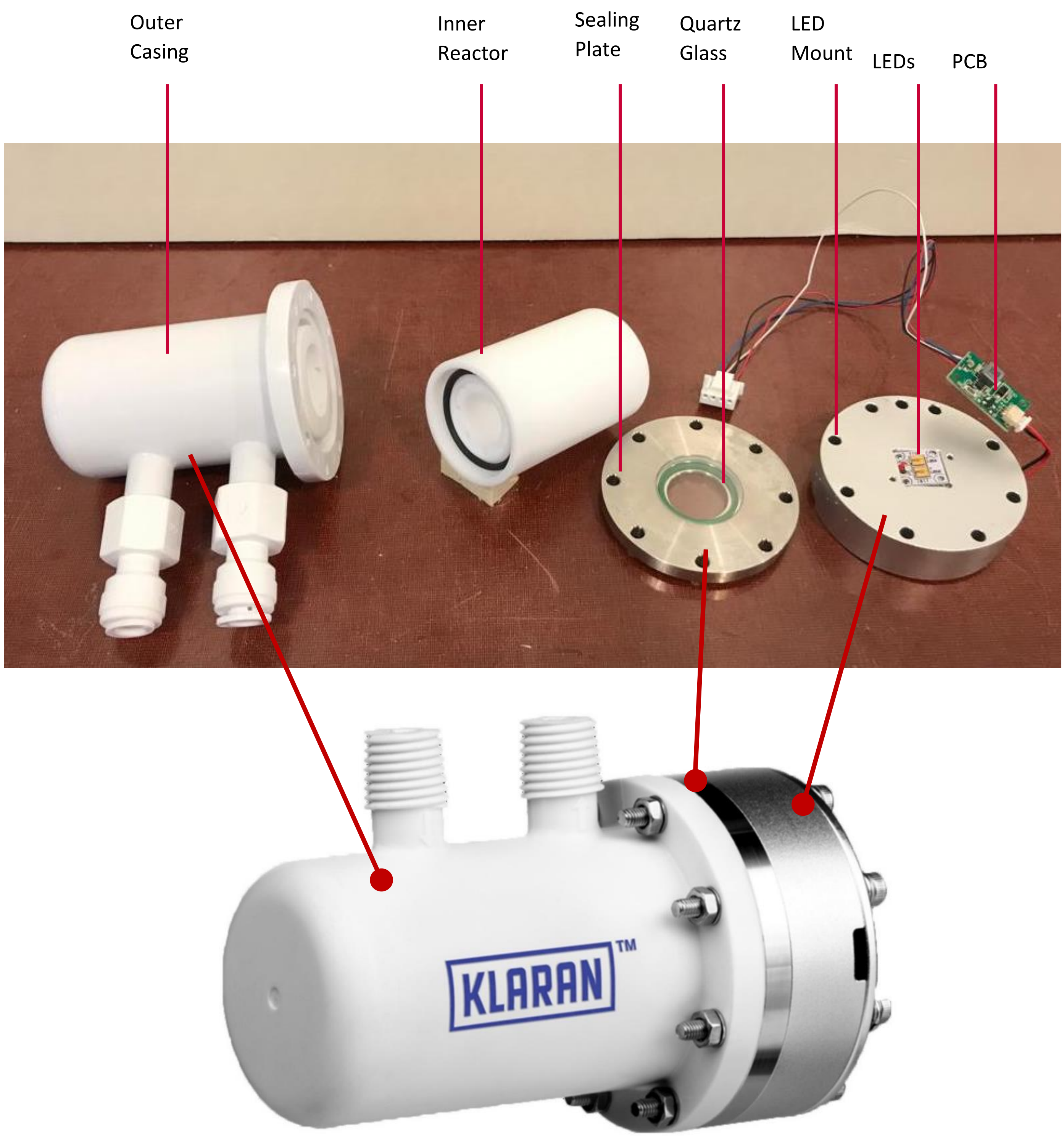
Different from the other two water treatment devices in the way that it has its own specifically designed reactor for optimal performance. Otherwise achieve thee flow rate of 3L/minutes is probably impossible. The advantage of such a system is that it provides disinfected water on demand. Where with the Steripen and Healter you have to wait some time to get a certain volume of water disinfected the Klaran can offer unlimited supply of disinfected water all the time.

The device does not have a battery and is plugged in to a wall socket. The on/off switch is integrated into the power adapter making it very uncomfortable to use. This means that to get disinfected water from the faucet you first have to turn on the device before you can open the faucet. On this power adapter there is also and RGB Led to indicate whether or not the UV_C Leds on the inside are turned on, since there is no way of visually confirming this since both LEDs are completely build-in into the casing.

The Klaran use two UV-C Leds to disinfect the water that are protected by a quartz glass and O-rings. These two parts are connected together and to the outer casing with 8 bolts and nuts (see the figure on the next page).



In the image below the component marked as inner reactor is added as an extra component, as you can see there is already a inner reactor mounted in the outer casing but could not be removed. For the purpose of this picture an extra inner reactor was added. This inner reactor regulated the flow as such to be optimally irradiated by the LEDS before flowing out of the device to the faucet. Component wise it looks a little bit different that the other devices, but the functionality of those components is virtually the same. The sealing plate and the quartz glass are connected with the green O-ring barely visible in the figure. This protects the LEDs and ensures that there are no water leaks.



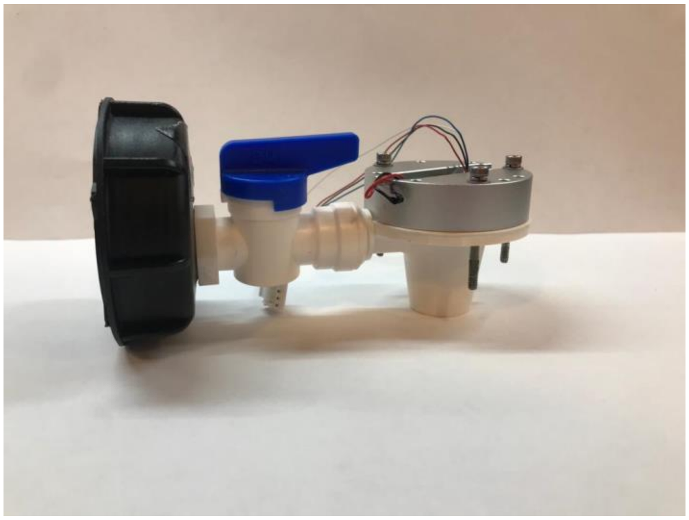
Appendix H: LED VLMU35CB20-275-120

This UV-C LED can be bought at a price of $ 3.86 per unit. When buying 2000 pieces this amount to 1.99 per LED. According to Bart Hermans (Head of the Electronic Product Development at Quooker), this price would get only 10 to 20 cents per unit cheaper when buying 30.000 units (10.000 UV-Tap products x 3 LEDs each). He determined this by looking at price difference from 1 unit to 2000 units, and based on his experience he estimated this price drop. He does however say that it will get cheaper in the future. In Appendix O the detailed datasheet of this LED can be found.

Appendix I: Prototyping

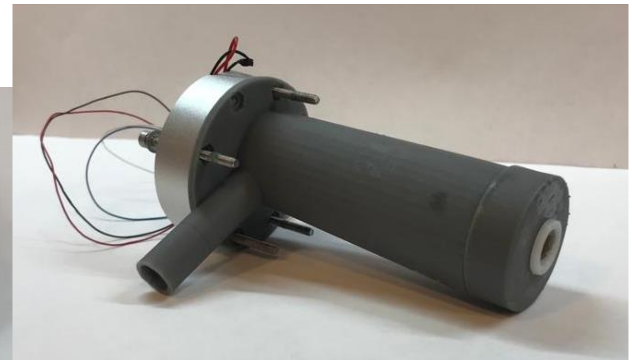
1. Evolution of the UV-Tap

1st Prototype

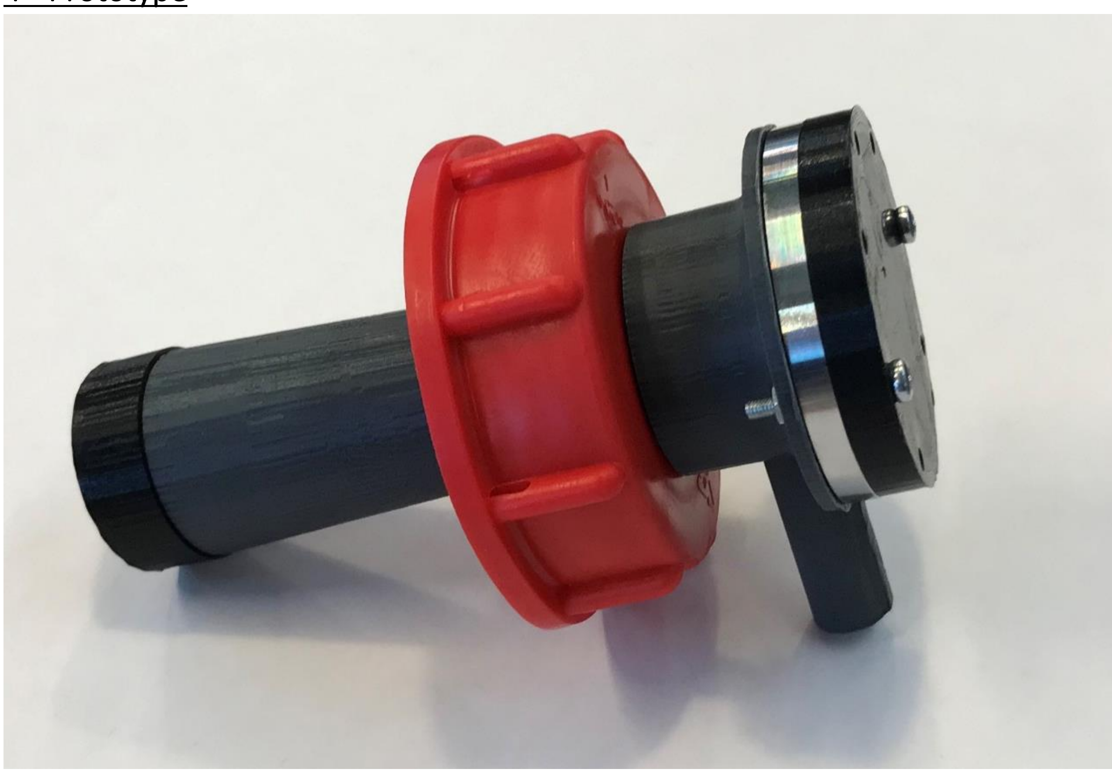


2nd Prototype

<u>3rd Prototype</u>



<u>4th Prototype</u>



5th – Final Prototype

2. Aeration

The aeration of the jerrycan presented itself to be one of the most challenging aspects of the prototyping. Due to the flexibility of the jerrycan and the pressure created by the water volume, getting air to enter the jerrycan presented itself to be a challenge. To solve the issue, I tried several different solutions, here the approaches that I tried but didn't suffice in my opinion are discussed.

Capillary tubes

One of the most common approaches for the aeration of a jerrycan relies on the working principle of capillary action. Practically this means that there are two tubes connected to the inside, one with a small diameter (the white tube in the picture) and a larger one (the stainless-steel tube). Due to the difference in size the water can flow more easily through the larger tube and doesn't pass through the small tube, seeking the way of the least resistance. This allows air to pass through the small white tube to the inside.

This however didn't work for the jerrycan in my case. This is due to the low flow rate combined with the pressure generated by the larger volume. The flow rate of 1.5 L/min is so low that the pressure on the inside still pushes water through the smaller tube making it impossible for air to pass through.

Handpumps

Another approach to equalise the pressure inside the jerrycan is to pump air inside. So at the same time the tap is opened the user can operate the pump to maintain the same water flow or even pressurise the jerrycan beforehand. In the end this approach wasn't chosen because it requires extra components, active contribution by the user and overall complexifies the usage.

One-way valve

A one-way-valve is a valve that lets water pass through in only one direction. It does however still require to be above the water level for ai to get inside the container. In the picture the valve is mounted on the top of the jerrycan so that it is always above the water level, it doesn't matter if the jerrycan is placed vertically or horizontally.

The method of aeration is quite simple and effective and was used for the functionality testing of the UV-C during this graduation project. However, it doesn't seem to be right to be used in the context. Drilling a hole in a water container isn't the smartest option, and during transport it might still start leaking water. The fit of the valve has to be really tight and be placed correctly and people would need to do this themselves at home which makes this solution a little more undesirable. Furthermore, it could be an opening that leads to recontamination.

3. Component Lifespan

For all the calculations, if possible, the worst set of circumstances have been chosen as the local conditions are far from optimal with electronics.

Battery

A battery usually last between 500 up to 1000 cycles. For each cycle the battery provides roughly 50L of water. In the end this amounts to 25.000 L.

500 x 50 = 25.000 L

UV-C LED

The UV-C LEDs have an operational time of around 10.000 hours. And for every minute they are active they disinfect approximately 1.5 litres. That means that in one lifetime the LEDs are capable of filtering up to 900.000 L. This is a lot more than the 25.000 L the battery can manage and therfreo are no a crucial component sfor the lifge of the product.

10.000 x (1.5 x 60) = 900.000 L

RGB LED

The RGB LEDs can last up to 50.000 hours. During operation they are on at the same time as the UV-C LEDs (so a maximum of 10.000 h) and some additional time during charging of the device. The device will be charged 500 (based on the battery life) and each charging cycles takes around 20 minutes. This means that in the total lifespan of the device the RGB LEDs are turned on for ~15.000 hours. Therefore, these LEDs will not break before the battery and are not of concern for the lifespan.

Microswitch

The specifications of the microswitch indicate that the electrical components of the switch can last for at least 50.000 cycles, whereas the mechanical component have a lifetime of at least a 100.000 cycles. Crucial to the lifetime of the switch is the amount of volume tapped each time, low volumes mean a lot switching on and off for little water and thus reduce the total volume of water a switch is capable to provide. The assumption is that the UV-Tap will mostly be used to fill glasses and sometimes bottles. The average volume per cycle take is 300 mL. At this volume the microswitch can last for up to 15.000 L.

Based on these calculations the microswitch is the most likely to break first, followed closely by the battery. The two LEDs have a much longer lifespan and are not necessary to be considered in the lifespan of the product.

Appendix J: Functionality Test Protocol

1. Test Description

1. Procure all necessary products for the test
    a. 3M Petri film
    b. 3M Petri film spacer tool
    c. Sterile swabs
    d. E. coli (150CFU/100mL)
    e. Jerrycan
    f. UV-C reactor
    g. 5L water
    h. Gloves
    i. Alcohol (to disinfect) (ethanol)
    j. Alcohol Wipes
    k. UV-C protection glasses
    l. Incubator
    m. Sealable plastic bags
    n. Sample collecting cup
2. Put on gloves and glasses
3. Disinfect working surface, outer jerrycan
4. Fill the jerrycan with 10L of tap water
5. Add approximately the E. coli suspension with approximately 15.000CFU to the jerrycan.
6. Concentration should be approximately 150 CFU/100mL
7. Properly mix water in a jerrycan, as to create equal concentration levels in the whole suspension
8. Disinfect working surface again
9. Prepare 5 3M Petri film
    a. Write sample number and name on it
10. Use a sterile swab to collect the sample. Let 100mL of the solution run over the swab and distribute the collected sample over the 3M Petri film
    a. Use the 3M spacer tool to equally distribute the sample over the whole film
11. Place the prepared Petri film in the preheated incubator at a temperature of 37 degrees
12. Dispose of the solution in a sealed plastic bag to which 50mL of alcohol or chlorine is added. Wait for 30min before disposing of the solution.
13. Repeat the steps 9 – 12 for the same sample type, as to have 2 samples for the same test
14. Repeat steps 9-13 for different products.
    a. Before executing step 10 it is important to have the to be tested product treat the water according to the specifications of said product.
    b. Collect the wat that comes through the outlet immediately with a swab, let approximately 100mL run over the swab.
15. Products to test
    a. Steripen
    b. Klaran UV-C reactor
    c. Own Prototype

    i. 1 LED
    ii. 2 LED
    iii. 3 LED

16. Thoroughly disinfect with alcohol all surfaces and tools worked with.
17. Compare the colony count on all the different Petri films after 48h

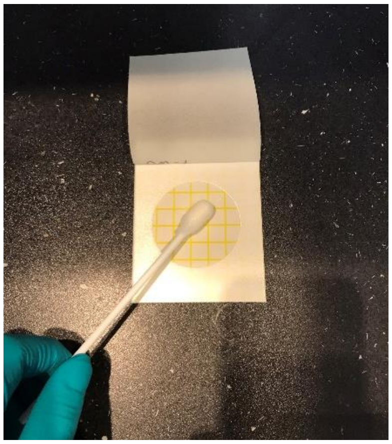
2. Test Execution

1. Required Attributes

2. Add E.coli sample to 5/10 L of water in the jerrycan

3. Collect Samples

4. Prepare Petrifilm



5. Place sample in incubator and wait for 24 hours.