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Water, Engineering and Development Centre
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Three-Pot Household Water Treatment System: Testing the Effectiveness

by

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A research project submitted in partial fulfillment of the requirements for the award of the degree of Master of Science of Loughborough University

August 2012

Supervisor: Mr. **Brian Skinner** - BSc CNAA, MSc Loughborough, CEng, MICE

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Acknowledgments

A long and tiring, but fruitful academic year is coming to its end with the present project. People I'd like to thank for this year and this project in specific...

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Acronyms, Abbreviations and Units

$_{o}$C……...Celsius degree
cfu……....colony forming units
cm……...centimeter
DO……Dissolved Oxygen
E. coli……Escherichia coliform
EHEC……..Enterohaemorrhagic Escherichia coli
ETEC……Enterotoxigenic Escherichia coli
gr……...…….grams
HWT……Household Water Treatment
HWTS……Household Water Treatment and Safe Storage
ID_{50}……..……median Infectious Dose
l……..……litre
lcd……..……..litres per capita per day
MDG……..Millennium Development Goals
mg……..……...milligram
ml……..…….millilitres
NTU……..Nephelometric Turbidity Units
p……..…….page
POU……..……..Point of Use
ppm……..……parts per million
RR……...……...Reduction Rate
SODIS……...Solar Disinfection
SS…….Suspended Solids
TCU……...True Colour Units
TDS……Total Dissolved Solids
UN……...United Nations
UNICEF…….United Nations Children's Fund
UV……..Ultra Violet
WEDC……..Water, Engineering and Development Centre
WHO……..World Health Organization
µS……...micro-Siemens

1.0 Introduction

1.1 Background

Water is one of the basic human needs, crucial for survival. Although two-thirds of the earth's surface is covered by water, only 2% of it is fresh water (Reed, 2012, p. 1.2), potentially suitable for human needs. This small amount is often contaminated and in addition the world's overpopulation, industrialization and climate change exacerbate the global water shortages (Jones, 1997, p.2).

It is commonly reported that 1,1 billion people lack access to safe drinking water. The fact that 2.6 billion people lack adequate access to sanitation as well, is a proof of why water is so often contaminated with faecal matter, thus why 1.8 million people die every year from diarrhoeal diseases (figures from: HWTS Network, 2007, p. 7). One of the Millennium Development Goals (MDGs), target 7C, was to halve by 2015 the proportion of the population without sustainable access to safe drinking water and basic sanitation facilities. Recently, that target of water was reported to have been reached already (UN, 2012). In spite of the proportion being halved, that still leaves the rest half without safe water, which is millions of people. "The lack of access to water and sanitation still for millions of people is the greatest development failure of modern era" (CIWEM, 2012, p. 1). So the battle to minimize the figure of people without access to safe water or to promote further development is an on-going long-term goal, even when the intermediary targets, like the MDGs, are achieved.

Less well known, since relatively recent, are the "conclusive evidence that simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of household stored water" (Sobsey, 2002, p. i). Household Water Treatment (HWT) options can have a large contribution on improving health of people (HWTS Network, 2007, p. 10), therefore play an active role to the long-term goal of development. Their contribution is only starting to be officially recognised. In the latest World Water Forum (6th World Water Forum, 2012, p.2), target 1.3.6 states that: "By 2015, 30 additional countries will have established national policies and/or regulations, regarding household water treatment and safe storage".

The three-pot water treatment system is a treatment option suitable for the household level, which consists of three containers. Water is initially stored in the first container for one day. Subsequently, it is being decanted into the next container, allowed to settle for another day. This is repeated for the third container as well. After three pots or three days of storage, water quality has significantly improved and water is safer for consumption than the initial one.

1.2 Research Contribution, Aim and Objectives

1.2.1 Research Contribution

On the one hand, there is still skepticism about the effectiveness of HWT interventions. Although research has "demonstrated the microbiological effectiveness and health impact of HWT as early as 1996, it was not immediately embraced by governments, NGOs or other potential implementers". "This view continues to persist widely among policy-makers and implementers, many of whom are unfamiliar with the more recent evidence" (Clasen, 2009, p. 54).

On the other hand, the three-pot water treatment system is usually not included in publications referring to HWT. The HWT options are officially: chemical disinfection, membrane-ceramic filters, granular media filters, solar disinfection, UV light technologies, thermal technologies, coagulation, precipitation and sedimentation (WHO, 2011, p. 141). Moreover, even when the three-pot water treatment system is mentioned, this is usually as a pre-treatment option or for cases of emergency. In addition, there are publications describing a similar procedure and referring to the three-pot system indirectly, but this particular name is less commonly referenced, thus less well-known.

The overall contribution of the present project follows the skepticism on the HWT options in combination with the common absence of the three-pot system from them. It is intended to test the effectiveness of the three-pot system, since it has never been tested before. In case the results are satisfactory, they may act as one more argument supporting that the three-pot system can be included clearly in the HWT options. Moreover, it is discussed why it should not be regarded only as an emergency or a pre-treatment option. Explaining why the name "three-pot system" should be used, may promote its reference by this name and therefore attribute to its recognition further more. Adding another option to the HWT "family" can put one more stone to the "safe drinking water barrier" humanity is trying to build in order to safeguard its health, therefore promote its development in a more holistic, equitable and sustainable way. The overall contribution of the three-pot system, generated the idea of the "development pyramid", shown in figure 1.1.

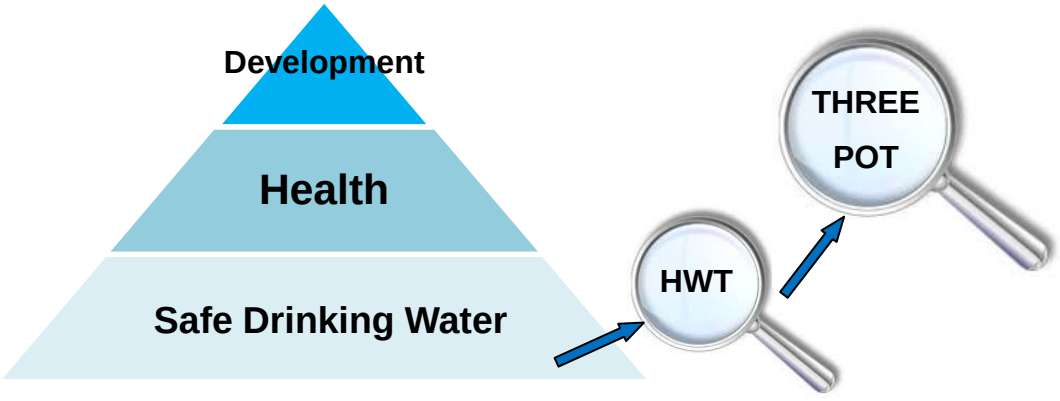


Figure 1.1: Three-pot System in the Development Pyramid (author, 2012)

1.2.2 Research Aim

The present research aims at testing the effectiveness of the three-pot household water treatment system, as stated in the project's title as well. Another possible title describing the aim in other words, suggested by the supervisor was: using household level storage to improve drinking water quality. However, this title was not opted, because it doesn't clearly refer to the three-pot system and the overall contribution mentioned above, intends to attribute recognition to the particular system itself and not only to its positive effects. The aim addresses the fact that there was no laboratory research traced particularly on the three-pot system (see section 2.3.1).

1.2.3 Research Objectives

The research objectives address some particular gaps in knowledge related to the three-pot system (see section 2.3.2). Here they are presented in the form of research questions so as to be more specific. Answering those, will allow conclusions for the research aim and subsequently for the research contribution. In that sense, the research questions are:

1. What is the bacteria removal effectiveness of the three-pot system?
2. How many days should the retention time be?
3. Is siphoning more effective than pouring?
4. Is the surface water of better quality than the water at the bottom?
5. How many pots should be used?

1.3 Project's Structure

In short, after the present introduction of the project (chapter 1), a literature review on the three-pot system and issues relevant to it follows (chapter 2). Then there is the methodology of the project and especially of the experimental work (chapter 3), followed by the laboratory results and their analysis (chapter 4). Last, recommendations on the three-pot system and on future research are given (chapter 5) and in the end the overall conclusions are summarised (chapter 6). The last two chapters are presenting the references (chapter 7) and the appendices (chapter 8).

2.0 Literature Review

The aim of the present chapter is to summarise the literature reviewed on the three-pot household water treatment system and to introduce the relevant issues connected to it. Literature was collected systematically and by the "snowball effect" (i.e.: sources found within one publication leading to even more relative sources). It was collected from various sources, presenting, the most important ones being: WEDC Resources Centre, WELL Resources Centre, Loughborough Library Catalogue, Google and Google scholar, WHO publications, UN publications, Oxfam, MSF and Red Cross papers, International Water and Sanitation Centre (IRC), Centre for Disease and Control Prevention (CDC), Rural Water Supply Network (RWSN), International Water Association (IWA), London School of Hygiene and Tropical Medicine (LSHTM), Sustainable Sanitation and Water Management (SSWM), Environmental Protection Agency (EPA), The International Network to promote Household Water Treatment and Safe Storage, Water Supply and Sanitation Collaborative Council (WSSCC), Science-Direct, Water-wiki and many others.

The keywords used in the searches, again presenting the most important ones, used in isolation or in several combinations, were: three pot water treatment (filtering, purification, settling) system (method, technique) / prolonged (plain, simple, safe) storage (settling, sedimentation) / household water treatment (management) or (point of use, point of consumption) system / water quality (improvement) . Guidance from one's supervisor was valuable.

2.1 Household Water Treatment and Safe Storage

2.1.1 Definition and Background

As pointed out in the introduction, the problem of safe drinking water still remains, despite all the national and international efforts. Only relatively recently it was officially recognised that "simple techniques for treating water at home and storing it in safe containers could save a huge number of lives each year" (WHO and UNICEF, 2005, p. 28).

Household water treatment and safe storage, usually abbreviated as HWTS (or HHWT, HWT), (also called point-of-use (POU) or point-of consumption water treatment systems and household water management) (HWTS Network, 2007, p.10) refer to simple and low-cost methods in order to improve and maintain the drinking water quality. For a system to be efficient at the HWT level the following aspects are important: "effectiveness in improving and maintaining microbial water quality, reducing waterborne infectious disease, technical difficulty or simplicity, accessibility, cost, socio-cultural acceptability, sustainability and potential for

dissemination" (Sobsey, 2002, p.3). To put it more simply: technical effectiveness, consumer acceptance and scalability (HWTS Network, p.26) are key issues for a sustainable HWTS.

Historically, most of the HWT interventions can be traced back to ancient times. Sedimentation, filtration, boiling and exposure to sunlight are physical methods recorded to improve the appearance and taste of water many hundred of years ago, although users at those time were unable to test the microbiological quality of the water (HWTS Network, p.11). All reviewed resources refer mainly to the book by M.N. Baker, called: The Quest for Pure Water; The History of Water Purification from the Earliest Records to the Twentieth Century, published by the American Water Works Association, New York, in 1948, who has concluded the most extensive research on the topic from a historical point of view.

2.1.2 Significance, Applications and Limitations

HWTS has been proved through recent research having a significant role to rectify many recent problems related to water quality. It is mainly reported to have a direct effect on diarrhoea reduction (Clasen et al. 2007 (a)). Moreover, it empowers the vulnerable and poor, towards self-reliance when it comes to covering one of their most basic needs, like water (Sobsey et al. 2008 and UNICEF, 2008, p.1). Also, only recently it was recognised that HWT needs to play an important role, if the Millennium Development Goal for water is to be achieved within the 2015 deadline (Clasen, 2009 and HWTS Network, 2007, p. 13). The indirect linkage of water with development is often pointed out through the effect of it on child mortality, school attendance, productivity, gender equity and life expectancy (WHO and UNICEF, 2005, p. 10-22).

Usually HWTS has been applicated in societies, where the options of a centralized water treatment system are limited, due to absence of infrastructure, finances or knowledge or where people have different priorities etc. However, the low cost and quick implementation of HWTS systems made them ideal for responding to disasters and emergencies as well. (Kayaga et al. 2011). This seems to have caused a confusion and a huge debate over the suitability of HWTS as a more permanent treatment alternative, to support actual development of a population. It is stated that HWTS are "on the edge of the tipping point" (Clasen, 2009, p. 59) on the way they are perceived from the global scientific community, since they have started gaining recognition only relatively recently.

The main argument in favor of HWTS systems is the fact that water often gets re-contaminated as it moves along from the source to the user (Sobsey, 2002). As a result, water at the POU is often more contaminated than it was initially (one may refer to this particular case study as a characteristic example: Rufener et al. 2010), so any centralized treatment

method can be a total waste of effort and money. Thus treatment at the household level is reported to be more effective and cost-effective than other options (Clasen et al. 2007 (b)). Interesting fact to cite is that “Household treatment cuts the primary transmission route for diarrhoeal disease and can pay back up to US$ 60 for every US$ 1 invested” (WHO and UNICEF, 2005, p. 23). A key idea for preventing re-contamination is safe storage, after the household treatment has taken place (Mintz et al. 1995). Safe storage is summarised to be, a vessel with some type of cover, together with a way of taking water out hygienically and occasional cleaning of the container (Smet et al. 1988, p. 10-1). Nowadays there is much more detail written about safe containers. It is pointed that in general HWTS should have a low-moderate technical difficulty (Sobsey, 2002, p.12, table 2 and 3), so the users can accept them more readily and such treatment systems are more likely to be sustainable and to be scaled up. These characteristics make HWTS suitable for development and not only for emergencies (UNICEF, 2008, p.2), especially for the poor families, who may not be able to afford a centralized water treatment system (WHO and UNICEF, 2005, p. 28).

Opponents of HWTS do not consider it as a permanent solution. They focus on the fact that HWTS alone is not the most important factor in the water equation for health improvement, because it focuses on the water quality aspect. There is a competition over water quality versus water quantity among researchers (see section 2.4.3) and opponents of HWTS are claiming that quantity is more important after all. They also focus on the other crucial factors needed in order for a health intervention to be successfully implemented, like hygiene and sanitation (Fewtrell et al. 2005), but also other factors like legislation, political commitment, education, capacity building, financial resources, monitoring and evaluating (WHO and UNICEF, 2005, p.23). Also, the opponents stand on the fact that the research into HWTS is relatively new, thus still limited and controversial (Clasen et al. 2007 (a), p.9 and WHO, 2011, p.146 and HWTS Network, p. 27). Another thing they claim is that even if there is adequate research, each case in the actual field is unique and methods relying on the user and not on strict technological applications cannot safeguard the result of safe water. As a result, these people argue that they can be featured only as a short term emergency measure, until the population is ready to move forward with more advanced techniques (WHO and UNICEF, 2005, p. 27).

Looking at the above debate with a critical eye, one could say that these are the two sides of the same coin. This debate can be seen as fruitful if one decides to stand on the supporting side of HWTS, because it raises some points of weakness, that can be targeted in order to make HWTS more robust in the long run. That is indeed the overall aim of the project as pointed out in the introduction, after focusing on a particular gap or weakness that was spotted (see section 2.3). Another way to conclude over the problem of emergency vs development is

the more holistic approach. There is no point in arguing about it, but it is wiser to deal with the same problem from many angles. “Promoting HWTS and improving water infrastructure are a complementary, not alternative, means to reduce waterborne disease” (HWTS Network, p. 27). One could say that the older idea of “appropriate technology” (Parr et al. 1999) is basically behind this recent admittance (Mintz et al. 2001, p. 1569). “Appropriate technology doesn’t imply modern and sophisticated technology versus basic technology, but on the contrary, out of a wide spectrum of possible methods, materials and systems, a choice must be made that is specifically tailored to a particular place” (Heber, 1985, p. 6). Besides, after reviewing the literature in chronological order (see characteristically the three-pot system on section 2.2.1) one may say that historically the households and therefore HWTS options existed before emergencies in the world. It is a fact that all the emergency water treatment manuals borrow HWTS techniques from literature referring to development and health.

2.1.3 Sedimentation in Household Water Treatment Systems

A review of the literature of HWTS specifically relating to sedimentation, since this is the main purification mechanism of the three-pot system (see section 2.2.4). Sedimentation, often characterized “plain sedimentation”, may also be called “settlement”, “gravity settling”, “storage” and “pre-treatment system” within the HWTS literature.

Among different publications there are small differences on which interventions are HWTS and which are not. Definitions of the various HWTS can be found in the latest guidelines (4th edition) by WHO (p. 141). According to WHO, HWTS are: • chemical disinfection • membrane-porous ceramic-composite filters • granular media filters • solar disinfection • UV light technologies • thermal technologies • coagulation • precipitation and/or sedimentation. Interestingly, “and” implies that sedimentation is used in combination with coagulation, while “or” implies plain sedimentation (without the use of coagulants) as a separate treatment option. Moreover, it is clear that the various HWTS can and should be used in different combinations, so as to achieve better results for human health, thus sedimentation is often only mentioned as a pre-treatment option. This idea is often called “multi-barrier approach” (WHO, 2011, p. 143 and Nath et al. 2006, p. 40 and Galvis, 2002, p. 267).

- Plain sedimentation

Sedimentation occurs in nature continuously, as a natural process contributing to the purification of lakes (Heber, 1985, p. 25). It is a solid-liquid separation process, where particles settle under the force of gravity (LeChevallier et al. 2004, p.12). “Sedimentation is the simplest treatment method” when it comes to water (Skinner, 2003, p. 101). The positive effects of plain sedimentation are common in all publications. Undisturbed storage basically allows suspended solids to settle down, thus there’s turbidity reduction, but also allows time

for pathogens to die off (Cairncross, 1993, p. 81), since the conditions are not suitable for their multiplication and survival (Skinner, 2003, p. 101). Along with suspended solids, attached pathogens will settle as well, so the water quality near the surface is further improved (Skinner et al. 1999 (a), p. 102). “Storage can be regarded as treatment”, because the suspended solids will settle, faecal coliforms will be considerably reduced and *Schistosoma Cercariae*, the intermediate host of schistosomiasis (bilharzia), will die after 48 hours of storage (Galvis, 2002, p. 275). Helminth ova and other protozoas are significantly reduced as well (Sobsey, 2002, p. 22).

In an attempt to quantify this positive effects, one could say that literature doesn't come to a common conclusion. Usually it is claimed that storing water for one day around 50% of most bacteria will die off and logically longer periods will lead to further reductions (Skinner et al. 1999 (a), p. 102). The same is being presented as the required performance, where plain sedimentation removes 50% of faecal coliforms and 50% of turbidity (Galvis, 2002, p. 281, table 12.5). “Overall reductions of viruses and bacteria by sedimentation rarely exceed 90%, but reductions of helminth ova and some protozoas can exceed 90%, especially with longer storage times of 1-2 days”. (Sobsey, 2002, p. 22)

In comparison to other water treatment procedures, it is reported (WHO, 2011, p. 146, table 7.8) that plain sedimentation has zero reduction value (on a $\log_{10}$ scale) on bacteria, viruses and protozoa when performed by unskilled people, but when performed by skilled personnel, bacteria and viruses have 0.5 log reduction and protozoa 1 log reduction. The same pattern is reported again (Galvis, 2002, p. 276, table 12.1) where sedimentation seems to have a positive effect only on taste/odour and some metals and zero on all pathogens and turbidity. Similarly, but a bit better, (Heber, 1985, p. 14, table 3 and Skinner et al. 1999 (a), p. 103), sedimentation has 1-2 ranking (on a 0-4 scale) on bacteria removal and 2 ranking on turbidity. One should not misinterpret these results. They are based on studies recorded in scientific literature and “the comparison is only general, due to the multiple factors affecting water treatment efficiency” (Galvis, 2002, p. 275). They don’t mean that sedimentation has zero effectiveness at improving water quality, as some may think at first. Proof of this is that within the same publications, there are separate references to sedimentation and its effectiveness at reducing the bacteria content, as already mentioned above. They just suggest that there are other methods that are much more effective, at achieving water quality improvement. Efficiency though, has a broader sense than effectiveness, as discussed in section 2.1.1.

- Sedimentation with coagulation

Settlement of water can improve its quality, since most suspended matter settles out to the bottom, but usually the finest particles will remain suspended, unless coagulants are added

(Reed et al. 199, p. 47). That argument is based on the fact that density, size and shape of the particles are crucial to the sedimentation process (Heber, 1985, p. 25 and Davis et al. 2002, p. 318). Particles that are lighter than water will not settle, unless they are attached towards each other, or towards the added material (Skinner et al. 1999 (b), p. 105), until they become larger. The added materials are called coagulants.

Basically, coagulants reduce the electrostatic repulsion between particles and allows the electronic attraction forces (Van der Walls') to flocculate the particles (Ives, 2002 (b), p. 296). Common coagulants are reported to be: chemically originated (aluminium sulphate and iron hydroxide), soil originated (clay and lime), plant originated (moringa seeds and polysaccharides) (Nath et al. 2006, p. 39). Details on coagulation is beyond the scope of this project. One may refer to Ken Ives, Coagulation and Flocculation (Ives, 2002 (b)), for further details.

It is worth mentioning that settlement processes, especially in larger volumes of water, "seldom perform in accordance with theory", since the density of water isn't uniformly distributed. Moreover, temperature of water and salt content (changing often through evaporation of water), can alter its density significantly, thus influence the sedimentation procedure (Heber, 1985, p.29).

All these scientific features in greater detail on the sedimentation process of particles are again beyond the scope of this literature review. However, the author would recommend the book of Martin Rhodes, Introduction to Particle Technology, for further understanding. Basically, sedimentation by gravitational force is ruled by Stoke' s Law, where the parameters are: diameter, effective solid density, liquid density, liquid viscosity and settling velocity (Rhodes, 2008). Shape, population and colloids of particles are also important issues looked in detail within the chapters of Rhodes' book. Some of these issues only are presented in section 2.2.4 within this project.

- Sedimentation as pre-treatment

Sedimentation is commonly regarded as initial part of a treatment process, thus called pre-treatment. It can be either plain sedimentation or sedimentation with coagulation. The difference now is that it is not regarded as worthy treatment process to be implemented on its own. "Sedimentation doesn't remove the harmful organisms, but it helps to clarify the water before other treatment takes place" (Cairncross, 1993, p. 81)

Usually it is reported that "gravity settling of highly turbid water for household use is recommended as a pre-treatment for systems that disinfect water with solar radiation, chlorine

or other chemical disinfectants" (Sobsey, 2002, p. 23). Turbidity, to put it simply, is less transparent water, with more flocks in it, within which pathogens may be "protected" (Campbell, 1983, p. 119 and Spellman, 2003, p. 370). Thus chemicals like chlorine or solar radiation cannot "attack" the harmful pathogens in the water so effectively so larger doses are required. In that sense, settlement reduces the turbidity and consequently, water demands less chlorine to be disinfected (Kotlarz et al. 2009) or less solar radiation. Furthermore, settlement of particles improves practically the aesthetic qualities of water (colour, taste and odour) and consumers may therefore be more willing to drink it (Sobsey, 2002, p. 23).

The necessity of sedimentation as a pre-treatment method is given in many tables within publications, even when the writers do not refer to plain sedimentation in their analysis. Tables like table 3 (Heber, 1985, p. 14) and table 12.4 (Galvis, 2002, p. 280), show clearly that especially in highly turbid and highly polluted water, plain sedimentation needs to be the initial step of the treatment process.

Overview of everything on sedimentation is nicely presented in part 4.2: Plain Sedimentation or Settling, by Sobsey, 2002 (p. 22), where this summary table is taken from.

Advantages	Disadvantages	Comments
Simple, low cost technology to reduce settable solids and perhaps some microbes for water	Only settable solids, such as sands, silts and larger microbes settle efficiently; clays and smaller microbes do not settle; only moderate to low microbe reductions	Can be applied to large and small volumes of water using commonly available water collection and storage vessels; settled material must be removed and vessels cleaned regularly
Removal of settable solids can reduce turbidities and make the water more amenable to other treatment methods to reduce microbes	In some waters solids are not efficiently removed by settling and alternative methods of removing solids are required	Reduced levels of solids (turbidity) improves penetration of UV radiation (from sunlight), decreases oxidant (e.g., chlorine) demand, decreases solids-associated pathogens
Recommended as a simple pre-treatment of household water prior to application of other treatments to reduce microbes	Unreliable method to reduce pathogens; solids are not efficiently removed by settling from some waters; can be labor-intensive	Pre-treatment to remove solids (turbidity) is recommended for turbid waters prior to solar or chemical disinfection

Table 2.1: Advantages and disadvantages of plain sedimentation for HWT (Source: Sobsey, 2002, p. 22)

Sedimentation can be used on much a bigger scale than that of HWTS, since it is an ancient method of purification, either when using smaller vessels or even bigger storage tanks (Sobsey, 2002, p. 22). The Romans were reported to have settling reservoirs within their water treatment system from 100 AD (Galvis, 2002, p. 271). Publications on water tanks, rainwater collection systems, waste stabilization ponds, water-wastewater treatment plants and so forth, always refer on the effectiveness of sedimentation as a crucial part of the treatment process. Much of the information already presented was based on sedimentation tank design characteristics (Skinner, 2003, p. 101, Ives, 2002 (a) and Heber, 1985, p 25).

2.2 The Three-Pot Water Treatment System

2.2.1 Definition and Background

As mentioned in the above section, the three-pot water treatment system is based both on the idea of HWTS and on the principle of sedimentation, which are traced back in ancient times (see sections 2.1.1 and 2.1.3). Searching the literature specifically for the three-pot water treatment system, it was concluded that the technique was initially launched with this name in a publication by the International Water and Sanitation Centre (IRC) in 1988 (Smet et al. 1988, p. 10.13).

The three-pot method is defined within this document to be "an effective means of purification", through prolonged storage, where "any type of storage containers can be used" (Smet et al. 1988, p. 10.13). The procedure is serial and basically is the following:

Day 1: Water is collected in pot 1.

Day 2: Water stored for a day in pot 1 is slowly poured in pot 2. Pot 1 is being cleaned and refilled with raw water.

Day 3: Water stored for a day in pot 2 is slowly poured in pot 3. Pot 2 is being cleaned and water stored for a day in pot 1 is slowly poured in pot 2. Pot 1 is being cleaned and refilled with raw water.

Users can consume water from pot 3 on day 3, which has been allowed to settle for 48 hours or can use the water from pot 3 on day 4, after three days has passed (one day per pot). Siphoning instead of pouring can be done as well.

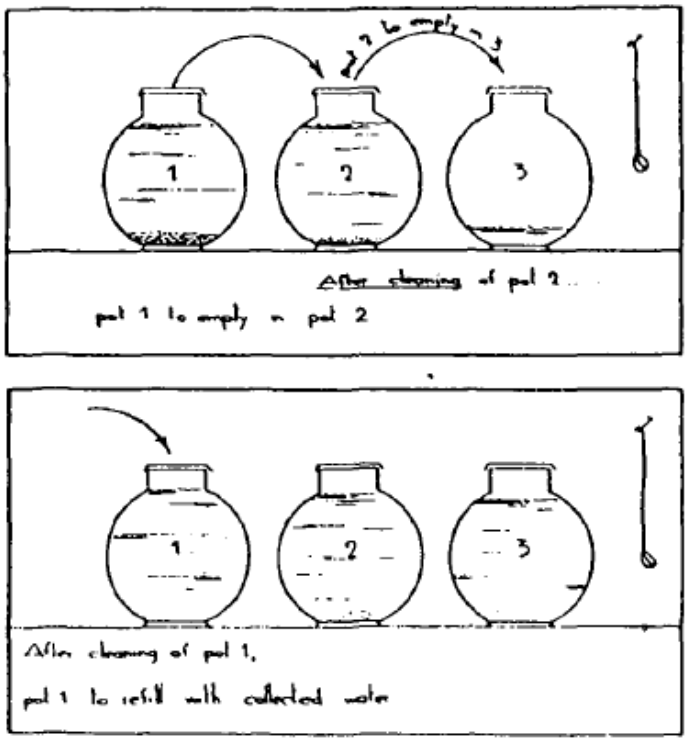


Figure 2.1: Prolonged storage (source: Smet et al. 1988, p. 10.13)

In chronological order, the three-pot system appeared again in literature in 1999, on a series of technical briefs by WEDC (Skinner et al. 1999 (a), p. 102). Although the procedure is the same and the main advantages are described under the “storage and settlement” heading (see: plain sedimentation in section 2.1.3), the contribution of the particular publication is a more comprehensive image, including the instructions. One could say that the particular paper’s significance is that it brought the three-pot more into the scene for HWT. Evidence of that is the number of publications and websites that started referring to it basically only after 1999 and the fact that the same image is being reproduced in most cases.

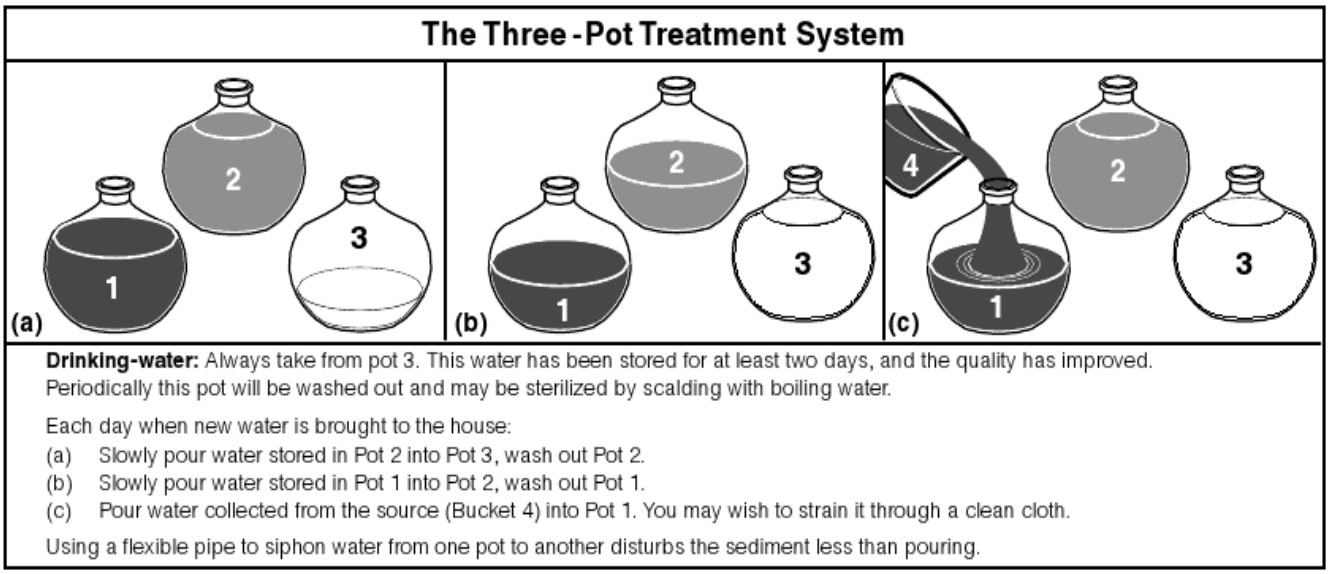


Figure 2.2: The three-pot treatment system (source: Skinner et al. 1999 (a), p. 102)

Then the three-pot was roughly mentioned as an alternative water treatment technology under the “storage and settlement” option in 2000 (CDC, 2000, p. 139). In figures 19 and 20 (CDC, 2000, p. 142-143), there is a comparison table for all HWTS, presenting technical and economic facts as well. In a publication in 2005, it is shown as a HWT option (Wijk et al. 2005), along with some advantages and limitations of the method (see section 2.2.2). Also, it was found again in a 2005 publication, as an option to make safe water for drinking and cooking (Conant, 2005, p. 38), where a slightly different idea of the method is introduced. Pots 1 is being filled with raw water on day 1 and pot 2 on day 2. Water settles for two days in the same pot, before being poured into pot 3, from which it is directly drinkable. The need for three pots makes sure that the user has two-day settled water every day, otherwise two pots are enough.

Again the three-pot is cited in 2008, as a method for household water treatment (IFRC, 2008, p. 16 and 30), but this is the first time it was found to be mentioned as an emergency measure. A more colorful illustration (p.16) and a factsheet (p. 30) are used this time. The fact that two instead of three pots can be sufficient with longer retention times is clearly presented as an “emergency tip”.

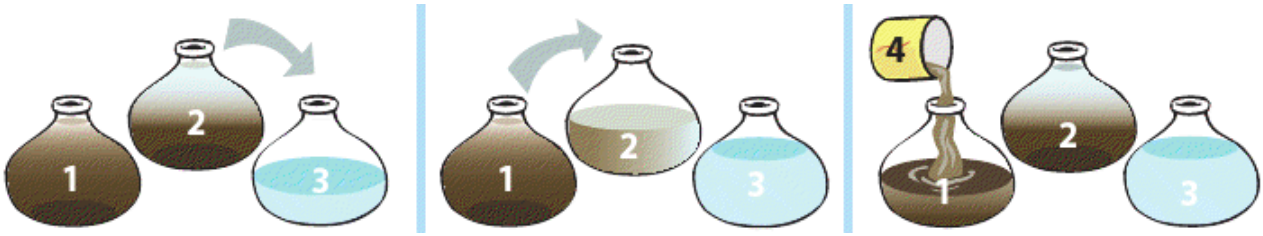


Figure 2.3: The three-pot method (Source: IFRC, 2008, p. 16)

Although, all publications are respectable and from well known institutions, the most official recognition one could say, comes with the 3rd edition of WHO drinking-water guidelines in 2008 (WHO, 2008, p. 141-c), where very roughly the three-pot is described as a simple sedimentation option for improving drinking-water quality at the household level (WHO includes the same section in the latest guidelines (WHO, 2011, p. 143) as well). Then it is more inclusively mentioned in 2010 again as an initial part of the HWTS option (CAWST, 2010, p. 4), with an attempt to give some more non-technical details (see section 2.2.2 within this project). In 2011 it was included in WHO technical notes for emergencies once more as part of the pre-treatment process (Kayaga et al. 2011). The most recent reference to the three-pot (HETV, 2012 (a)) was on an online update of the (CDC, 2000) publication in 2012, where the "gap in knowledge" was spotted (see section 2.3).

It is a fact there are quite a few publications and websites referring to the three-pot system, but most reproduce the above mentioned ones, therefore it is not worth discussing these on this project. Depicting all the images was done on purpose, so that each time the original publication can be traced easily.

2.2.2 Overview of Literature on Three-Pot

On this section, a summary table and an overview of the literature found directly on three-pot system is presented. For review of the "indirect" literature, meaning the sedimentation process, see section 2.1.3. The publications are in chronological order, the notes are actually what each publication claims and the last column is the author's comment.

Publication	Notes	Comment
1. Smet et al. 1988, p. 10.13	• household water treatment • 24-48 hours storage period on each pot • evidence that prolonged storage improves water quality • disease causing organisms will still be present after treatment	• first appearance in official papers and first illustration • no reference to that evidence

	• settlement of silt and death of pathogens • siphoning can be used • safe storage, periodically clean vessels	• no justification why
2. Skinner et al. 1999 (a), p. 102	• household water treatment • 24 hours storage period on each pot • 50% of most bacteria will die after a day • longer retention times are better • *cercariae* die after 48 hours • disease causing organisms will still be present after treatment • settlement of silt, death of pathogens and settlement of attached pathogens • water near the top has better quality • siphoning will disturb the sediments less • safe storage, periodically clean vessels with boiling water	• second appearance that brings the three-pot in the scene of HWTS, along with the most commonly reproduced illustration • better explanation on the removal mechanism • better justification on siphoning
3. CDC, 2000, p. 139	• household water treatment • 24 hours storage period on each pot • 50% of most bacteria will die after a day • water near the top has better quality • *cercariae* die after 48 hours • disease causing organisms will still be present after treatment • settlement of silt, death of pathogens, reduction of turbidity • pots are easily available locally • no lab tests, no field tests on the method • cost of three pots only as capital investment, zero recurrent costs, as long as the pots last	• basically reproducing Skinner et al. 1999 (A), p. 102 • mentioning clearly the turbidity improvement • first comparison of the three-pot with the rest HWTS (figure 19-20, p. 142-143) • first critique of economic aspects as well
4. Wijk et al. 2005	• household water treatment • 24 hours storage period on each pot • 50% of most bacteria will die after a day • longer retention times can have 90% reduction • disease causing organisms will still be present after treatment • cloth at the inlet point can hold	• basically reproducing Skinner et al. 1999 (A), p. 102

	sediments and guinea worm • simple to use and maintain, affordable, cost-effective, sustainable, suitable for rural/peri-urban areas • safe storage and handling, periodically clean vessels with soap/disinfectant	• first critique of socio-economic aspects as well and idea of sustainability
5. Conant, 2005, p. 38	• household water treatment • 48 hours storage period on each pot • 5-6 days are advised • disease causing organisms will still be present after treatment • *giardia* never dies • one pot can be used but less safe • siphoning will disturb the sediments less • periodically clean vessels with boiling water	• alternative way of storing the water • idea of using only one pot
6. IFRC, 2008, p. 16	• emergencies measure • 24 hours storage period on each pot • disease causing organisms will still be present after treatment • cloth at the inlet point can hold sediments • siphoning will disturb the sediments less • two pots are minimum requirement, but require more retention time • local materials, cheap and easy method • advised for contaminated, muddy water, when boiling isn't a option (decision tree, p. 27) • periodically clean vessels with boiling water	• first appearance in emergency manuals, along with a more colorful illustration and factsheet • idea of using two pots • critique of socio-economic aspects as well • decision tree to show suitability of three-pot
7. WHO, 2008, p. 141-c	• household water treatment • 24 hours storage period on each pot • disease causing organisms will still be present after treatment • settlement of silt and settlement of attached pathogens • suggestion of cloth	• mentioned only roughly, but first globally official recognition of three-pot system as a HWTS method

8. CAWST, 2010, p. 4	• initial stage of household water treatment • 24 hours storage period on each pot • longer retention times can have 90% reduction • disease causing organisms will still be present after treatment • ladling or any gentle-to-the-sediments method • lifespan depends on containers • direct cost practically zero • simple and easy, therefore robust • effectiveness tested on the lab, not on field • periodically clean vessels with water	• only as part of the overall household water treatment • good critique of socio-economic aspects as well • using (Sobsey, 2002) as a reference, but there are no lab tests on three-pot in that publication, 90% refer to plain sedimentation studies
9. Kayaga et al. 2011	• emergencies measure as pre-treatment • 24 hours storage period on each pot • 50% of most bacteria will die after a day • longer retention times are better • *cercariae* die after 48 hours • disease causing organisms will still be present after treatment • settlement of silt, death of pathogens and settlement of attached pathogens • siphoning will disturb the sediments less • safe storage, periodically clean vessels with boiling water	• basically reproducing Skinner et al. 1999 (A), p. 102
10. HETV, 2012 (B)	• household water treatment • 24 hours storage period on each pot • 50% of most bacteria will die after a day • water near the top has better quality • *cercariae* die after 48 hours • disease causing organisms will still be present after treatment • settlement of silt, death of pathogens, reduction of turbidity • pots are easily available locally	• same as (CDC, 2000) only updated in 2012

	• no lab tests, no field tests on the method • cost of three pots only as capital investment, zero recurrent costs, as long as the pots last • there are filed tests, but uncertain if any lab tests exist	• after the update, field tests were traced, but not lab ones

Table 2.2: Overview of literature review on the three-pot

As mentioned above, there are several more publications on three-pot, but they all refer or reproduce the ones summarised on table 2.2. Even among these publications, there is a tendency to reproduce the first two ones, but still there is a new contribution on each case. That is how it was decided which publications would be included in the literature review and which should be left out.

In summary, the three-pot system is mainly described as a HWT option in development and health publications and is found only in two emergency ones (IFRC, 2008, p. 16 and Kayaga et al. 2011). The procedure doesn't differ that much on its basis. There are only slight operational differences, such as: one-two-three pots, pouring-siphoning-ladling water out, 24-48 hours as retention time, use of cloth for further quality improvement (see section 2.2.3). Moreover, it is commonly cited that at the end of the treatment period, the pathogens will have been reduced, but not totally removed. The removal efficiency ranges from 50%-90% and that percentage varies with different types of pathogens. The magnitude of the effect of these slight differences remains to be researched (see section 2.3 and chapter 5).

Only relatively recently the idea of overall efficiency of HWTS and not only microbiological effectiveness started being introduced with the presentation of socio-economic aspects as well. In (CDC, 2000, p. 143, figure 20), there's a capital and recurrent cost analysis, where the three-pot system is claimed not to have costs apart from the initial purchase of the pots (if not already available). Then in (Wijk et al. 2005), it is suggested that the three-pot is simple to use and maintain, affordable, cost-effective and therefore sustainable and suitable for rural/peri-urban areas. Similarly it is presented in (CAWST, 2010, p. 5), where it is characterized as "robust" instead of "sustainable".

To summarise the advantages, limitations and ideas on further improvement, table 2.3 was created. The literature review has also lead to identification of the "gap in knowledge", as shown on table 2.2 and explained on section 2.3.

Advantages	Limitations	Further improvement
• both as a regular HWT option and for emergencies	• disease causing pathogens are reduced but not eliminated	• use of straining cloth at the inlet
• pots are easily available at the local level	• water near the surface is better than that at the bottom	• siphoning instead of pouring water
• cheap, basically there's only the cost of the pots initially	• improved water after 24-48 hours minimum	• periodically clean vessels
• flexible, any vessel can be used, 1, 2 or 3 pots as well		• further storage longer than 48 hours
• simple and easy to use and maintain		
• cost-effective and sustainable (or robust)		
• suitable for rural and peri-urban communities		

Table 2.3: Summary of literature review on the three-pot

2.2.3 Design Characteristics

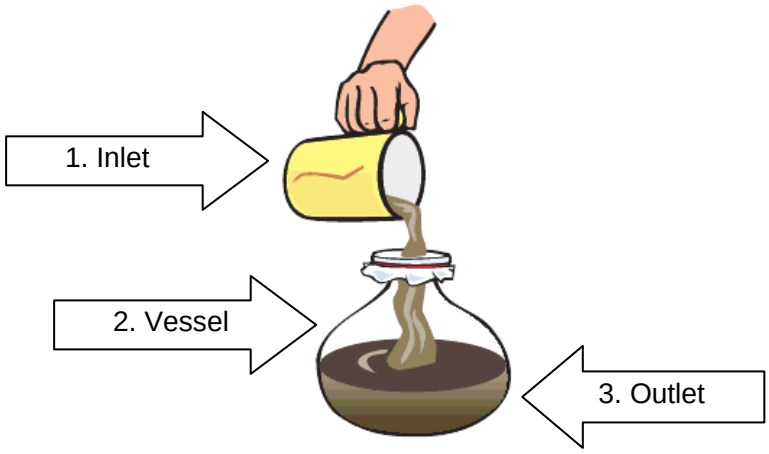


Figure 2.4: Design characteristics (based on: IFRC, 2008, p. 33)

Studying all the above literature on the three-pot system, the author came up with figure 2.4, just to depict the design characteristics and to summarise the areas were the publications have small differences. This idea was conceived after identifying the gap in knowledge (see section 2.3) and before the laboratory experiments, so as to decide the methodological details for the experimental procedure (see chapter 3). Similar concept was initially found in previous thesis as well (Qi, 2007).

The design characteristics are:

1. a. Inlet water quality → not specified

b. Inlet water quantity → 2-3 lcd only for drinking in emergencies up to as much is needed for all the household purposes

c. Use of cloth or not at the inlet point → cloth can filter out larger sediments and guinea worm

2. a. Size of vessel → not specified, depends on the water quantity

b. Shape of vessel → not specified, depends on availability and preference

c. Material of vessel → not specified in connection to the efficiency (only in (Smet et al. 1988, p. 10.13) earthen potters are better for their cooling effects)

d. Rest vessel characteristics (colour, opening, lid, handle, tap) → not specified (mentioning only that vessels need to be periodically cleaned)

e. Number of pots in use → three-pots are best, only two-pots are still feasible, one-pot is possible (but in (Conant, 2005, p. 38) is claimed to be less safe)

f. Retention time (days of storage) → usually 24-48 hours or as long as possible (in (Conant, 2005, p. 38) 5-6 days are claimed to be better) in each vessel or in total

3. a. Method of decanting → pouring, siphoning or ladling

b. Point of abstraction → not specified (in (Skinner et al. 1999 (a), p. 102) suggested better at the top)

c. Outlet water quality → depends on many variables (usually claimed that there's 50% reduction in pathogens after one storage day and up to 90% in total)

For details on the design characteristics and how they may affect the three-pot system, refer to section 2.4 of the "Related Issues".

2.2.4 Purification Mechanisms

In the present section, the purification (quality improvement) mechanisms of the three-pot system is described, based on water/wastewater literature in general. Referring to publications on sedimentation tanks (LeChevallier et al. 2004, p. 9, table 2.2), the purification processes of the three-pot system are mainly physical and biological. The rest processes mentioned in the particular table, basically describe the situation in sedimentation tanks. They can potentially occur in a pot, but to a smaller extent. In that sense and consulting other literature as well, the two basic mechanisms are:

1) Physical: a) Transportation of substances
   b) Aeration
   c) Floatation of substances
2) Biological: Die-off of pathogens

It is understood that the main purification processes for the three-pot are sedimentation of substances and die-off of pathogens. However, the author decided to look at the topic from a wider perspective and the above larger categories were stated. In similar sense, aeration is included basically to describe better the case of pouring the water in comparison with siphoning (see chapter 4) and the use of three pots instead of one. Likewise, floatation will occur with solids which have lower density than water (Spellman, 2003, p. 545) or are being held at the surface by the force of buoyancy, as observed during the experiments with small leaves and insects.

In more detail:

1-a) <u>Transportation</u>

Transportation includes the movement of any type and size of particles that may exist in the water, organic or inorganic. In recent bibliography, there is a separation between suspended and colloidal particles. Colloids are sized smaller than 1μm and are dispersed within the water, so it is more difficult for them to settle on their own (Mara et al. 2003, p. 633). In figure 2.5, one can see separation techniques for different sized particles. As one notices, bacteria fall under both categories and viruses are colloidal.

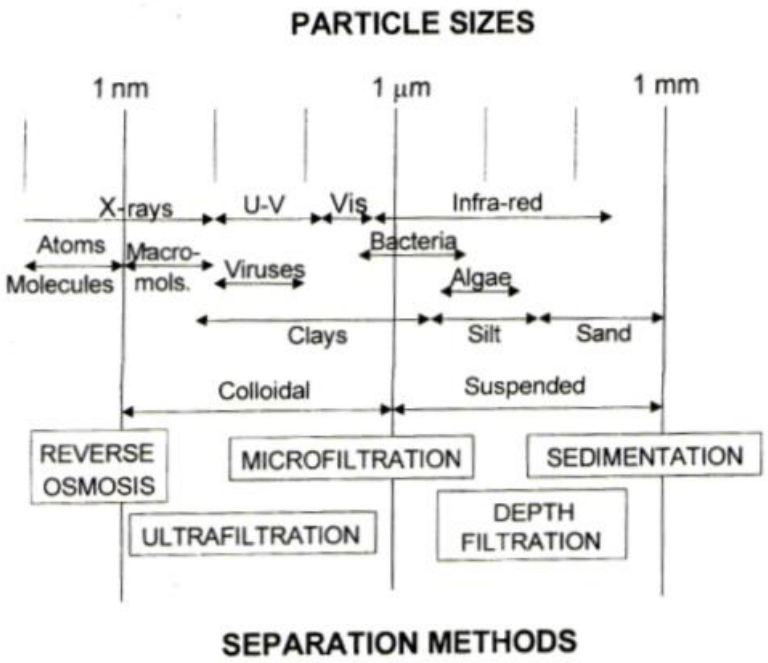


Figure 2.5: Separation techniques for different particle sizes (source: Mara et al. 2003, p. 634)

Either as a suspended particle or as a colloid, in the three-pot case, transportation involves sedimentation and diffusion (LeChevallier et al. 2004, p. 68), which are also involved in grain filtration.

- ***Sedimentation*** occurs when gravity exceeds buoyancy and drag forces on a single particle (Rhodes, 2008, p. 31). The drag force is basically described by Stoke' s law which was proposed in 1851 (Rhodes, 2008, p. 29). That gives a settling velocity U_T under gravity :

$$U_T = \frac{x^2(\rho_p - \rho_f)g}{18\mu}$$

where: x is the spherical solid's radius, ρ_p is the particle's density, ρ_f is the fluid's density, g is the acceleration due to gravity and μ is the fluid's viscosity. Shapes other than sphere affect the basic law (Rhodes, 2008, p. 33). Also, the basic law on a single particle is affected when there is a multiple particle system, since the motion of each particle is influenced by the motion of nearby particles (Rhodes, 2008, p. 51). Both of these, apply in the case of settling raw water. As shown in figure 2.5 or from Stoke's law, sedimentation is more effective when the particle is bigger.

- ***Diffusion*** is ruled by Brown's movement law and thermal energy. According to this, random motion increases the contact probability between particles and thermal energy (translated into water temperature) increases these random collisions (Rhodes, 2008, p. 119).

In cases of grain filtering, authors refer to attachment or adsorption, separately to transportation, as a purification mechanism. Applying the idea of adsorption can be used in the three-pot case, in order to explain the attachment of suspended particles to one another and the formation of colloids. The forces that rule both transportation and attachment, besides Stoke's and Brown's mentioned above (body forces), are Coulomb and van der Walls (surface forces) (Huisman et al. 1974, p.30). Surface forces contribute to transportation before any contact is made (Huisman et al. 1974, p.30) and in the case of colloids, they play an even more significant role than the body forces (Rhodes, 2008., p. 117).

- ***Mass attraction*** is ruled by van der Walls forces. It is the universal attraction force for atoms and molecules basically, therefore it applies when particles are in proximity (Mara et al. 2003, p. 635).

- ***Electric interaction*** is ruled by Coulomb forces. It is actually attractive or repellent forces, between same or opposite charged surface layers (single or double layers) (Mara et al. 2003, p. 635). Organic colloids, including bacteria are usually negatively charged, therefore they are most likely to be repelled by one another (Huisman et al. 1974, p.30).

There is also the DLVO theory, that looks at these two surface forces in combination and predicts the stability of colloids, depending on particles separation distance and salt concentration (Mara et al. 2003, p. 637). One interesting point to note is that based on

coagulation kinetics theories (Mara et al. 2003, p. 642), collision of particles occur better in turbulent flow and the higher the particle concentration, the better. For details on colloids in general, one may refer to chapter 38: Coagulation and filtration in (Mara et al. 2003) or chapter 5: Colloids and fine particles in (Rhodes, 2008).

To sum up, many variables will affect the transportation mechanism, so it is difficult to predict every time the effectiveness based on theoretical models. These variables are: particle size and shape, particle density, particle surface charge, liquid density, liquid viscosity, liquid temperature, salt content, settling velocity, particles population, colloids, turbulence.

1-b) <u>Aeration</u>

Aeration (or oxygenation) is mainly the exchange of oxygen and carbon dioxide with the atmosphere. It is basically described in literature with the use of aerators in water treatment procedures, but aeration occurs naturally from any water surface. Aerators basically magnify this natural process. With aeration, the oxygen content of water is increased, carbon dioxide is decreased and volatile organic compounds responsible for bad taste and odour (like hydrogen sulphide and methane) are removed (Ives, 2002, p. 286). It is also used for oxidizing iron and manganese (Skinner et al. 1999, p. 102). Moreover, increasing the dissolved oxygen content, makes the water taste less “flat” (Reed, 2011, p. 16) and particularly in sunlight, supports some chemical reactions, which indirectly, lead to microbial reductions (Sobsey, 2002, p. 34). Last it can reduce temperature as well (Heber, 1985, p. 32).

In that sense, one could see the positive effect of pouring water from one pot to the other, each day for three days, instead of storing the water in one pot for three days. The idea is similar to cascade aeration, where water flows through basins by gravity (Heber, 1985, p. 32, figure 4). The difference is that on the three-pot option, the procedure is manual, like in shaking water aeration (Skinner et al. 1999, p. 102). Aeration can also explain any difference between pouring and siphoning, since more contact is allowed between air and water in the first case.

1-c) <u>Floatation of substances</u>

Floatation will occur in solids which have lower density than water (Spellman, 2003, p. 545). It is mainly practised mechanically in water and wastewater treatment plants with dissolved air, to separate and remove suspended solids, algae, fungi, oils and pathogens attached to it (Rubio et al. 2007). There are cases in which protozoa are more effectively removed by mechanical flotation than sedimentation itself (Mara et al. 2003, p. 713). In the three-pot system, flotation occurs naturally as a result of the force of buoyancy of small leaves, insects, algae and oils, as observed during the experiments.

2) <u>Die-off of pathogens</u>

Reduction of pathogens in the three-pot system is mainly due to their sedimentation (alone or adsorbed to suspended solids) and natural die-off. Death in nature may occur by aging, by starvation or by predation by other organisms (Mara et al. 2003, p. 486). The ability to survive is called persistence (Feachem et al. 1983, p.59).

Aging is part of the natural growth cycle, as shown in figure 2.6. The environmental conditions (oxygen, pH, temperature, nutrients, toxicity) prolong or speed up the natural death procedure (Spellman, 2003, p. 329).

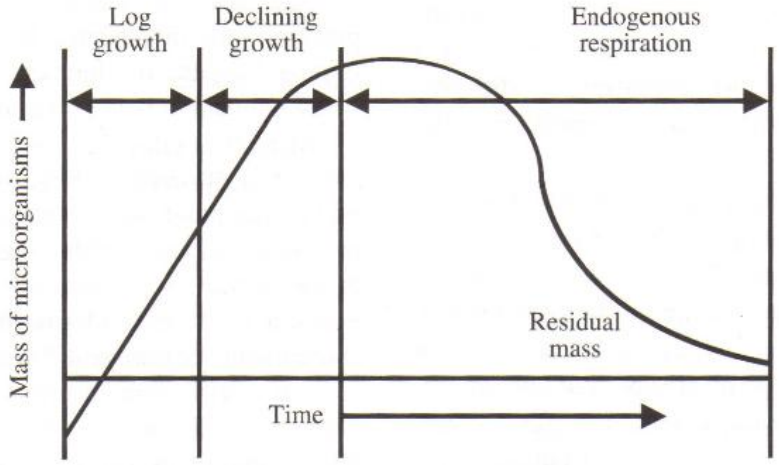


Figure 2.6: Micro-organism growth curve (source: Spellman, 2003, p. 329)

Starvation is when there is not enough food for pathogens to grow and multiply. Organic food in a closed system (like the pot) will decrease in quantity as time goes by. Food is being consumed by pathogens continuously, but logically some of it is being adsorbed by suspended solids as well. This actually raises natural competition between pathogens (Huisman et al. 1974, p.22) and only the most persistent will be able to survive. Predation is when certain organisms are using other pathogens as their food, as it is reported in some cases (Mara et al. 2003, p. 616).

“For any given system, there are essentially two factors in pathogen removal: how long the pathogen stays in the system and how quickly it dies” (Mara et al. 2003, p. 482 and Feachem et al. 1983, p. 59). In other words, retention time and type of pathogen, affect the above curve or natural death, besides the environmental conditions. Based on experiments, die-off kinetics of pathogens are based on first order equations, so they follow an exponential curve, which is basically the last part of the whole growth cycle. Reproduced in all literature from (Feachem et al. 1983, p. 207):

$$\frac{dC}{dT} = -kC \text{ or } C = Co\, e^{-kT}$$

where: C is the concentration of pathogens at T time, T is time, k is the die-off rate and Co is the concentration at T=0. Death rates are higher in natural water, with active flora and fauna, and increase with the rise of temperature (Feachem et al. 1983, p. 209). According to that theory, the probability of a pathogen dying is independent of its age. But practical studies, show evidence of multiplication or even recovery (Mara et al. 2003, p. 617). This is of limited duration and occurs in specific nutrient, temperature and non-competitive environments (Feachem et al. 1983, p. 209). This is logical to happen, since it is actually the initial stage of the growth curve in figure 2.6. In a limited environment though, where the conditions are stable and there is no active treatment, but with time allowed to pass, passive treatment is being applied in a natural way (Strauss, 1985, p. 4). This is called the "self-purification" process of water bodies (Mara et al. 2003, p. 616).

The last theory worth to mention is borrowed from die-off kinetics in ponds, reproduced form (Marais, 1974). For a single pond:

$$N_e = \frac{N_i}{1 + K_t \Theta}$$

where: N_e is the number of bacteria per unit of effluent volume, N_i likewise for influent volume, Θ is the mean hydraulic retention time in days and K_t is a constant depending on temperature. From observations, for temperatures 5-20 ^{o}C, $K_t = 2.6 * 1.19^{(T-20)}$, where T is temperature. For a series a ponds with the same retention time, that equation would become:

$$N_e = \frac{N_i}{(1 + K_t \Theta_p)^n}$$

where: n is the number of ponds and Θ_p the mean hydraulic retention time in each pond. As a result of multiple ponds in series, water quality is further improved, than when one single pond is used. This is basically because short-circuiting and its resulting turbulence are being minimized, therefore sedimentation is aided (Mara et al. 2003, p. 487 and LeChevallier et al. 2004, p.9). It would be interesting to see if that mathematical model can be applied in the case of three-pots instead of three-ponds.

2.3 Gaps in Knowledge

2.3.1 Absence of laboratory experiments

In an attempt to find and compare studies on the HWT methods, (CDC, 2000) on p. 142, figure 19, states that there are no lab, nor field tests on "storage and settlement", translated as the three-pot system in this case. However, an updated version of this figure was found on-line (HETV, 2012 (b)). Of course since 2000 that the original CDC handbook was published, research on HWT options has thrived, as they have gained more recognition. So on the updated figure, it is stated that there are field tests on the three-pot system, but there's

uncertainty if there are any lab tests, since they didn't seem to be able to trace any. Therefore the question mark in the relevant column (see figure 2.5). This gap in knowledge resulting form lack of laboratory testing is what the present project is attempting to cover.

System	Process	Removal	Lab tests	Field tests	Advantages	Constraints
Storage & settlement	Raw water is added to the 1st pot, poured or preferably siphoned into 2nd pot after 24 hours, and into 3rd after further 24 hours	About 50 percent of most bacteria die-off, Schistosomiasis cerceriae die-off, significant removal of turbidity	?	Yes	Pots available in most households	Only partial removal of pathogenic organisms

Figure 2.7: Gap in knowledge (based on: HETV, 2012 (b))

The fact that the table was updated after 2000, therefore it is assumed to be correct, was double checked by looking at the rest HWT options mentioned. Characteristically, the slow sand filters and the rapid sand filters were both stated not to have lab/field tests on the 2000 version, but later, the updated 2012 version, stated correctly that lab/field tests exist.

2.3.2 Gaps in Knowledge

Once the initial gap in knowledge was traced, the specific objectives of the lab research needed to be decided. By looking at the design characteristics (section 2.2.3), it became clear that there were plenty of variables that could be tested. A robust laboratory test usually keeps all the variables constant, except the one that is under examination (see chapter 3). The author, with the valuable guidance of the supervisor, decided that it is worth focusing on testing the information found in literature, that is not properly justified, but keeps on being reproduced. That were considered to the more specific gaps in knowledge.

- Publication referring to the removal effectiveness of pathogens on the three-pot system, usually claim a 50% bacteria reduction for one day storage and up to 90% with longer retention times (see table 2.2). The source of this information was traced in literature about sedimentation (see plain sedimentation part of section 2.1.3). As mentioned above, since the three-pot system, only recently started to be looked at separately, most publications reproduce one another. Usually (Skinner et al. 1999 (a), p. 102) is being reproduced on publications that claim the 50% reduction and that publication was not based on any experimental work. Only after (Sobsey, 2002) presented the up-to-90% reduction (p.22) in his section on plain sedimentation, some later publications on the three-pot referred to that percentage (Wijk et al. 2005 and CAWST, 2010, p. 4). These two publications refer to Sobsey for that 90% figure.

The point is that Sobsey has reviewed previously existing literature to write his report. As a result these numbers are based on research done on plain sedimentation and not on the three pot system in particular. One doesn't claim that the general rules of sedimentation do not apply in this case, but since there are so many variables involved in settlement itself, it would be worth for one to research the subject of sedimentation on such a small scale. In that sense, the researcher decided to examine the reduction efficiency for bacteria using the three-pot system.

The small scale of the three-pot is probably one of the reasons why there hasn't been much research done on the topic, according to author's opinion, since there are plenty of publications on sedimentation, waste stabilization ponds, storage tanks etc., which are large scale systems. Also testing the effectiveness of such a simple and small scale system may seem not worth for an institution to spend its time and resources on. Last, it is interesting that almost all HWT options, give a chance to institutions and companies to launch new products in the market. Research have always been reported to go along with the market demands. The three-pot system on the other hand, consisting of any three containers available, doesn't give many opportunities for market expansion, thus research may not be promoted for it. Important fact to note is that the only HWT option which managed to be recognised and was scaled up without dealing with market terms was solar disinfection, known by the name SODIS.

For the other gaps in knowledge, it wasn't possible to trace the initial literature they were based on, like for the effectiveness on bacteria removal. Looking at table 2.2 and section 2.2.3, the researcher identified points not properly justified that can be seen as possible features to investigate through experimentation.

- The factor that changes more within the three-pot literature is the retention time, starting from 24 hours, until 6 days. It is commonly said that longer retention times lead to further improvement, but it would be interesting to examine that particular argument.

- Another thing not properly justified is the use of siphoning instead of pouring. Most literature mentions that the sediments will be less disturbed, but again it would be interesting to examine if actually the use of a siphon affects the effectiveness of the three-pot system.

- Another point of difference is the use of 1-2-3 pots. As mentioned above, three-pots are advised, two-pots are considered as minimum, but even with one pot the treatment may work, although not advised. The idea of comparing the three-pot results to the one-stable pot results is worth testing.

- Last, it is stated that water near the surface is of better quality than that near the bottom of the pot. By taking samples from both points one may be able to test if there is actually a difference and hence understand better the purification mechanism, in particular for the three-pot.

2.4 Related Issues

The related issues are variables that are inevitably connected to the three-pot system and they are worth to mention, since they had an impact on research methodology as well.

2.4.1 Water Quantity

Water is undeniably connected with survival, health, well-being and development. “An adequate amount of safe water is necessary to prevent death from dehydration, to reduce the risk of water-related disease and to provide for consumption, cooking and personal and domestic hygienic requirements” (Sphere, 2011, p. 83). Apart from health, when “water availability is poor, people will loose time, energy or money, that could have been invested elsewhere” (Rottier et al. 2003, p. 52).

The uses of water are many, but there is an hierarchy on the needs that people cover with them (Reed, 2005, p. 2, figure 1). Domestic water, including water for drinking, food preparation, laundry, personal and domestic hygiene (WHO, 2011, p. 83), is the most essential for everyday life, therefore is hierarchically higher. Within that part, drinking water is the minimum requirement for preserving life, thus it’s on the top of all. Drinking water is the amount the body needs to compensate for losses of respiration perspiration, urination and defecation (Howard et al. 2003, p. 4).

The water quantity each person needs per day (lcd=litres/capita/day), is something depending in many factors like: cultural, socio-economic status, hygiene awareness, productive uses of water, cost, quality, effort, distance from source and so forth (Howard et al. 2003, p. 17 and Nozaic, 2002, p, 62). For drinking water, it depends on individual physiology, sex, age, climate, food and work load (Howard et al. 2003, chapter 3, p. 3).

Literature on emergencies looks at the aspect of minimum requirement of water, as well as quantities needed in normal conditions. There are small differences about lcd, depending on what each publication defines as “basic survival needs”. In general, it is agreed that 3-5 lcd are needed for survival immediately after a disaster (drinking and cooking only, with no use for hygiene included), 15 lcd as an intermediate supply measure (hygiene included) and 20-50 lcd in normal conditions of development (DeVeer, 2002, p. 538, table 24.1). Many other

publications refer to the number of 7.5 lcd, as the basic survival quantity, including very basic hygiene (Sphere, 2011, p. 98), since that number is sufficient for most people, under most conditions (WHO, 2011, p. 83). Referring only to drinking water, the minimum quantity of intake, excluding water indirectly consumed through food, for an average adult in average conditions, that is 2 lcd (Howard et al. 2003, p. 6 and WHO, 2011, p. 83).

In cases of emergency or where the availability of good quality water is not large, it is advised that people should treat at least their drinking water, if there is no other option (Skinner et al. 1999, p. 101). Apart from looking how much water each person needs, one should consider how many people there are in the household as well (Reed, 2005, p. 1). In that sense, accepting that people need on average 2 lcd water for drinking, for an average household size of five people, the absolute minimum requirement would be 10 l/day. This fact, along with the fact that in the local market of Loughborough there were no other sized pots with lids for safe storage, led to the use of 10 l pots for the experiments. This is a manageable weight for a single person to lift for pouring the water out. For larger containers, two people or the use of a siphon is likely to be required.

2.4.2 Water Quality

Water quality is undeniably connected with health. Parameters in order to determine and measure quality are categorized similarly in different publications. More officially (WHO, 2011), the categories are: microbial, chemical, radiological and acceptability issues. One may refer to chapters 7, 8, 9 and 10 in (WHO, 2011) for details. The principal concern in water remains the microbiological quality, since it is related to many common diseases (Howard, 2002 p. 10).

Water-related diseases are those where water helps or hinders the transmission of communicable diseases (DFID, 1998, p. 63). The classification of transmission mechanisms to: water-borne / water-washed / water-based / water-related is widely used, adopted from (Cairncross et al. 1993, p. 4), is widely used. Pathogens are the micro-organisms that are responsible for the diseases. Most common pathogens are: viruses, bacteria, protozoa, helminths (worms), rickettsiae and fungi (Rottier et al. 2003, p. 9). In (Cairncross et al. 1993, p. 10, table 1.2) one can find examples of these pathogens and which diseases they are responsible for, according to the above classification. Figure 2.8, gives a quick description on some of them. For further detail, one may refer to (Mara et al. 2003), chapters 2, 3 and 4.

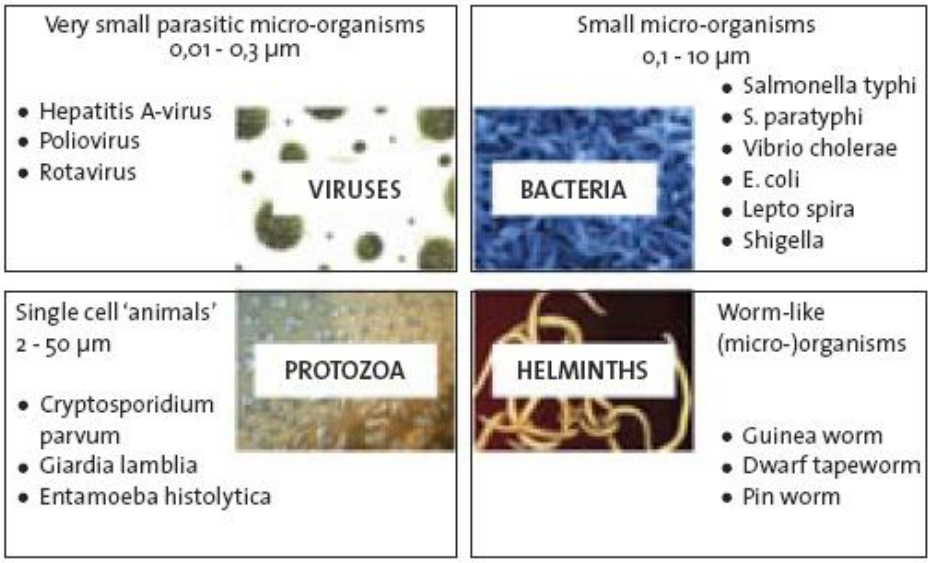


Figure 2.8: Some water-related pathogens (source: NWP, 2010, p. 11)

In studies reviewing contamination of drinking water with pathogens, conclude that the majority of those which are of main concern, are excreta related (Ashbolt, 2004, p. 231). This means that they are spread by pathogens principally found in human faeces and are transmitted by the faecal-oral route (Howard, 2002 p. 4). It is far too complex to detect all the harmful pathogens in water, therefore tests look for indicator bacteria (Cairncross, 1993). Their presence/absence indicates faecal contamination and therefore, there is a probability that other pathogens may be present as well (Pickford, 1991, p. 73). In that sense, the absence of these indicators should characterize water as low risk, rather than as safe (Howard, 2002, p. 12).

Looking at the characteristics that a pathogen should have in order to become an indicator (Howard, 2002 p. 12, box 2), it is difficult to find one ideal organism to cover them all (Mara et al. p. 105). The closest match are the thermotolerant (faecal) coliform bacteria. These are a sub-group of the total coliform group. Total coliform bacteria (that grow at 37 ^{o}C) include non-faecal bacteria as well, thus they are not ideal indicator for faecal pollution. On the contrary, thermotolerant (faecal) coliform bacteria (that grow at 44 ^{o}C) nearly always indicate faecal contamination. Usually, 95% of the thermotolerant bacteria are the *Escherichia coli (E. coli)* that is always found in the gut of warm-blooded animals (Bartram et al. 1996, p. 10.2). Therefore, *E. coli* is widely used as an indicator bacterium for faecal pollution in most tests and in the present project as well. *E. coli* is further subdivided in six types (Hunter, 2003). All types cause diarrhoea, with different severity, but the most common type met worldwide is the Enterotoxigenic *E. coli* (ETEC).

Apart from *E. coli*, which is the typical microbial parameter checked in water quality tests, other common parameters, which will be tested in this project are: temperature, colour,

turbidity, pH, total dissolved solids (TDS), suspended solids (SS), conductivity and dissolved oxygen (DO) (Spellman, 2003, p. 368 and EPA, 1997, chapter 5). Some parameters (e.g. chemicals) were not tested in this case, since the focus was to be on the microbiological water quality. Other parameters (e.g. taste and odour) could not be tested within the laboratory (see section 3.1.5). According to (WHO, 2011)'s categorization, pH and TDS are chemical parameters, but since they are not of health concern, they can be regarded as acceptability issues (WHO, 2011, p. 177).

The official guidelines for drinking water quality (WHO, 2011), state the values all water parameters should have in order for it to be safe for consumption. For the parameters chosen to be tested, these are depicted on table 2.4, along with the reference of the page of the particular publication.

Parameter	p.	WHO Guideline
E. coli	149	Not detectable in 100 ml
Temperature	230	No health concern – may affect acceptability
Colour	224	No health concern – may affect acceptability (desirable level < 15 TCU)
Turbidity	228	No health concern – may affect acceptability (desirable level < 5 NTU)
pH	227	No health concern – may affect acceptability (desirable level 6.5-8.5)
TDS	228	No health concern – may affect acceptability (desirable level 600-1000 mg/l)
DO	225	No health concern – may affect acceptability
SS	-	No health concern – may affect acceptability [a]
Conductivity	-	No health concern – may affect acceptability [b]

a: there is no reference on suspended solids within the guidelines

b: conductivity is not mentioned separately, but is expressed through TDS

Table 2.4: WHO drinking water guidelines (based on: WHO, 2011)

The applicability of these guidelines and especially the *E. coli* one, has been widely debated. The most common argument is that WHO sets the desirable values for guidance, but theses are not very practical for untreated or partially treated water in developing countries, therefore acceptable and attainable limits need to be set according to the individual circumstances (Davis et al. 2002, p. 202). There are cases where these standards are not met even in developed countries, so for rural or developing regions, they are too stringent (Cairncross et al. 1993, p. 32). At best, people will ignore the standard and at worst, they may turn to an alternative water source, which may be even more polluted, out of ignorance of the reason why the guideline was set in the first place (Feachem et al. 1983, 211). Overall, "a good deal of common sense is needed in the use and interpretation of bacteriological water quality standards for untreated water" (Cairncross et al. 1993, p. 34). Guidelines can be regarded as the "highest desirable" level, but it is wiser to have "a maximum permissible" one as well.

Interim improvements should be incrementally leading from the “permissible” to the desirable one (Nozaic, 2002, p 68).

WHO suggests zero faecal coliforms in any 100 ml sample of drinking water, since the guidelines are formed for life-long consumption of water. But this doesn't mean that people cannot survive if they ingest some numbers of faecal coliforms. “Many healthy farming families in the UK regularly drink water with tens if not hundreds of faecal coliforms per 100 ml” (Cairncross, 1993). That raises the issue of “infectious dose” or when water can be characterized as safe. Infectious dose is when a sufficient number of pathogens has been ingested, so the disease occurs (Mara et al. 2003, p 58). It is commonly reported as ID_{50} (median Infectious Dose), meaning the number of organisms that infects 50% of the individuals. This number varies among pathogens and different people. Indeed for *E. coli*, for the commonest type-ETEC this can be 10^8-10^{10} organisms, while for EHEC (Enterohaemorrhagic) 100-10^6 (Hunter, 2003, p. 67-68).

The idea of infectious dose interpreted as safety, gives a classification of risks within the publications, for faecal coliforms or *E.* coli in particular, as shown in table 2.5. The classification is the same either in development or emergency manuals. Only in (WHO and UNICEF, 2005) there is a classification (table 3, p. 27) that characterizes contaminated water differently according to the population. The smaller the population (e.g. rural places) the less strict the standards are for a supply to be acceptable. This is logical according to the law of probabilities, one may comment, but very theoretical to be practiced safely. Note that this risk categorization refers only to *E. coli* and doesn’t include the risk of having other pathogens present in the water.

Count (per 100 ml)	**Risk category** (Nozaic, 2002, p. 69)	**Inference** (House et al. 1999, p. 79)	**Action** (Harvey, 2007)
0	Conformity with WHO	Reasonable quality	may be consumed as it is
1-10	Low risk	Reasonable quality	may be consumed as it is
11-100	Intermediate risk	Polluted	treat if possible but may be consumed untreated
101-1000	High risk	Dangerous	must be treated
>1000	Very high risk	Very dangerous	reject or treat heavily

Table 2.5: Risk classification for *E. coli* in water supplies

Again there is a debate on whether WHO guideline for zero coliforms is suitable in each case. That limit is said to be pointless for developing countries (Feachem et al. 1983, p. 211), for rural areas or emergencies (Nath et al. 2006, p. 35), where more flexibility is required. Others, suggest no more than 10 faecal coliforms/100ml (Davis et al. 2002, p. 202). A moderately good quality can even be <100 faecal coliforms/100 ml (Feachem et al. 1983, p. 210). Combining all the above details, the threshold in the present project, for water quality to be

characterized polluted and must be treated, was decided to be 1000 faecal coliforms/100 ml (see chapter 3 for how this affects the methodology). Interesting point to mention is that any classification and process, needs to be regularly checked, since all pathogens tend to evolve (Ashbolt, 2004, p. 236).

The principle one could say behind all that, is the idea of “improvement” and how each publication perceives it. That can be improvement strictly on water quality or improvement to a person’s life linked to water. Improvement of water quality is lowering the numbers of pathogens to an acceptable level and not necessarily eliminating them – this is sterilization (Spellman, 2003, p. 314). “ A moderately effective water treatment that raises the levels of the most important quality parameters – those that affect health – without meeting all the parameters and standards” may be perceived as an improvement in water quality (Heber, 1985, p. 13). When people use 1000 faecal coliform/100 ml drinking water, a treatment that provides 50 faecal coliform/100 ml, is already a major improvement (Feachem et al. 1983, p. 211).

Improvement to a person’s life linked to water is a broader concept. When it comes to a general health outcome, it is described officially (WHO, 2011, p. 38), with disability adjusted life years (DALY). “In many parts of the world, the implementation of a water quality intervention that results in an estimated health gain of more than 5% would be considered extremely worthwhile” (WHO, 2011, p. 136). The improvement also has to do with water affecting important aspects of living, like child mortality, school attendance, equity, productivity and so forth (WHO and UNICEF, 2005, p. 10). Diseases related to water and poor health, are expensive in money, time and energy and hinder development at a personal and national level (Rottier et al. 2003, p. 44).

Improvement, in any case, needs to be progressive, with realistic goals between the incremental steps (WHO and UNICEF, 2005, p. 27). With the narrow or the broader perspective and with the strict or more flexible guidelines, any water treatment intervention, is crucial for the overall improvement of people’s lives and should be regarded as an extra contribution to that difficult goal. A water treatment intervention that improves water quality should not be eliminated, just because it doesn't meet some standards from the beginning.

2.4.3 Water quantity versus water quality

A number of factors play an important role in interrupting the transmission of diseases. The most commonly mentioned are water, sanitation and hygiene (Pickford, 1991, p. 69). More specifically, crucial aspects are: water quantity, water quality, education, vector control, excreta disposal and water management (Pickford, 1991, p. 77). Publications debate

significantly, over the importance of water quality versus water quantity. An attempt to review the literature on the topic, was included in section 2.1.2, when looking at the point-of-use and household water treatment options, since these claim that quality is more important after all.

Good review of this debate or the shifting in the HWTS paradigm as often referred, can be found in a short version in (Clasen, 2005). To summarise here, initially quality was regarded more significant, but around 1990, due to Esrey's research, quantity appeared to have a greater effect than quality, but also that good hygiene and sanitation have even greater impacts (House et al. 1999, p. 80, table 6). Only around 2000, researchers started to question this fact, since HWTS appeared to be twice as effective to traditional source-based interventions, but the HWTS interventions were never reviewed within Esrey's work (Clasen, 2009, p. 54).

Other publications, do not take side in this debate, but more wisely claim that: "the relative importance of water quality and water quantity depends on the situation" (House et al. 1999, p. 80). In emergencies for example, it is usually stated that "until minimum standards for both water quantity and quality are met, the priority is to provide equitable access to an adequate quantity of water even if it is of intermediate quality" (Sphere, 2011, p. 98).

In a similar sense one may comment, that overall, it is not a matter of "versus", but a matter of "and". Since there doesn't seem to be a clear conclusion out of all these arguments about the "versus", one could see the positive side of all this research and say that quality "and" quantity, always play some positive role. "In spite of doubts about the detail, it is clear that such environmental interventions can have a substantial effect... We know enough to do a lot..." (Cairncross et al. 2010, p. 203).

2.4.4 Issues related to the design characteristics

On this section there is a review on the literature that affected the design characteristics (as summarised in section 2.2.3) of the experiments. Using the same order as before:

1. a. Inlet water quality

As explained in section 2.4.2, the threshold for one to consider the water so polluted that needs treatment was decided to be 1000 faecal coliforms/100ml. This is a commonly found concentration for *E. coli* in surface waters, as reported in publications (for example, streams in developing countries (Cairncross et al. 1993, p. 33, table 3.1) may have up to 10000 *E. coli*/100ml). The selection of surface water and the particular loading of bacteria is described in chapter 3.

1. b. Inlet water quantity

As explained in section 2.4.1, 10 litres of water will be used, as the amount of water treated by each three-pot system.

1. c. Use of cloth or not at the inlet point

Cloth filtration is reported to have advantages in water filtration, especially by trapping solids, helmiths (like *guinea* worm) and cholera virus. Since the effectiveness depends on the cloth as well, use of a cloth use would introduce many new variables, that couldn't be tested at this point and the focus should remain on the three-pot system. Thus no cloth was used.

2. a. Size of vessel

As explained in page section 2.4.1, according to the quantity and the availability of containers with lid in Loughborough, 10 litres vessels will be used. These are in accordance with water collection standards as well (see 2.e: number of pots).

2. b. Shape of vessel

Shape was decided to be cylindrical, that of a typical household bucket. Buckets are easily available everywhere, and the user can collect, transport, treat (in the three-pot case), store and consume water from the same vessel easily (Reed, 2011). They are also stackable and they don't have edges to concentrate the water load, thus become worn out more quickly (Reed, 2011, p. 6). The absence of corners don't facilitate the bacteria colonies to grow as well (Oxfam, 2008, p. 4). Besides, there weren't many other options in the market either.

2. c. Material of vessel

The containers available in the market were mainly plastic. Plastic can be used in this case, since it is commonly found everywhere and people choose it, since it is light, durable, strong and cheap (Reed, 2011, p. 11). Also, the aim was to use an inactive material, so as not to affect the bacteria removal. Different materials are reported to alter the water parameters like pH, turbidity, conductivity, TDS and therefore the bacteria die-off rates (Qi, 2007) or even the chlorine required for water treatment (Ogutu et al. 2001). Plastic is relatively inactive in producing salts and altering pH (Ensslin, 2005), so its effect on bacteria removal is considered minimal.

2. d. Rest vessel characteristics (colour, opening, lid, handle, tap)

The colour was intentionally light, so that one could inspect the suspended solids gathering at the bottom. If the buckets are placed somewhere with sun exposure, transparent or translucent materials could promote algae growth, if regular cleaning does not take place. The opening needs to be wide enough, for water to be poured in and out without spillages and

wastages (Reed, 2011, p. 10), but also for the container to be cleaned easily (Reed, 2011, p. 18). Containers with a tight lid were chosen, so as to promote safe storage and prevent re-contamination (Reed, 2011, p. 13). Handles assist carrying the container and may assist with pouring the water as well, but do not affect the experiments. Last, since the idea was to test pouring and siphoning, tap use was irrelevant in this case. As mentioned before, 10 litres weight is manageable when pouring water out. In larger volumes, siphoning or other decanting methods may have to be used.

2. e. Number of pots in use

There are water collection standards, which claim that “two vessels of 10-20 litres for collecting water, plus one 20 litres vessel for water storage, per 5 person household” is ideal for emergencies (Reed, 2005, p. 3). Alternatively, this is an interim measure, since for emergencies one 10-20 litres container is enough (DeVeer, 2002, p. 538, table 24.1). Taking that into consideration, along with the facts on the three-pot literature (three containers are best, with two it’s still feasible and with one is possible, but maybe less safe), the researcher decided to use three-pots in comparison with one-pot (see 2.3.2: gaps in knowledge).

2. f. Retention time (days of storage)

Within the literature for three-pot , retention time was from 24 hours, until 6 days, with longer retention times claimed to lead to further improvement. One may refer to section 2.2.4 on die-off of pathogens for more details on retention time.

3. a. Method of decanting

The three-pot options were pouring, siphoning or ladling. Pouring is simple, but is difficult to do with large filled containers (Reed, 2011, p. 13) and it may lead to wastages. Siphoning can be used to overcome the weight lifting issue, but regular cleaning of the siphon needs to be done, so as not to pollute the water, when it is dipped into it. Ladling the water with a dipper is simple and easy, but it raises the risk of recontamination again, if the users are not aware of hygiene issues (Reed, 2011, p. 13) and it is a slow process as well. In this case, the researcher decided to compare pouring and siphoning (see 2.3.2: gaps in knowledge).

3. b. Point of abstraction

For the three-pot, it is stated that water near the surface is of better quality than near the bottom. By taking samples from both points the researcher will test if there is actually a difference, in order to conclude on whether bacteria settle and/or die, as part of the purification mechanism.

3. c. Outlet water quality

The parameters to be checked, as explained in section 2.4.2, are *E. coli,* temperature, colour, turbidity, pH, total dissolved solids (TDS), suspended solids (SS), conductivity and dissolved oxygen (DO). There should be a comparison with WHO guidelines (table 2.4), but as commented before, these values cannot be the only argument against or in favor of any treatment method. In (DeVeer, 2002, p. 538, table 24.1) one may find different values, depending on emergency, interim or development cases, but also in (Novaic, 2002, p. 71, table 4.8 and p. 72, table 4.9) there are different standards depending on the country of origin.

3.0 Methodology

The present chapter explains how the research was planned and how the experiments were conducted in order to answer the research questions and meet the objectives.

3.1 Planning Procedure

3.1.1 Overview

The aim of the project is to test the effectiveness of the three-pot water treatment system. Thorough literature review was conducted in order to understand the issues related to the three-pot system and identify particular gaps in knowledge (see section 2.3.2). That led to the formation of five research questions. By answering these, the aim of the project can be addressed more specifically. The research questions are:

1. What is the bacteria removal effectiveness of the three-pot system?
2. How many days should the retention time be?
3. Is siphoning more effective than pouring?
4. Is the surface water of better quality than the water at the bottom?
5. How many pots should be used?

In order to answer these questions, experiments A and B were conducted (see section 3.2). In summary, experiment A was conducted in three trials with different raw water quality for each one. The typical three-pot system procedure, were water is allowed to settle one day per each pot, before being decanted, was followed. Three containers in series were used within each three-day time period. Water was poured and siphoned in parallel three-pot systems. Experiment B was conducted in two trials, again with different raw water quality for each. Two pots were used in rotation within a period of 7 days. Water was poured after being allowed to settle for a day. Experiment A addressed specifically question 3, experiment B addressed specifically question 4 and both of them addressed questions 1, 2 and 5.

Data for the measured parameters were collected in Excel sheets (see appendices 8.1 and 8.2). Excel was used to create all the tables and graphs within this project. In order to conduct proper analysis, literature research was repeated to address more specific questions. For the shake of triangulation, results from similar tests in previous researches were attempted to be found. With a minor exception (see section 4.2.1), no similar research was found. The three-pot system is an area where laboratory experiments haven't been conducted yet, as presented in section 2.3.1.

3.1.2 Water source

The laboratory experiments were aimed to be conducted in as realistic conditions as possible. For that reason, water needed to be transferred from a natural surface source. Adjacent to WEDC, there are two brooks, Holywell and Burleigh, shown on the map. They were both accessible and nearby Sir Frank Gibb Laboratories of the Civil and Building Engineering Department of Loughborough University (lab on the map), were the experiments were to be held. The final choice would be based on the *E. coli* loading of each brook. As mentioned in section 2.4.2, within this project, the threshold for a water sample to be characterized as contaminated, was chosen to be 1000 cfu/100 ml.

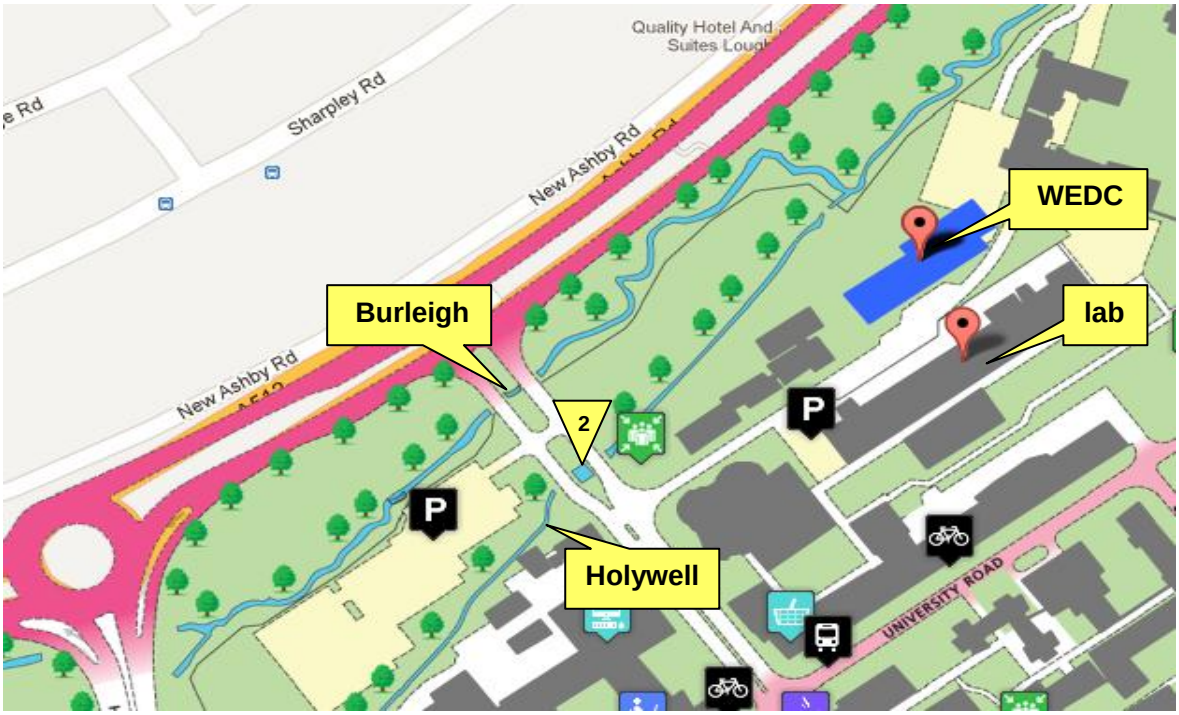


Figure 3.1: Map of WEDC area, showing the water source location (adopted from: http://maps.lboro.ac.uk/)

From the literature review, two previous thesis were found were the same choice between the brooks needed to be made. In (Huang, 2006), various water sources near WEDC were sampled. The particular author, took samples only one day of August within his project, so his results were not perceived that representative for the brooks. However, in (Thye, 2007), more samples were taken within the experimental period (July-August). It is stated that the two brooks didn't differ that much around that period of time, but Holywell was chosen for accessibility reasons. Last, laboratory keeps annual records for Holywell brook contamination. Reviewing these, the average concentration of *E. coli* was 1410-1820 cfu/100 ml.

Since bacteria concentrations vary within a year due to several factors, it was wiser to conduct trial tests prior to the actual experiments, in order to have a clear picture of the two brooks,

thus finalise the choice. The exact locations are the ones shown on the map for Burleigh and Holywell brooks. Burleigh was accessible only at the particular point, due to absence of blocking vegetation. Holywell on the other hand was accessible at more locations. Location no. 2, was an additional abstraction point for Holywell brook with wider banks, thus more stagnant water. It was intentionally chosen to see if that would make any difference to the water quality. See appendix 8.4 for the results of testing these three locations. These trial tests were conducted with the valuable help of Mrs. Jayshree Bhuptani, Deputy School Superintendent, Analytical Chemist and Supervisor of the laboratory, as a teaching session for all the experimental procedures.

As shown in appendix 8.4, the first location had 890 cfu/100 ml, which was closer to the 1000 cfu/100 ml threshold. Burleigh had 580 cfu/100 ml, which was quite lower, therefore that brook was not opted. The second location in Holywell brook, where the water was more stagnant, had 770 cfu/100 ml, although only about 20 meters away from the first location. The banks were wider and water was moving slower, but also the water level dropped. That is actually the evidence that sedimentation is a natural self-purification process of water bodies. As mentioned in (Mara et al. p. 616), rivers usually contain higher levels of bacteria than lakes, because of the sorter residence time of water in rivers, therefore the self-purification process has less time to effect. Along with pathogens, suspended solids have more time to settle as well, which brings down the levels of turbidity and colour. This is shown in the results of appendix 8.4. Dissolved oxygen on the other hand is a bit higher in the second location, again as expected. The level of water is lower and air can pass through the water column more easily. The final point of abstraction from Holywell brook, pointed in the map under the name “Holywell”, is shown in reality in figure 3.2.

Figure 3.2: Point of abstraction in Holywell brook (author, 2012)

3.1.3 Water collection and transportation

Prior to any collection and laboratory experiments, a risk assessment was conducted by the author and approved from the laboratory department. For the experiments, water collection was done manually with the aid of a hand trolley. A laboratory water group technician, Mr. Geoffrey Russell, was providing his valuable help in this task every time. Water was abstracted directly with a 10 l bucket from the brook and was being decanted in a 100 l container, shown in figure 3.3. This amount was sufficient to fill the first pot from all three-pot systems tested each time. Collection was done every morning at 9:00 pm, in an attempt to have similar temperature for all raw water. The container was covered during transportation, to avoid spillages and recontamination. Safety precautions were followed according to the risk assessment guidance to minimize the hazards associated to the task.

Figure 3.3: Water collection and transportation (author, 2012)

Water was then decanted with the aid of the 10 l bucket into the first pot of each three-pot system within the laboratory. It was understood that while water was transferred, some settlement of suspended solids and bacteria might have occurred. For this reason, water was stirred thoroughly with the aid of a wooden stick, before it was decanted in the lab, in an attempt to re-suspend the settled matter. Despite stirring up the water, there was still the concern of having different quality within the water column of the 100 l container. The aim was to have similar initial quality in all three-pot systems for them to be comparable. For that reason the first pots were not filled in series. Instead, every time a 10 l bucket was abstracting water from the 100 l container, all pots were filled with some amount of this water. That way the first pots were filled gradually, with water evenly abstracted through the 100 l water column.

3.1.4 Water sampling

Water was sampled with the a 100 ml scaled glass syringe from each pot. In total 125 ml were needed in order to test all the parameters (see section 3.1.5) and placed in 125 ml bottles.

Suitable labels were placed on the bottles to avoid mixing up the samples. All samples of raw water were analysed as soon as possible, to ensure that the real conditions were captured. Moreover, the typical three-pot system procedure is about allowing water to settle for 24 hours before decanting each time. Therefore, all the rest samples apart from the raw water were analysed around the same time every day. That would ensure that water would have been allowed to settle approximately for 24 hours before analysis each day, thus safeguarding that the three-pot system procedure was followed.

The syringe was the optimum decision for sampling water from the pots in this case, since it caused almost no disturbance to the water and its suspended matter. It had a long and very thin needle able to touch the bottom of the container, thus allow measurements at any depth. Alternatively, a pipette could be used, but when immersed into the water, it trapped a small amount of water while moving along. For measurements from a specific point, that would be problematic, since the water sampled wouldn't necessarily come from that point. Another option was to place small horizontal tubes with some kind of a tap, coming out of the container, to take the measurements from each point. There was the concern though that sediments and bacteria would settle on the tube's edges, thus these measurements might be higher than the actual ones within the rest of the container. As a result a removable equipment like the syringe was opted.

The syringe was sampling water from the same point within each container, so as to have comparable measurements. When only one sample from each container was taken, the syringe was placed at the middle height and at the centre of the circular bottom. That gave a middle-centred measurement, which was assumed to be representative for the whole container. When points from other heights were to be sampled (surface or bottom), the syringe was placed again at the centre of the circular shape, but at the appropriate height at each case. Bottom measurements were conducted with the syringe touching the bottom, to be able to sample the microscopic bacteria, if present.

3.1.5 Testing parameters and equipment

The parameters to be tested within this project, as mentioned in section 2.4.2 as well, were: *E. coli*, temperature, colour, turbidity, pH, total dissolved solids (TDS), suspended solids (SS), conductivity and dissolved oxygen (DO) (Spellman, 2003, p. 368 and EPA, 1997, chapter 5). Each parameter's brief description follows:

- *E. coli* is a type of bacterium. It belongs to the thermotolerant (faecal) coliform bacteria group. This is a sub-group of the total coliform group. They grow at 44 ^{o}C. Usually, 95% of the thermotolerant bacteria are the *Escherichia coli (E. coli)*, found in the guts of warm-blooded

animals (Bartram et al. 1996, p. 10.2). Therefore, *E. coli* is widely used as an indicator bacterium for faecal pollution in most tests and in the present project as well. *E. coli* is further subdivided in six types (Hunter, 2003). They all cause diarrhoea, with different severity, but the most common type met worldwide is the Enterotoxigenic *E. coli* (ETEC). Within this project, *E. coli* is measured in cfu/100 ml.

- Temperature is a physical property of water, quantifying the amount of heat enclosed within it. It is not usually an evaluating factor for water, but it affects many other biological and chemical processes (EPA, 1997, p. 147), like the solubility of oxygen, the rate of bacterial activity and the rate at which other gases are transferred to and from the water (Spellman, 2003, p. 372). Ambient temperature (i.e.: temperature of the surrounding environment) has the most profound effect on shallow surface water (Spellman, 2003, p. 373). Within this project, it is measured in ^{o}C.

- Colour is a physical characteristic of water. While pure water is colorless, natural water takes on color from foreign substances like organic matter, vegetation, minerals, various microorganisms and wastes (Spellman, 2003, p. 371). Color is classified as true and apparent. Color contributed by suspended solids is characterized apparent. True color is the result of dissolved chemicals that cannot be seen and is separated from apparent color by filtering the water (Spellman, 2003, p. 299). Color is not necessarily a problem, but it affects acceptability and it may be an indication of pollution. Within this project, colour is measured in Hazen. True Colour Units (TCU), can be used only for true color, after filtration.

- Turbidity is a measure of water clarity and is caused by the presence of suspended matter, which decrease the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. Turbidity can affect the color of the water, thus acceptability. Higher turbidity can increase the water temperatures because suspended particles absorb more heat. This in turn, can reduce the concentration of dissolved oxygen, because warm water holds less dissolved oxygen than cold (EPA, 1997, p. 154). Also, the colloidal matter associated with turbidity provides absorption sites for microorganisms that may be harmful or cause undesirable taste and odour (Spellman, 2003, p. 370). Within this project, turbidity is measured in NTU.

- pH is used to indicate how acidic or basic a substance is. It is actually a measurement of the hydrogen ions (H^+) concentration. More H^+ result to an acidic substance, therefore a low pH, while less H^+ or more OH^-, result to a basic substance, therefore to a high pH. pH is important to the chemical reactions within the water and too low or too high values can inhibit

the growth of microorganisms (Spellman, 2003, p. 300). pH is measured with the scale of 0-14 pH units.

- Total dissolved solids (TDS) are part of the total solids within water. They are mainly minerals, salts, metals, anions and cations dissolved in water, which still remain in water after filtration. They can be both organic and inorganic. Too low or too high concentrations result in unacceptable taste (Spellman, 2003, p. 373). Within this project, TDS are measured in ppm.

- Suspended solids (SS) are part of the total solids within water. SS include silt and clay particles, plankton, algae, fine organic debris and other particulate matter, which can be trapped by a filter. SS can act as carriers for pathogens and substances attached to them. They also affect the turbidity and colour levels, thus affecting acceptability as well (EPA, 1997, p. 176. Within this project, SS are measured in mg/l.

- Conductivity is a measure of the ability of water to pass an electrical current. It is affected by the amount of inorganic anions and cations in water. Moreover, it is affected by temperature, with warmer waters rising the conductivity. (Spellman, 2003, p. 420). Basically, attachment of inorganic matter with the settled solids, can significantly reduce conductivity. Also, there is a connection with TDS and pH since these are partly or totally anions and cations too. Within this project, conductivity is measured in μS/cm.

- Dissolved oxygen (DO) is the oxygen within the water. Since it is a gas, its solubility in water depends on the water temperature, when the pressure is the atmospheric one. The higher the temperature, the lower the saturation level of the gas (Spellman, 2003, p. 299). Oxygen is exchanged between water and the atmosphere through its surface. It can be consumed and/or produced within the water body, depending on the biological activity of the organisms present in the water (EPA, 1997, p. 139). Within this project, DO is measured in mg/l.

The equipment used to test each parameter, along with the procedure were according to standard operational methods. For each parameter, a brief description follows:

- *E. coli* were measured with the Membrane Filter for members of the Coliform group (MFC) standard procedure. Initially, 3,7 gr of broth were added to 100 ml of distilled water in a conical flask. After proper mixing of those two elements, 1 ml of rosolic acid was added as well. The conical flask was placed for approximately 1,5 minutes in the microwave oven at maximum temperature, until small bubbles immerged from the liquid (beginning of boiling point). That solution was left to come in room temperature, within a bath of tap water. In the

meantime, the sterile Petri dishes (50 mm) were placed in order for proper labeling according to the samples. A sterile nutrient pad was added in each Petri dish. With a sterilized pipette, 2,5 ml of the broth solution was placed onto the pad, to create the nutrient conditions for the bacteria to grow. The specific nutrient assists the growth of thermotolerant (faecal) coliforms in particular, thus it was chosen. Since 95% of the thermotolerant bacteria are *E. coli*, the bacteria growing onto the pad were considered to be *E. coli* as well. In that sense, within this project, when the author refers to *E. coli* counts, it is actually thermotolerant counts.

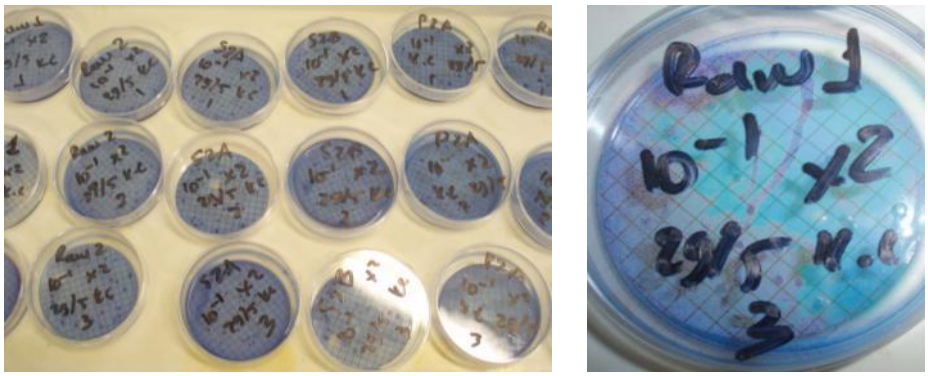


Figure 3.4: Labeled Petri Dishes in series and in detail (author, 2012)

Once the dishes were ready, the membrane filtration procedure could begin. A sterile Nalgen filter holder with receiver was used. A membrane filter cellulose paper (white, gridded with 0.45 μm pore size) was picked from its sterile pack with lab forceps and placed onto the holder. The forceps were sterilized each time above fire. In 225 ml of ringer's solution (i.e.: isotonic solution of water with several salts, similar to the bodily liquids), 25 ml of the water sample was added and mixed properly. That gives a ratio between them of 1/10 or 10^{-1} dilution, as usually called. Then, 50 ml of this solution was added on the upper part of the membrane kit and vacuumed manually into the receiver. The filter was then picked up and placed carefully on top of the nutrient pad in the Petri dish, avoiding capturing air bubbles. Once all the filters were placed in their dishes, they were placed in the 44 $_{o}$C incubator for 18-24 hours.

Figure 3.5: Nalgen filter holder with receiver (author, 2012)

After that period has passed, the *E. coli* formed blue colonies. With a magnifier they were counted one by one. Since the filtered water was 50 ml, that number was multiplied by 2, to be converted into cfu per 100 ml. That number was then multiplied by 10, since it was 10^{-1} diluted, so as finally to be expressed into cfu/100 ml. It is always advised to incubate two samples

minimum for each *E. coli* measurement one wishes to take and use their mean value. This way the result is double-checked and thus not random. In general, if there is time and resources, three-five samples are the best option. In experiment A, three measurements were taken (MLSB a-b-c in appendix 8.1), whereas in experiment B, due to limited resources only two measurements were taken (MLSB a-b in appendix 8.2).

In the trial testing prior to the experiments, done as training session, the typical field Membrane Lauryl Sulphate Broth (MLSB) filtration procedure was practiced as well. The field kits normally use Sulphate Broth medium as a nutrient for the bacteria. With that, the exact same procedure is followed, but the initial medium is prepared with 52 gr of it in 1 l of distilled water. This produces yellowish *E. coli* colonies. The MLSB medium was not opted because it produced less distinct and clear colonies, making them less easy to count. Also, as shown in appendix 8.4 for MFC and MLSB measurements in the trial testing, the MLSB method produced less consistent results between the two measurements (a-b) which were taken for reliability reasons, while the MFC method was found more reliable and could be trusted. (To avoid confusion, note that in the appendices MLSB is mistakenly written where MFC is supposed to be and the other way around).

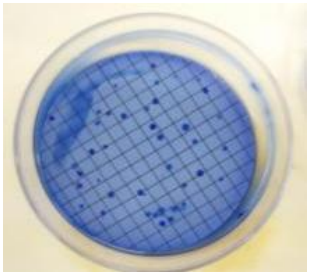


Figure 3.6: Petri dish with blue distinct colonies after MLSB medium (author, 2012)

- Temperature was measured with a Digital High Temperature 8'' lab thermometer in ^{o}C. The probe was placed in the sample for sufficient time, until the indication in the screen stabilized. The ambient temperature was measured by the typical mercury-glass thermometer placed in the laboratory wall.

Figure 3.7: Digital High Temperature 8'' lab thermometer (author, 2012)

- Colour was measured with the Siemens Photometer P15 in Hazen units. 10 ml of distilled water were initially placed in the plastic tube to calibrate the equipment for zero colour units. Then 10 ml of the actual water to be tested were taken with a syringe from the sample bottles and placed in the photometer's tube. The digital screen displayed the units. The tubes were cleaned after every use with distilled water.

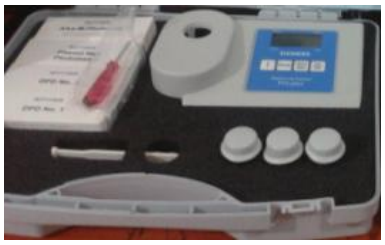


Figure 3.8: Siemens Photometer P15 lab colour meter (author, 2012)

- Turbidity was measured with the Hach 2100N turbidity meter in NTU. A standard sample was initially placed in the turbidity meter for calibration at 15 NTU. Then 20 ml of the actual water to be tested were taken with a syringe from the sample bottles and placed in the meter's tube. Before sampling, the bottles were agitated to ensure better mixing. The tubes were wiped with suitable cloth to remove any oils or matter placed on them from the user's fingers. The digital screen displayed the units. It was advised to take the first reading displayed, since suspended matter settled within the meter's tube and the readings gradually dropped. The tubes were cleaned after every use with distilled water.

Figure 3.9: Hach 2100N lab turbidity meter (author, 2012)

- pH/TDS/Conductivity were measured with the Hanna Instrument HI9812. Calibration was done with distilled water at 7.0 pH units. The probe was immersed in the sample bottles, stirring the water three times. Then it remained calm, until the reading in the digital screen stabilised. By selecting the appropriate function, one could measure pH, TDS in ppm and conductivity in μS/cm, with the same equipment. The probe was rinsed with distilled water after every use and its cup was replaced.

Figure 3.10: Hanna Instrument HI9812 (author, 2012)

- Suspended solids (SS) were measured with the use of particular filters, the Glass microfiber paper filters (size 70 mm). Filters were labeled according to the samples. Then they

were weighted in a digital scale, after the scale was calibrated at zero weight. The measurements were recorded. Then the filters were placed onto a filtering flask and 100 ml of the sample bottles were measured and poured over the filters. A small electric suction pump connected to the filtering flask assisted the filtering process. When all the water was filtered, the filters were removed and placed in the 105 ^{o}C oven for 1 hour. After taken out of the oven, they were let to cool down in room temperature for about 15 minutes, in a small chamber were atmospheric humidity was absorbed by special gravel placed at the bottom of the chamber. Last the filters were weighted again on the scale and records of the measurements were taken. The increase in weight gave the suspended solids loading. As recorded in the raw data excel sheets in the appendices, the used filter weight minus the clean filter weight, gives the suspended solids in gr/100 ml. These numbers were very small, thus changed into mg/l (gr/ml*10000=mg/l) for the final record.

Figure 3.11: Suspended solids Glass microfiber paper filters in use (author, 2012)

Note that all filters were handled with laboratory forceps, throughout the process, so as to avoid dirt and oils from the user's fingers to be deposited on the filters. These would add up to the weight of the suspended solids and the measurements wouldn't represent the actual suspended solids loading of the water. Moreover, in case the suspended solids filter pack has been opened in advance, the filters tended to gather humidity from the atmosphere. As a result in their first weighting procedure, the humidity increased the actual weight of the filter, without the user realizing that. After water was filtered through the paper and the filters were placed in the oven, humidity was evaporating along with the water. When the filters were weighted for a second time, they were found to be less heavy than before, despite the suspended solids loading. That was because the humidity was not present any more within the filter. These readings produced false results. It was wiser then, if better quality filters which do not absorb humidity that easily are not available, to pre-wet the paper filters with distilled water, following the same filtering procedure, using the flask and the small pump. Then the filters can be placed in the oven for at least an hour. Alternatively, they can remain there for long, until the time to be used arrives. That safeguards that the humidity from the air is no longer present and that the filters are not given another chance to re-absorb it.

- Dissolved oxygen (DO) was measured with the YSI Model 58 meter in mg/l. While the probe was still covered with its cup containing a wet sponge, the meter needed to be calibrated at zero reading. Then the temperature knob was turned to the temperature reading and the probe was allowed to take the room temperature. The knob was then turned to the 0.1 ml/l mark. That oxygen reading needed to correspond to the previous room temperature. The chart displayed on the back of the meter, gave the expected DO for each temperature. Finally the knob was turned to the regular DO indication again. The probe could now be immersed to the sample and very gently stir the water three times, until the reading on the digital screen was stabilised. The probe was rinsed with distilled water after every use and its cup was replaced.

Figure 3.12: YSI Model 58 dissolved oxygen lab meter (author, 2012)

The parameters of taste and odour could not be tested within the laboratory. Taste and odour tests exist, either trying to detect specific substances in the chemical composition, or based on statistical analysis of subjective comments given by people actually consuming or smelling what it is to be tested. Usually a threshold level above which odour/taste is detected is recorded (Spellman, 2003, p. 431). Alternatively, a favor level can be recorded. This obviously wasn't possible to be done in the present case.

To conduct all the measurements 125 ml of water were abstracted in total with a syringe and placed in labeled bottles of the same size. First, the bacteria measurement was conducted, using 25 ml. With the remaining 100 ml all the rest measurements were done. With instruments having a probe, that was directly immersed in the labeled bottle. With measurements needing the water to be placed on a separate tube, water was returned to its initial bottle after the measurement was done. Last measurement was that of the suspended solids, were the remaining 100 ml were used up. Taking only 125 ml of water was the minimum possible amount. It was decided to do that in order not to abstract larger quantities, since the water volume within the pots was already not very large.

3.2 Testing Procedure

In this section the procedure followed to conduct the experiments will be described in more detail. For ease of reading, the research questions are repeated here:

1. What is the bacteria removal effectiveness of the three-pot system?
2. How many days should the retention time be?
3. Is siphoning more effective than pouring?
4. Is the surface water of better quality than the water at the bottom?
5. How many pots should be used?

3.2.1 Experiment A

Experiment A was designed to address specifically research question 3 and questions 1, 2 and 5 along with experiment B (see section 3.1.1). It was conducted in three trials (1-2-3), with each trial having different initial raw water quality. As shown in appendices 8.1.1-8.1.2-8.1.3, the basic difference was in the *E. coli* loading, with trial 1 having 3408 cfu/100ml, trial 2 having 880 cfu/100ml and trial 3 having 823 cfu/100ml.

The typical three-pot system procedure, where water is allowed to settle one day per each pot, was followed. In that sense, three containers in series were used. However, since the main focus was to test the decanting method (question 3), there were two systems running in parallel, one where the water was siphoned and another one where the water was poured. For reliability reasons each three-pot system was duplicated in A and B systems. A and B systems double-checked one another. That would ensure that the results are not random. Stable buckets where water was not decanted at all, played the role of a control system for each three-pot system. That would address question 5 as well. The bacteria removal effectiveness results from this experiment within the three-days period, would finally address questions 1 and 2.

All this design resulted in having the following three-pot systems: Siphoning A and B, Pouring A and B, Control Siphoning and Control Pouring for each of the three trials, as shown in appendix 8.1. The two control systems double-checked themselves for reliability. Since the pots in use where three in each system, that produced a number of 18 pots to be handled within each trial, as depicted in the following figure. In order not to be mixed up, siphoning and pouring systems were placed in parallel series and were given different colour pots (black for siphoning and red for pouring). Control systems had different colours as well. Control siphoning had blue pots, while control pouring had green pots.

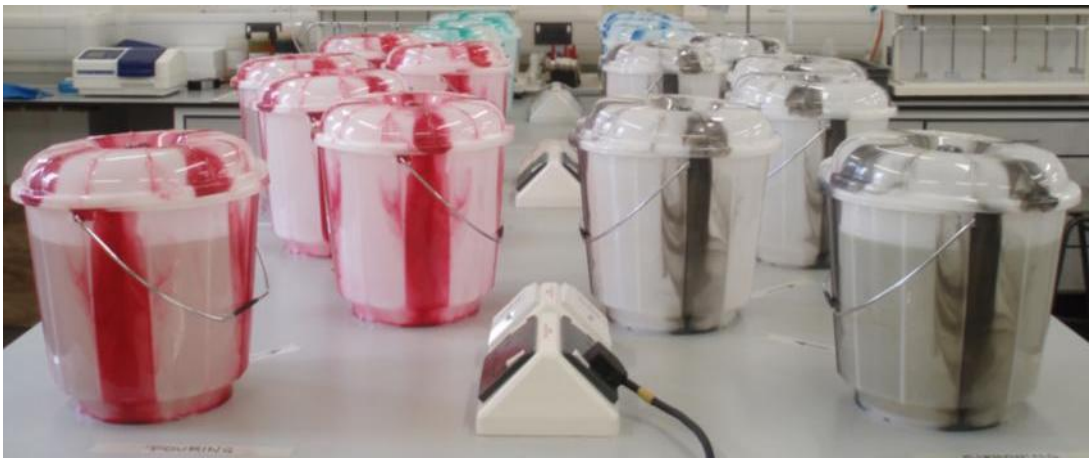


Figure 3.13: Experimental setup: Pouring systems in red (right front side) – Siphoning systems in black (left front side) – Control pouring systems in green (right back side) – Control siphoning systems in blue (left back side) (author, 2012)

Moreover, proper labeling was given to the pots and distinctive arrows and lines were drawn to separate the systems and indicate the order of decanting, as shown in figure 3.14. Prior to placement, right after the purchase of the pots, each container was checked for cracks by being filled with tap water and then calibrated from 0.5-10 litres, to be easier to distinguish the volume of water within each pot.

Figure 3.14: Labels, distinctive lines and arrows separating the three-pot systems marked in the picture (author, 2012)

Every morning at the same time, water was being decanted to the next container. All the measurements were done on samples from the water that was being transferred into the new pot to see any improvement on the quality after one day of storage. The only measurement that was done both before and after the water was decanted was the dissolved oxygen one. That was done in an attempt to see the effect of aeration in the treatment process, compared especially between the siphoning and pouring systems. Every time the water was decanted, the left volume of water was thrown away, in such a way that it would carry along all the

settled solids with it. Alternatively, tap water could be used for better cleaning, but the idea was to create realistic conditions, where availability of water is small. It wouldn't be very logical for somebody who has enough water to throw for cleaning purposes to be in need of using the three-pot technique for drinking water. The pots were cleaned with tap water thoroughly only after each trial, so that any bacteria or solids from the previous trial, wouldn't affect the next trial's results. With the same principle, the siphon was cleaned after every trial as well.

The volume left behind each time was measured with a volumetric cylinder, thus it was easy to calculate the volume of water transferred into the next pot each time. Records are shown in appendix 8.1 for each system. Moreover, the flow rate of water was measured as well. The time to decant the water was measured with a stopwatch several times in the training day, prior to the actual experiments. The average time of all, showed how slower the siphoning procedure was compared to the siphoning one. The results are shown in appendix 8.4. As explained in the "bucket and stopwatch" method (Pickford, 1991, p. 109), the flow rate was calculated according to the volume transferred each time. The results can be seen in appendix 8.1 for each system.

Seeing the time records for pouring and siphoning, the rate of decanting was attempted to be kept similar in each case. Pouring was performed in a stable way, with calm moves that would disturb the water and the suspended solids as less as possible. Pouring was stopped before the suspended solids were carried along with the transferred water, according to the researcher's eye. Siphoning was practiced with the aid of a laboratory stand with a clamp. The idea was to siphon water from the centre of the bucket and from the same height each time, so the siphon was fixed in a particular position with the clamp. That height was decided prior to the experiments after several trials. It placed the siphon 5 cm above the bottom of the bucket, at the 0.5 l calibration line. Solids were always at the bottom of the container, so they were not disturbed or sucked by the siphon. Siphoning was practiced in a stable way, using the pump at the same rate of the passing seconds within a minute, so as not to create air bubbles within the water. Again it was stopped before the suspended solids were carried along with the transferred water, according to the researcher's eye.

Overall, the basic materials used were the 18 pots, one siphon, a laboratory stand with clamp to hold the siphon in a stable position, one 100 ml syringe for sampling the water, 18 bottles of 125 ml each for keeping the sampled water, the volumetric cylinder for measuring the amount of water left behind and a stopwatch to measure the time to decant the water. All the materials were found within the laboratory equipment, apart from the siphon and the buckets. The siphon was purchased from a local shop with aquarium supplies. It consisted of a flexible tube with a small manual pump. The pots were purchased from a local shop with home supplies. As

explained in section 2.4.1, 10 l pots were decided to be used. Besides, there were no other sized pots with a fit lid for safe storage in the local market of Loughborough.

Figure 3.15: Siphon used for the experiments (author, 2012)

3.2.2. Experiment B

Experiment B was designed to address specifically research question 4 and questions 1, 2 and 5, along with experiment A (see 3.1.1). It was conducted in two trials (1-2), with each trial having different initial raw water quality. As shown in appendices 8.2.1-8.2.2, their only difference was in the *E. coli* loading, with trial 1 having 8780 cfu/100ml and trial 2 having 17400 cfu/100ml.

In this case, the typical three-pot system procedure, where water is allowed to settle one day per each pot, was not followed. Instead, 7 days were decided to be the retention time. That would address research question 2. Two containers were used this time in rotation, so as not to have 7 pots in series. Since siphoning and pouring didn't seem to have much difference from experiment A, in experiment B only pouring was practiced, since it was a lot quicker. Water was poured after being allowed to settle for a day. Trial 1 and 2 experiments were conducted in parallel. For reliability reasons each 7-day system was duplicated in A and B systems. A and B systems double-checked one another. That would ensure that the results are not random. Stable buckets were water was not decanted at all, played the role of a control system for each 7-day system. That would address question 5 as well. The bacteria removal effectiveness from this experiment would address question 1. Moreover, measurements were taken from the water transferred into the next pot and from the water left behind. That would address research question 4.

All this design resulted in having the following 7-day systems: “9000” A and B, “17000” A and B, Control “9000” and Control “17000”. The numbers indicate the rounded-up figure of *E. coli*. For each system, “transferred” water and “left” water measurements were taken, while in the case of the control systems, these were converted into surface and bottom measurements, in order to be comparable with the decanted water ones. Raw data for these systems are shown in appendix 8.2. Since the pots in use where two in each system, that produced a number of 8

pots to be handled within each trial, adding another 2 control pots, as depicted in the following figure. In order not to be mixed up, “9000” and “17000” systems were placed in parallel series and were given different colour pots (black for the “9000” and red for the “17000”). Control systems had different colours as well. Control “9000” had a blue pot, while control “17000” had a green pot. Again, proper labeling was given to the pots and distinctive arrows and lines were drawn to separate the systems and indicate the order of decanting.

Figure 3.16: Experimental setup: “17000” systems in red (right front side) – “9000” systems in black (left front side) – Control “17000” system in green (right back side) – Control “9000” system in blue (left back side) (author, 2012)

In experiment A, even for trial 1 with 3408 cfu/100 ml, after three days the bacteria dropped to around 120 cfu/100 ml. Therefore, the intention within experiment B, where the treatment would last 7 days, was to have higher bacteria concentrations than in experiment A. The stream was expected to have higher bacteria loading than in experiment A. That was because during the first experiment, there was no significance rainfall in the area. However, before experiment B, heavy rainfall occurred for two days. As explained in (Mara et al. 2003, p. 616), apart from increased run-off during rainfall which could transfer more bacteria within a stream, bacteria already present in the stream which may be attached to the solids on the stream bed, are re-suspended during rains. Also, the increased stream flow, allows less time for the self-purification process of sedimentation, thus more contamination is usually reported.

Naturally, after rain, water had *E. coli* at 8780 cfu/100 ml. That was already contaminated enough, but it was worth testing how the 7-day treatment would result in case of even higher bacteria concentrations. In order to create the second higher bacteria loading, raw water was artificially dosed with laboratory cultivated *E. coli*. The laboratory culture contained approximately *E. coli* at 4000 cfu/100 ml. Adding 1 ml of that culture in 10 l of raw water dosed up the water with approximately 8000 cfu/100 ml, so the final water resulted in having 17400 cfu/100 ml.

The procedure for experiment B, was similar to that of experiment A, thus here described in summary. Every morning at the same time, water was poured to the next container. Measurements were done both on the water transferred into the next container and on the water left behind. That was done in an attempt to see if there is a difference in quality, between surface and bottom water. Every time the water was decanted, the left volume of water was thrown away after being sampled, in such a way that it would carry along all the settled solids with it. Pouring was performed in a stable way, with calm moves that would disturb the water and the suspended solids as less as possible. This time, instead of relying on eyesight, standard volume was left behind for all systems. That was initially 1 l to ensure that no suspended solids were transferred. After two days that most of the visible suspended solids were not present any more, that volume became 0.5 l. If that change wasn't done, the water for treatment after 7 days would be only 3 litres, while it started with 10 l. Records are shown in appendix 8.2 for each system.

3.2.3 Unexpected conditions

Some unexpected conditions appeared during the experiments. After two days of proper use, one of the containers developed a tiny hole at the bottom, through which water was leaking out. Fortunately, it was spotted immediately and not much water was wasted. One of the empty pots was used, until the hole was filled with silicon and left to dry. The problem didn't re-appear.

Another issue was the flotation of oils on the water surface to a very small extent in some pots in experiment A. There was the concern that this could be the initial stage of a biofilm formation (i.e. surface attached matrix composed of micro-organisms), with *E. coli* floating instead of settling. Fortunately, this was not the case. One may refer to section 4.1.3 for further details.

The issue with the suspended solids filters gathering humidity, thus producing false results, mentioned in section 3.1.5, was one of the major unexpected limitations of the project. This couldn't be foreseen and avoided. It emerged in experiment A and it was made sure that it wouldn't occur again in experiment B, by pre-wetting the filters.

Another limitation occurred when the syringe was abstracting water from the bottom of the containers. The syringe was always placed in the centre of the circular bottom of the pot, to produce comparable results from all pots. However, this proved to be faulty, because the syringe was gradually clearing the particular spot each day by sucking 100 ml out. This was noticed from the suspended solids which "disappeared" from the centre of the pot. Therefore, these results could not be trusted (see section 4.2.4). Alternatively, the syringe could abstract

water form a different point each time, but then one could claim that the measurements are not comparable.

Last limitation occurred when water was sampled from the middle-centre of the vessel. Since the syringe was handled manually, the point of abstraction wasn't kept steady while the syringe was used. So these measurements were a bit more random, one may say. In some cases where the results are not uniform, with no obvious explanation, this random effect is assumed to be the cause.

4.0 Results and Analysis

This chapter presents the laboratory results of the experimental work of the project. The graphs of the measured parameters are shown, along with comments and observations. Detailed Excel sheets of the graph data are presented in the appendices. Then the analysis in the form of discussion follows, where the results are compared with existing theories and standards. Limitations of the author's work are stated in the last section, with suggestions for future improvement.

4.1 Lab Results

In order to answer the research questions, experiments A and B were conducted (see section 3.2). In summary, experiment A was conducted in three trials with different raw water quality for each one. The typical three-pot system procedure, were water is allowed to settle one day per each pot, before being decanted, was followed. Three containers in series were used within each three-day time period. Water was poured and siphoned in parallel three-pot systems. Experiment B was conducted in two trials, again with different raw water quality for each. Two pots were used in rotation within a period of 7 days. Water was poured after being allowed to settle for a day. Experiment A addressed specifically question 3, experiment B addressed specifically question 4 and both of them addressed questions 1, 2 and 5 (see section 1.2.3).

The two experiments will be presented separately at this stage. The *E. coli* colonies as seen from the laboratory microscope in all experiments are depicted in figure 4.1.

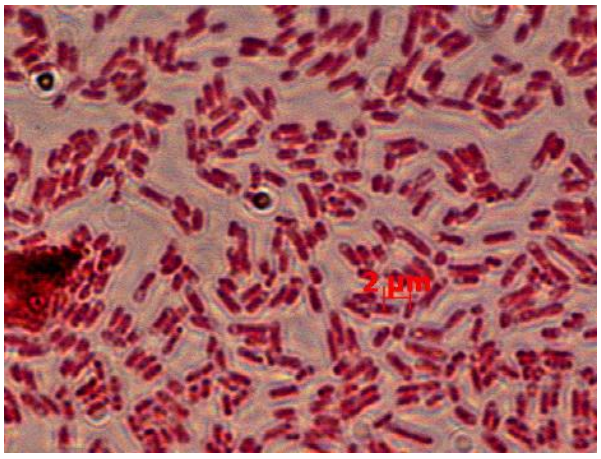


Figure 4.1: *E. coli* colonies in water (author, 2012)

4.1.1 Experiment A

As described in chapter 3, experiment A was basically done to test the typical three-pot system procedure, which says that water remains stable on each pot for a day and it can be

consumed at the beginning of day four from pot three. Siphoning and pouring were to be tested as well. The stable (control) pots, allow comparison between the undisturbed water and the water disturbed by pouring each day. Days on the graphs are listed as 0-1-2-3. On day 0, the raw water was collected.

In order to have more reliable results, the particular experiment was repeated three times (trials 1-2-3). The initial intention was for the influent water to be of similar - if not identical – quality (especially when it comes to *E. coli* loading). But since it was decided to use raw water for more realistic results, the concentration depended on the day of collection from the stream. As a result, only two of the three repetitions were done with similar water quality. That fact though, was advantageous for investigating the overall removal efficiency of *E. coli*, since data for different initial bacterial loading were collected at a later stage. One may refer to appendix 8.1 for the raw data completed in excel during experiment A. Notice that on each trial, siphoning and pouring procedures were performed twice in parallel, so that each experiment was double-checked and thus minimizing the possibilities of the results being random. In that sense, there are six graphs have siphoning A, siphoning B, pouring A, pouring B, control siphoning and control pouring. The latter two are the undisturbed pots mentioned above and they double-check one another as well.

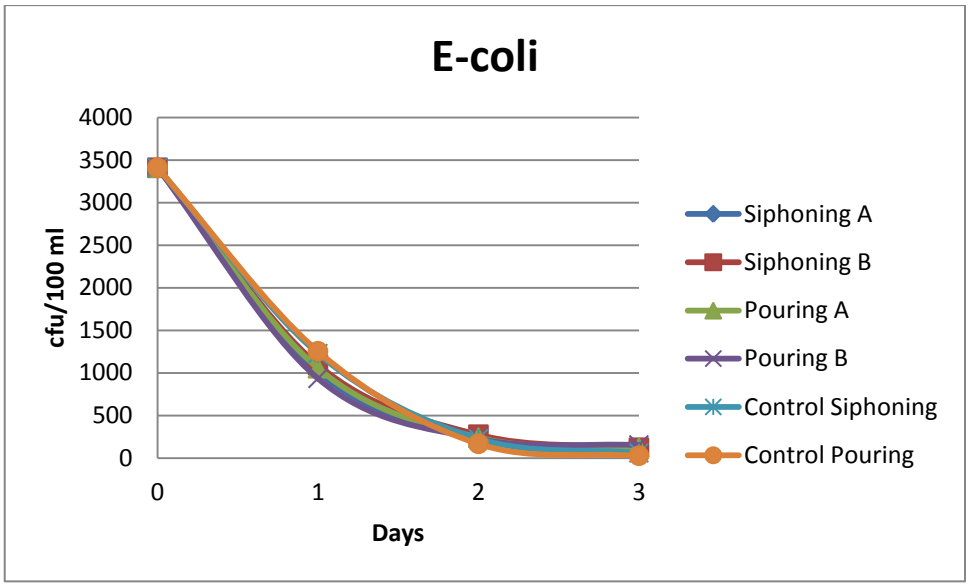
Reduction or removal rates (RR) usually found as %, are given by the formula (Singer, 2010, p. 47):

$$RR\% = \frac{(Influent - Effluent)}{Influent} \times 100$$

where in this case, influent is the raw water and effluent is the final water sampled after three days, ideally suitable for consumption. However, percentages removal rates alone do not show the concentrations that are being measured (i.e.: that of the raw water and subsequent improvements to its quality). Thus, actual counts of the parameters are shown in the graphs, so that one can have a clear picture of the actual quality improvement. Reduction rates however, can be used to compare the trials which have different initial water quality, exactly because they are independent from these values, as shown by the formula.

Taking the measured parameters in order, the graphs created are:

- *E. coli*
  - Trial 1



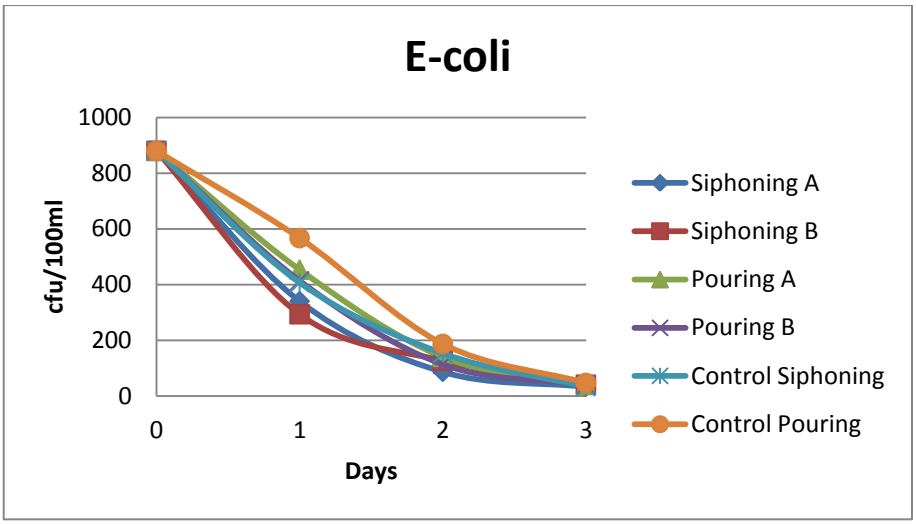
Graph 4.1: E. coli counts reduction over time in experiment A-trial 1

From the initial loading of 3408 cfu/100ml, after three days in the pots, the *E. coli* reduced to about 99 cfu/100ml (the average value of the six similar samples). As one may notice there is no significance difference between A and B curves. Since A and B systems were used to double-check one another, the similar curves prove that the results were not random. Also, there is not much difference between siphoning and pouring, nor between the three-pots and the control buckets. The *E. coli* removal rates are summarised in table 4.1.

	Raw water	Final water	E. coli RR %	Average RR %
Siphoning A	3408	113	96,67	96,58
Siphoning B	3408	120	96,48	
Pouring A	3408	120	96,48	95,99
Pouring B	3408	153	95,50	
Control Siphoning	3408	60	98,24	98,73
Control Pouring	3408	27	99,22	

Table 4.1: *E. coli* removal rates for experiment A-trial 1

- Trial 2



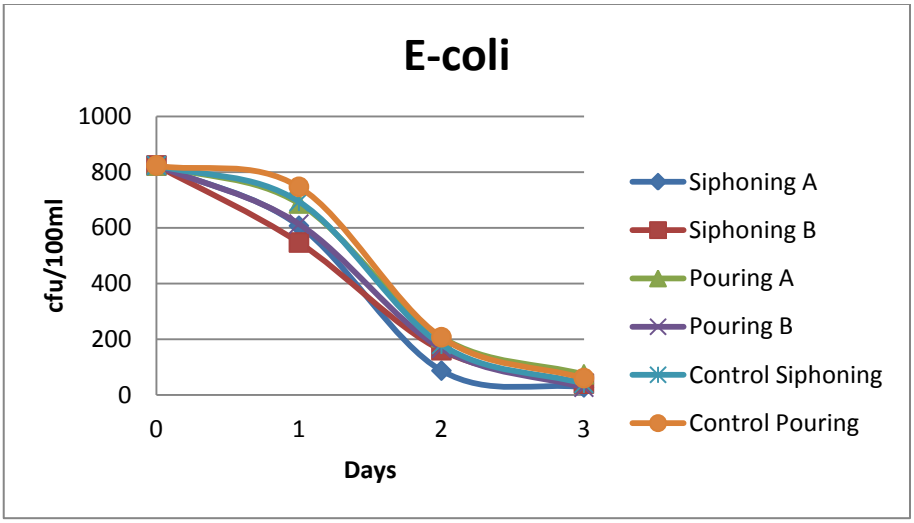
Graph 4.2: E. coli counts reduction over time in experiment A-trial 2

For Trial 2 the initial loading was 880 cfu/100ml. After three days in the pots, the *E. coli* reduced to about 39 cfu/100ml (the average value of the six similar samples). All the samples from day 3, no matter the decanting method or the number of pots, seem to have similar bacteria loadings. The *E. coli* removal rates are summarised in table 4.2.

	Raw water	Final water	E. coli RR %	Average RR %
Siphoning A	880	33	96,21	95,83
Siphoning B	880	40	95,45	
Pouring A	880	40	95,45	95,45
Pouring B	880	40	95,45	
Control Siphoning	880	33	96,21	95,45
Control Pouring	880	47	94,70	

Table 4.2: *E. coli* removal rates for experiment A-trial 2

- Trial 3



Graph 4.3: E. coli counts reduction over time in experiment A-trial 3

For Trial 3 the initial loading was 823 cfu/100ml. After three days in the pots, the *E. coli* reduced to 44 cfu/100ml (the average value of the six similar samples). All the samples from day 3, no matter the decanting method or the number of pots, seem to have similar bacteria loadings. The *E. coli* removal rates are summarised in table 4.3.

	Raw water	Final water	E. coli RR %	Average RR %
Siphoning A	823	27	96,76	95,95
Siphoning B	823	40	95,14	
Pouring A	823	73	91,09	93,93
Pouring B	823	27	96,76	
Control Siphoning	823	40	95,14	93,93
Control Pouring	823	60	92,71	

Table 4.3: *E. coli* removal rates for experiment A- trial 3

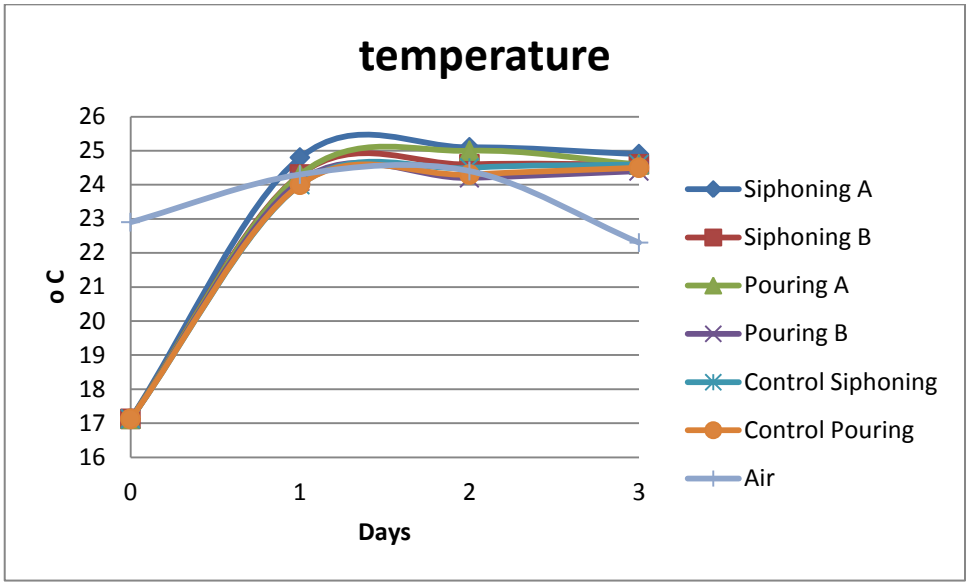
In the graphs on trial 2 and 3, there are some smaller differences on day 1, which tend to lessen on day 2, until they seem to be minimized on day 3. This is not the case for trial 1 though. That fact is probably due to uneven settlement rates of the bacteria. When only one day has passed, bacteria are still more afloat, compared to the rest days, when they have settled further. Moreover, sedimentation is assisted by the amount of suspended solids, as explained in section 2.2.4. Trial 1 had more than double suspended solids loading than trial 2 and 3. That could explain why *E. coli* sedimentation rated are more uniform in trial 1, even from day 1, compared to trials 2 and 3. In table 4.4, the average removal rated from all trials are shown, summarizing the figures from tables 4.1-4.2-4.3. For further analysis refer to section 4.2.

	Average RR%
Siphoning	96,12
Pouring	95,12
Control	96,04

Table 4.4: Average *E. coli* removal rates for all trials in experiment A

For the rest of the parameters, the graphs shown here are from trial 1. This is done for space economy and writing efficiency, since the results between the trials didn't differ that much. However, the graphs for trial 2 and 3 are placed without comments in the appendices. Instead of placing all the graphs, summary tables for all trials are shown.

- Temperature



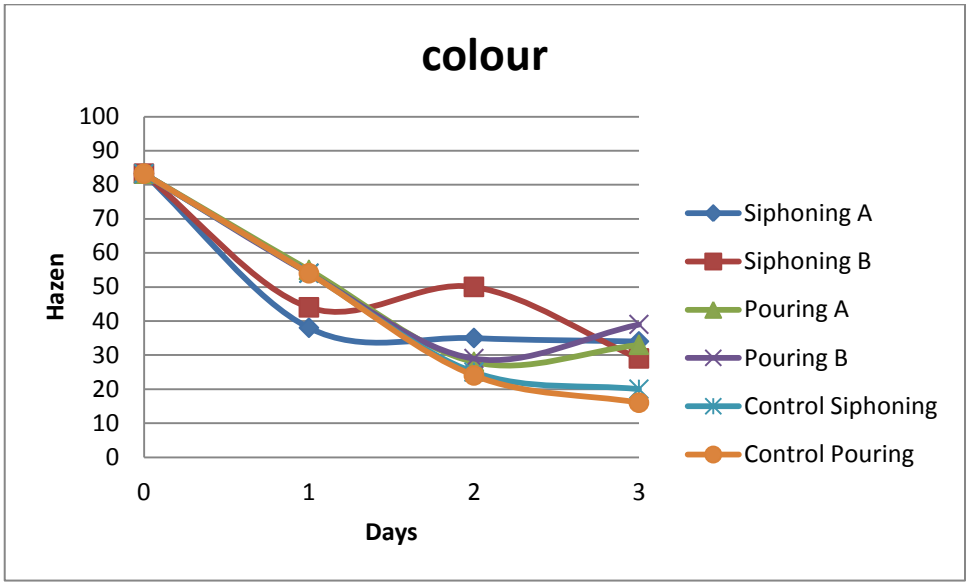
Graph 4.4: Temperature over time in experiment A-trial 1

Ambient (air) temperature is shown in graph 4.4, since this was the only factor altering the water temperature. Obviously, the method of decanting the water does not affect the temperature. Temperature in the raw-running stream water was at 17 ^{o}C, in spite of the air temperature being at 23 ^{o}C. After storing the water even for one day, water temperature reaches air temperature at about 24,5 ^{o}C. Interestingly but also expected, noticed in all trials, is the fact that water "follows" the air temperature with delay. This is because the specific heat capacity of water is higher than air. Even at the magnitude of a 10l container, this basic law of physics, still applies. That explains the stable curve of temperature on day 3, even when the air temperature dropped. Last, all three trials were conducted in similar temperatures, so the significance of this variable and how it may be affecting the procedure, cannot be established. Table 4.5 summarises the average temperatures from all trials.

	Average (^{o}C)	
	Raw water	**Final water**
Siphoning	17,07	23,40
Pouring	17,07	23,12
Control	17,07	23,12

Table 4.5: Average temperature for all trials in experiment A

- Colour



Graph 4.5: Colour reduction over time in experiment A-trial 1

As one may notice on the graphs of colour reduction and especially the ones placed in the appendices for the rest of the trials, the results are not uniform, therefore it is difficult to comment on the removal efficiency of colour. Colour is basically due to suspended matter, as explained in the methodology, so it is logical for colour levels to drop, along with the settlement of suspended solids. However, suspended matter in the samples taken each time from the middle-centre of the vessel for measurements, doesn't represent the suspended solids in the whole container. These types of measurements are a bit randomized, so the results are not very uniform. One tried to rationalize and explain the occurrence of this random effect, maybe due to the disturbance of the decanting method, but there doesn't seem to be a pattern for that. In trial 3, characteristically, one control container has the biggest fluctuation, even though it is not disturbed at all. As a result, the effect is considered to be random.

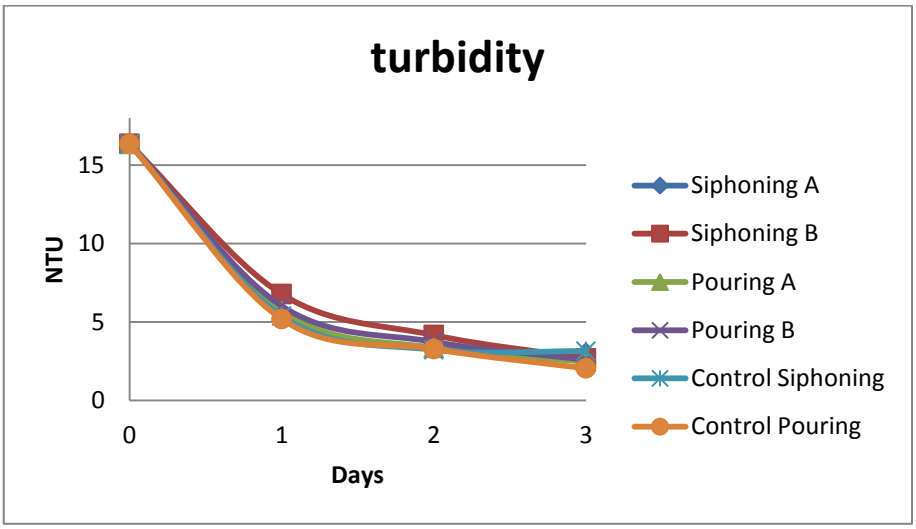
In total, the colour curves drop, but in some points, due to this random effect, they seem to rise again. Thus, the author suggests that this is not an actual rise of the colour level in the whole container and the focus should be on the overall reduction of colour. Control siphoning and pouring curves in graph 4.5 is a model representation. In table 4.6, there is a summary of the reduction rates for all trials. This table is formed like table 4.4 based on the separate trials, but here it's done in one stage for writing efficiency. As one may notice, trial 1 water has double the levels of colour compared to the other two trials, which basically follow the levels of suspended solids. Again as pointed on the *E. coli* graphs, the larger amount of suspended solids assist the sedimentation processes better. That could explain why trial 1 colour graphs are more uniform and even why the RR % are higher than in trials 2 and 3, despite of the random effect. Note though that double loading on the suspended solids in trial 1, gives double levels of colour initially, but the reduction rates are only higher and not double. The

random effect and possible experimental error is thought to be responsible for the two negative figures, which imply that colour levels rose.

		Colour (Hazen)			
	Trial	**Raw water**	**Final water**	**Colour RR %**	**Average RR %**
Siphoning A	1	83	34	59,04	46,98
	2	45	20	55,56	
	3	30	17	43,33	
Siphoning B	1	83	29	65,06	
	2	45	14	68,89	
	3	30	33	-10,00	
Pouring A	1	83	33	60,24	33,32
	2	45	38	15,56	
	3	30	26	13,33	
Pouring B	1	83	39	53,01	
	2	45	22	51,11	
	3	30	28	6,67	
Control Siphoning	1	83	20	75,90	39,25
	2	45	25	44,44	
	3	30	32	-6,67	
Control Pouring	1	83	16	80,72	
	2	45	31	31,11	
	3	30	27	10,00	

Table 4.6: Average colour reduction for all trials in experiment A

- Turbidity



Graph 4.6: Turbidity reduction over time in experiment A-trial 1

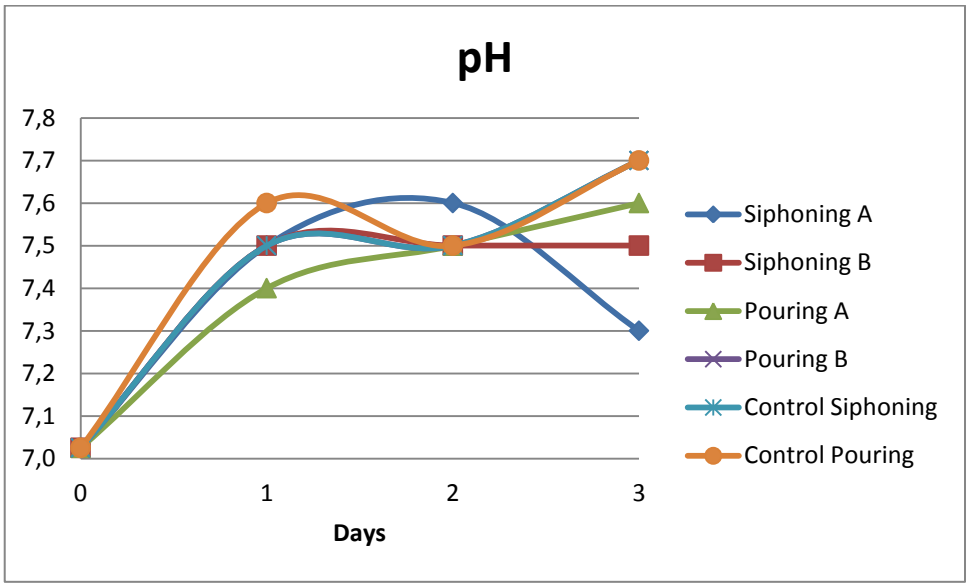
Turbidity is also inter-connected with the suspended solids, so it is logical for the turbidity levels to drop, along with the settlement of suspended solids. The three trials produce similar results, which are summarised in table 4.7. The double loading of suspended solids in trial 1

gives apparently almost double turbidity. The reduction rate in turbidity is therefore usually higher than the reduction in colour, but not twice the value.

		Turbidity (NTU)			
	Trial	Raw water	Final water	Turbidity RR %	Average RR %
Siphoning A	1	16,00	3,03	81,06	81,15
	2	7,78	1,34	82,78	
	3	6,04	1,27	78,97	
Siphoning B	1	16,00	2,68	83,25	
	2	7,78	1,19	84,70	
	3	6,04	1,44	76,16	
Pouring A	1	16,00	2,48	84,50	76,70
	2	7,78	2,44	68,64	
	3	6,04	1,83	69,70	
Pouring B	1	16,00	2,60	83,75	
	2	7,78	2,10	73,01	
	3	6,04	1,17	80,63	
Control Siphoning	1	16,00	3,14	80,38	82,78
	2	7,78	1,20	84,58	
	3	6,04	1,11	81,62	
Control Pouring	1	16,00	2,05	87,19	
	2	7,78	1,43	81,62	
	3	6,04	1,13	81,29	

Table 4.7: Average turbidity reduction for all trials in experiment A

- pH



Graph 4.7: pH over time in experiment A-trial 1

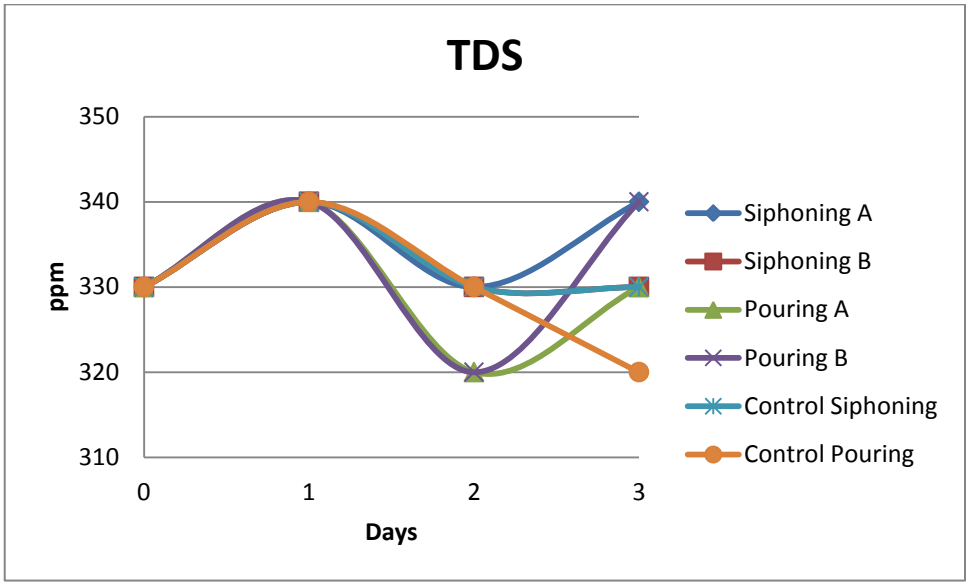
pH in natural waters depends on the source and since the same stream was used, all three trials have initial pH around 7. This value characterizing water as basic, is expected for raw

water. pH in all trials slightly rises (less than 1 pH degree), but overall it can be characterized as being stable. According to the author's opinion, a possible suggestion on the reason for this rise can be made, even if it needs further research (similar idea found in Beeman, 1931). pH is measured by measuring the hydrogen ions (H^+) and it rises when the (H^+) drop (Spellman, 2003, p. 300). *E. coli* is a negatively charged pathogen (Mara et al. 2003, p. 479). On a colloid level, an attachment between the two will inactivate the *E. coli* and will result in pH rise. Note that this idea refers to the attachment mechanism only and not the natural die-off of bacteria, thus the pH rise doesn't necessarily follow the overall *E. coli* reduction rates. In table 4.8, the pH rise for all trials is shown.

		pH			
	Trial	**Raw water**	**Final water**	**pH rise %**	**Average rise %**
Siphoning A	1	7,00	7,3	4,29	3,25
	2	7,35	7,4	0,68	
	3	7,50	7,8	4,00	
Siphoning B	1	7,00	7,5	7,14	
	2	7,35	7,5	2,04	
	3	7,50	7,6	1,33	
Pouring A	1	7,00	7,6	8,57	5,34
	2	7,35	7,6	3,40	
	3	7,50	7,7	2,67	
Pouring B	1	7,00	7,7	10,00	
	2	7,35	7,6	3,40	
	3	7,50	7,8	4,00	
Control Siphoning	1	7,00	7,7	10,00	6,25
	2	7,35	7,7	4,76	
	3	7,50	7,8	4,00	
Control Pouring	1	7,00	7,7	10,00	
	2	7,35	7,7	4,76	
	3	7,50	7,8	4,00	

Table 4.8: Average pH rise for all trials in experiment A

- Total Dissolved Solids



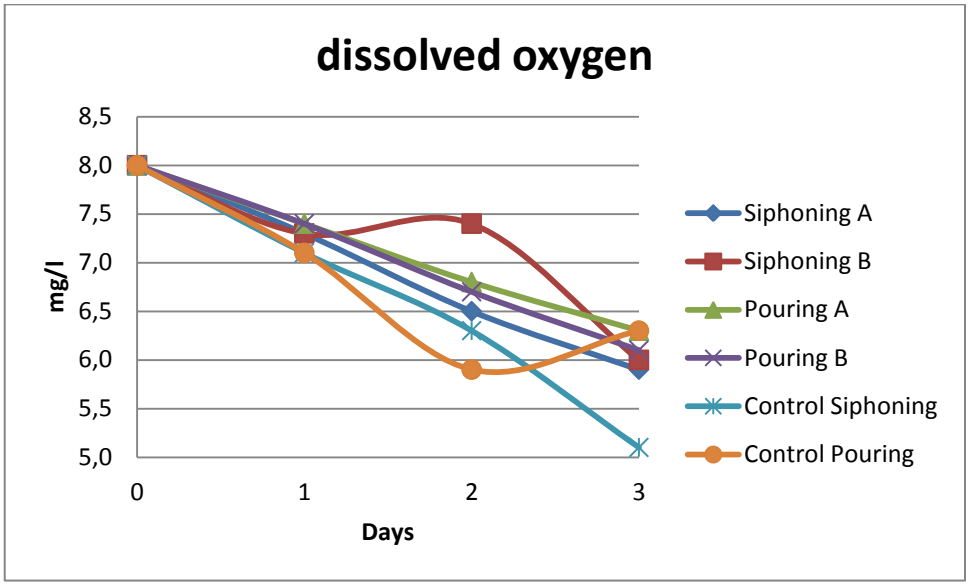
Graph 4.8: Total Dissolved Solids over time in experiment A-trial 1

Total dissolved solids move between 320-340 ppm for all trials. The initial TDS figure is similar in all trials, which is expected, since water comes from the same source. It is difficult to comment and conclude on TDS curves, because some of them seem to slightly rise and others to drop, always within the above mentioned range. TDS are only part of the total solids in water (Spellman, 2003, p. 373), therefore settlement alone doesn't result in TDS dropping, as one may initially think. Minerals, salts, anions and so forth, which are actually what is called TDS, may be released or trapped through various procedures, therefore it is difficult to explain what happened in each situation. As explained in the methodology, TDS was measured through electrical conductivity facilities. That gave figures with accuracy of 10 units. Alternative measurements only for TDS, with higher accuracy exist, if one wishes to research in detail these curves. The random effect may again be responsible for these non uniform curves. Table 4.9 shows the average TDS results from all trials. Reduction or raising rates were found of small significance in the particular case, thus not included.

	TDS (ppm)	
	Raw water	**Final water**
Siphoning	330	333
Pouring	330	320
Control	330	342

Table 4.9: Average TDS values for all trials in experiment A

- Dissolved Oxygen



Graph 4.9: Dissolved oxygen over time in experiment A-trial 1

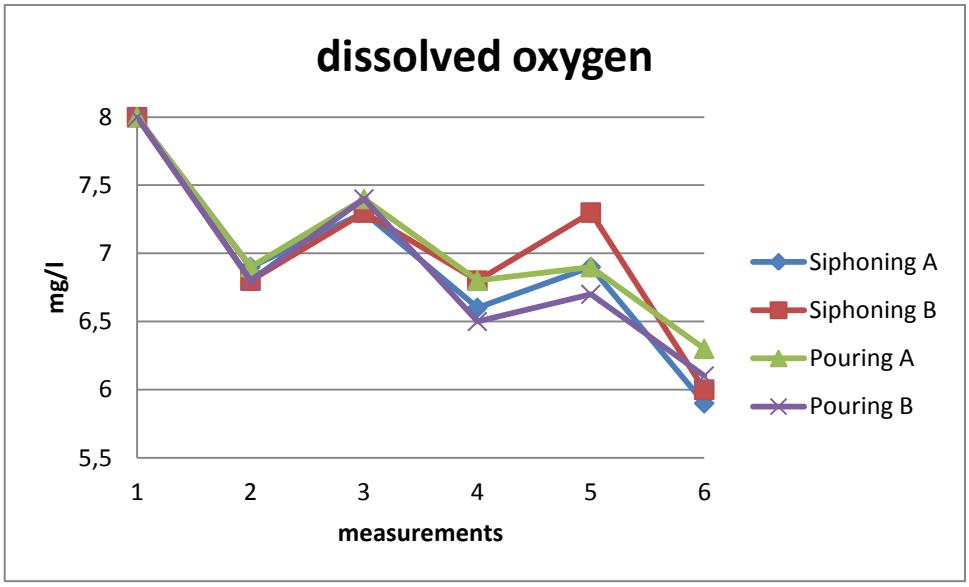
Initially the raw water has a dissolved oxygen value of around 8 mg/l, which after three days of storing and decanting, drops. Oxygen gets into water from the surrounding atmosphere through the air-water interface and as part of the photosynthetic cycle. In this case only the first procedure applies. In fact, "in flowing water, oxygen-rich water at the surface is constantly being replaced by internal water containing less oxygen as a result of turbulence, creating a greater potential for exchange of oxygen across the air-water interface. Because stagnant water undergoes less internal mixing, the upper layer of oxygen-rich water tends to stay at the surface, resulting in lower dissolved oxygen levels throughout the water column" (NCSU, 2012). In this case, since the water remains stationery most of the time, oxygen cannot be replenished that easily, therefore the levels drop. Moreover, any gas dissolved in water is affected by temperature and pressure (Spellman, 2003, p. 299). The small rise in temperature could be another reason for the reduction of the DO levels. Another explanation is that bacteria are aerobic and heterotrophic organisms, so oxygen is consumed by them to sustain their living (Mara et al. 2003, p. 4 and 27). Table 4.10 shows the DO reduction in all trials.

		DO (mg/l)			
	Trial	**Raw water**	**Final water**	**DO RR %**	**Average RR %**
Siphoning A	1	8	5,9	26,25	19,38
	2	8,5	7	17,65	
	3	8,4	7,2	14,29	
Siphoning B	1	8	6	25,00	
	2	8,5	6,8	20,00	
	3	8,4	7,3	13,10	
Pouring A	1	8	6,3	21,25	18,33
	2	8,5	6,9	18,82	
	3	8,4	7,3	13,10	

Pouring B	1	8	6,1	23,75	
	2	8,5	6,7	21,18	
	3	8,4	7,4	11,90	
Control Siphoning	1	8	5,1	36,25	23,77
	2	8,5	6,4	24,71	
	3	8,4	6,8	19,05	
Control Pouring	1	8	6,3	21,25	
	2	8,5	6,5	23,53	
	3	8,4	6,9	17,86	

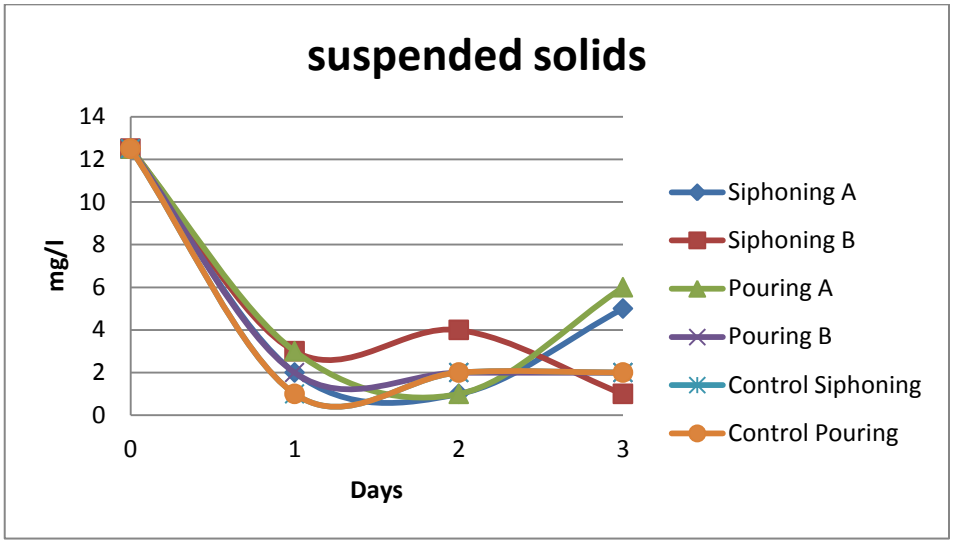
Table 4.10: Average DO reduction for all trials in experiment A

As one may notice in the stationary control buckets, where there aren't any chances for re-aeration at all, the DO drops more than in the procedure where water is being decanted every day, as explained above. That supports the theory that aeration is one of the purification mechanisms of the three-pot system (see 2.2.4). For that reason, measurements of the DO were taken in the water before and after decanting. Indeed, the oxygen content rose slightly after each decanting procedure, so that reduced the overall reduction rate. Characteristically, graph 4.11 was made after trial 1 measurements (see appendix 8.1.1). Measurement 1 is the raw water, measurements 2 and 4 are before decanting, while 3 and 5 are after decanting and measurement 6 is the final water. Measurements 1, 3, 5 and 6 where used for graph 4.9 as well.



Graph 4.10: Dissolved oxygen before and after decanting in experiment A-trial 1

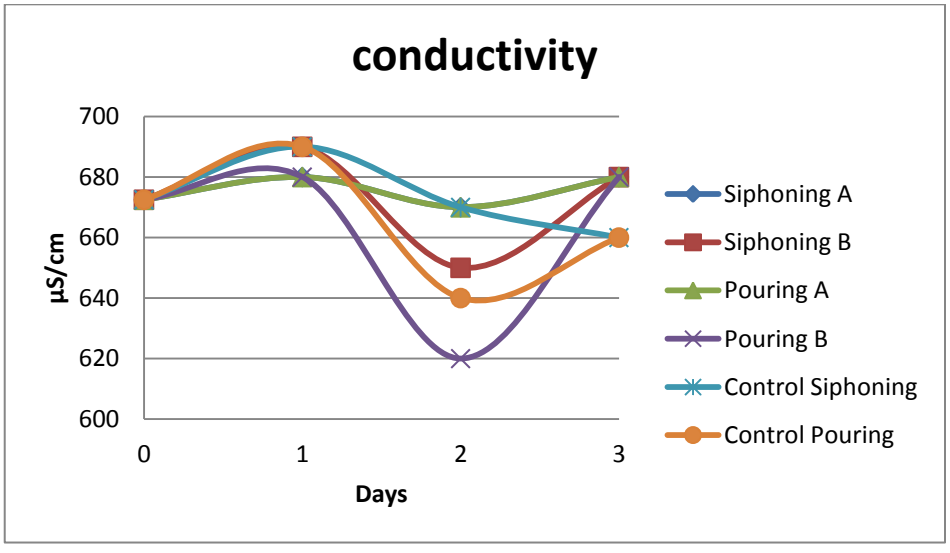
- Suspended Solids



Graph 4.11: Suspended Solids over time in experiment A-trial 1

The concentration of suspended solids is expected to fall, since the solids will slowly settle-out of suspension. The measurements and therefore the graphs, especially from the other trials, are not uniform at all. There are irrational cases where SS seem to rise. This is due to a laboratory technical detail of the filters used to test the SS, which as mentioned in the methodology, wasn't noticed until later. Thus, one wouldn't fully trust the suspended solids measurements and graphs from this experimentation. As a result there is not much point in creating a table with the average reduction rates. Suspended solids are initially 13 mg/l (trial 1), 3,5 mg/l (trial 2) and 5 mg/l (trial 3). The larger amount of suspended solids in trial 1, as explained earlier, may again be responsible for the slightly more uniform results, despite of the laboratory mistake.

- Conductivity



Graph 4.12: Conductivity over time in experiment A-trial 1

Conductivity for all trials seem to fall and rise again over the days and in total it is slightly reduced. It is affected by the amount of inorganic anions and cations in water (Spellman, 2003, p. 420). Basically, attachment of inorganic matter with the settled solids, can significantly reduce conductivity. Moreover, it is affected by temperature, with warmer waters raising the conductivity. Also, there is a connection with TDS and pH since these are partly or totally anions and cations too. All these variables change in different ways, thus conductivity is a difficult parameter to examine separately and comment upon. The results may actually be totally rational. On the other hand, the electrical conductivity meter in the laboratory, gave figures with accuracy of 10 units only, so more accurate results were not possible. Table 4.11 shows the average conductivity results from all trials. Reduction or raising rates were found of small significance in the particular case, since some times the level dropped and others rose, thus not included.

	conductivity (μS/cm)	
	Raw water	**Final water**
Siphoning	670	673
Pouring	660	647
Control	710	690

Table 4.11: Average conductivity values for all trials in experiment A

4.1.2 Experiment B

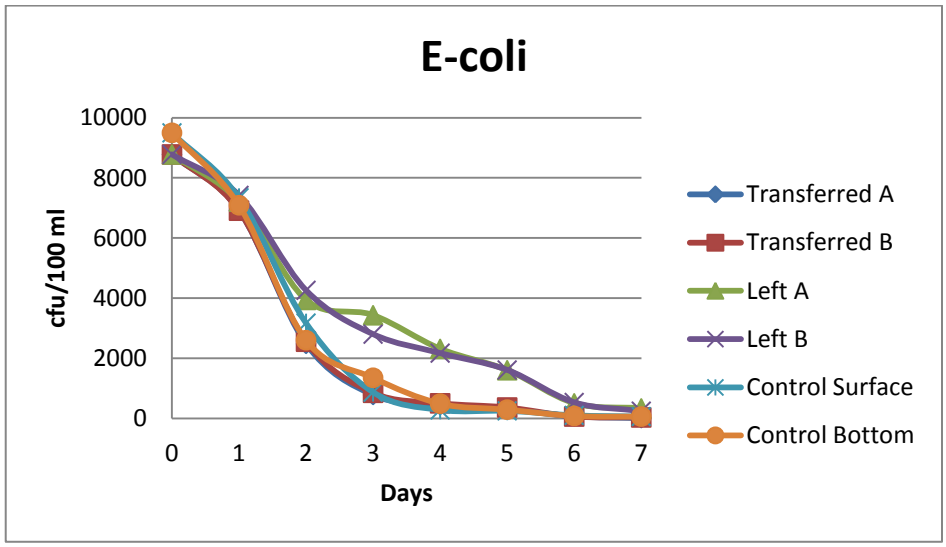
Experiment B was conducted in an attempt to find the reduction rates of *E. coli* when the loading is higher, when treating water by plain storage and decanting. Obviously, looking at tables 4.1, 4.2 and 4.3, three days wouldn't be enough to produce an acceptable level of *E. coli*, so in this case the procedure was repeated beyond the three days formerly used, until the bacteria levels dropped significantly. A duration of 7 days was chosen to be a suitable standard period. Since there has already been testing for a loading of about 800 and 3500 cfu/100 ml in experiment A, natural water after rain with about 9000 cfu/100 ml (trial 1) and the same water with artificial *E. coli* loading of about 17000 cfu/100 ml (trial 2) were used (see chapter 3 for details). Pouring was chosen to be the decanting method, since it didn't seem to result in significant differences from siphoning in experiment A, and it was an easier and quicker procedure.

When water was decanted, it was sampled from both containers. Therefore there was a sample of what is being transferred in the next container and one of what is left in the previous one. That allowed a comparison between the surface and bottom of the water body. Both procedures again, run in parallel twice, so that measurements (A and B) could double-check one another. Control vessels with stagnant water were used for comparison with the decanting procedure, from where surface and bottom samples were taken as well. In that sense, Transferred A, Transferred B, Left A, Left B, Control Surface and Control Bottom were the

curves formed in the graph. Days on the graphs are listed from 0 to 7, for pointing that on day 0, the raw water was collected. One may refer to appendix 8.2 for the raw data completed in excel during experiment B.

Taking the measured parameters in order and with the same definition in removal rates as before, the graphs created are:

- *E. coli*
  - Trial 1



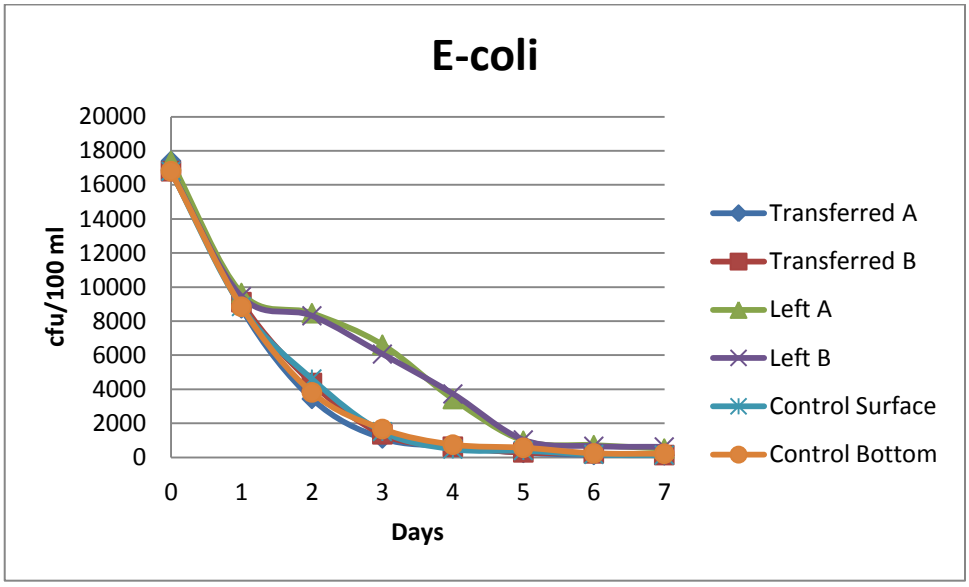
Graph 4.13: E. coli counts reduction over time in experiment B-trial 1

From the initial loading of about 8780 cfu/100ml, after seven days in the containers, the *E. coli* reduced to about 20 cfu/100ml (the average values of the two transferred samples) in 7 days. As one may notice there is no significance difference between A and B samples, so the results are not random. Once more the control containers give similar water quality. However, the samples taken from the bottom of the vessels have higher bacteria counts. That is a proof that bacteria settle down faster than they die-off. On the first day bacteria are still afloat so are found almost evenly at the surface and at the bottom of the container. The “gap” between the curves, tend to close as the days pass, since bacteria die-off as well, either near the surface or at the bottom. The *E. coli* removal rates are summarised in table 4.12.

	Raw water	Final water	E. coli RR %	Average RR %
Transferred A	8780	10	99,89	99,77
Transferred B	8780	30	99,66	
Left A	8780	330	96,24	96,75
Left B	8780	240	97,27	
Control Surface	9500	60	99,37	99,37
Control Bottom	9500	60	99,37	

Table 4.12: E. coli removal rates for experiment B-trial 1

- Trial 2



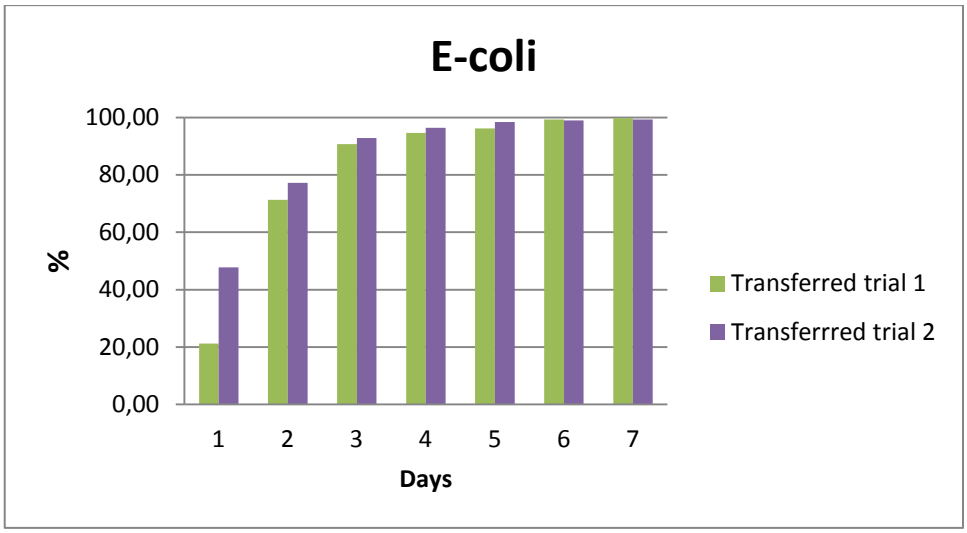
Graph 4.14: E. coli counts reduction over time in experiment B-trial 2

From the initial loading of about 17100 cfu/100ml, after seven days in the containers, the *E. coli* reduced to about 125 cfu/100ml (the average values of the two transferred samples) in 7 days. Again, there is no significance difference between A and B samples, the control containers give similar water quality and the samples taken from the bottom of the vessels have higher bacteria counts. The *E. coli* removal rates are summarised in table 4.13.

	Raw water	Final water	E. coli RR %	Average RR %
Transferred A	17400	120	99,31	99,27
Transferred B	16800	130	99,23	
Left A	17400	510	97,07	96,78
Left B	17400	610	96,49	
Control Surface	16800	130	99,23	98,99
Control Bottom	16800	210	98,75	

Table 4.13: E. coli removal rates for experiment B-trial 2

In trial 1 and 2, same water was used, so all the other parameters are stable, therefore it is easier to comment on the bacteria removal rates for different bacteria loadings. The reduction rate is similar, around 99%, in spite of the initial bacteria counts. Trial 2 final water though is quite contaminated to be characterized of low risk. Yet the treatment is undeniable. Interesting fact is that the bacteria counts seem to drop more rapidly, when the loading of bacteria is bigger, especially in the first day of storage. Characteristically, for transferred water only, looking at the reduction rates percentage, graph 4.15 shows the different “speed” at which bacteria reduce. The average values of A and B where used for each trial in this graph.



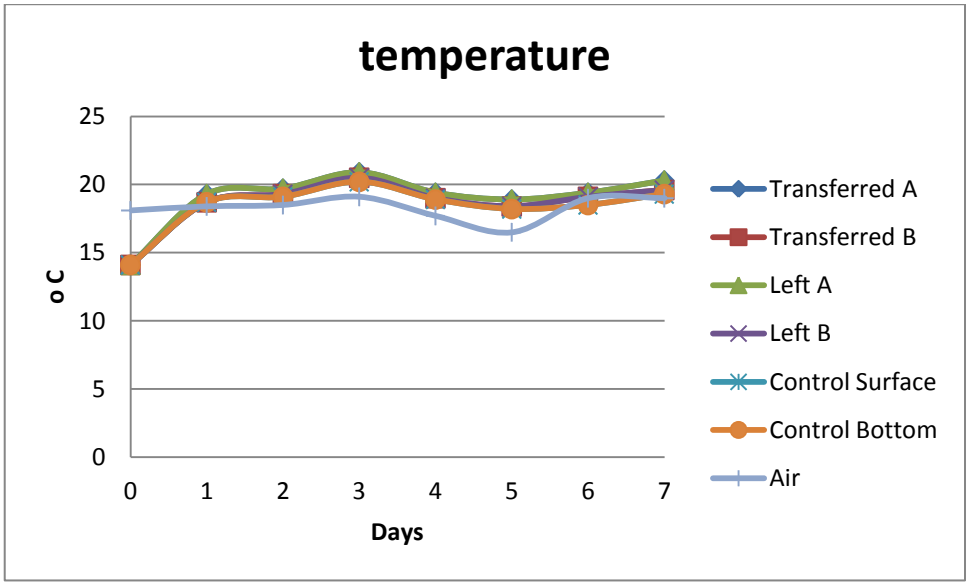
Graph 4.15: E. coli reduction rates for transferred water in both trials in experiment B

Since the suspended solids are the same in both trials, this effect doesn't have to do with the attachment to any solids. One possible explanation is that the bigger population of bacteria, assists flocculation, as explained in section 2.2.4, therefore the settlement is quicker. Another possible explanation, that needs further research comes from the fact that trial 2 water is partly loaded with laboratory cultivated *E. coli*. These may have a different behaviour compared to naturally grown *E. coli*. Laboratory bacteria mixed in the raw water, seem to find themselves in a new environment with natural characteristics. Being grown and kept in fridge conditions, make them less adaptable to changes and robust. Therefore, natural water may come as a shock and once they found themselves in it, they rapidly died off.

That fact could also explain why the speed of the reduction for the natural bacteria (trial 1) is higher on day 2 than day 1. These bacteria may be suddenly restricted within a pot, but it takes at least a day for the conditions like temperature, depletion of nutrients and so forth to start happening in such an extent that bacteria will begin to be affected. Maybe in larger containers these more adaptable bacteria, will need more days until they are affected by the changes. One couldn't trace literature to support this argument properly. The idea though was based on plenty of articles found under the google search term "in vitro-in vivo *E. coli*" (in vitro: in laboratory conditions, in vivo: in realistic conditions). They are usually examined from medical researchers to conclude on the effectiveness of various pharmaceutical products and not specifically on the in vivo-in vitro differences. The key idea though is that they may respond in similar way, but they do respond with different rates. Characteristically, just in an attempt to show how in vitro *E. coli* are less resilient, in a particular experiment by (Kolling et al. 2001), it is stated that they did not recover in vitro, whereas there are studies that they recover in vivo.

For the rest parameters, the graphs shown here are from trial 1. This is done for space economy and writing efficiency, since the initial water quality, apart from the bacteria loading, is identical and the results between the trials didn't differ that much. The graphs for trial 2 are placed in the appendices, without comments. Instead of placing all the graphs in this section, summary tables for both trials are shown.

- Temperature



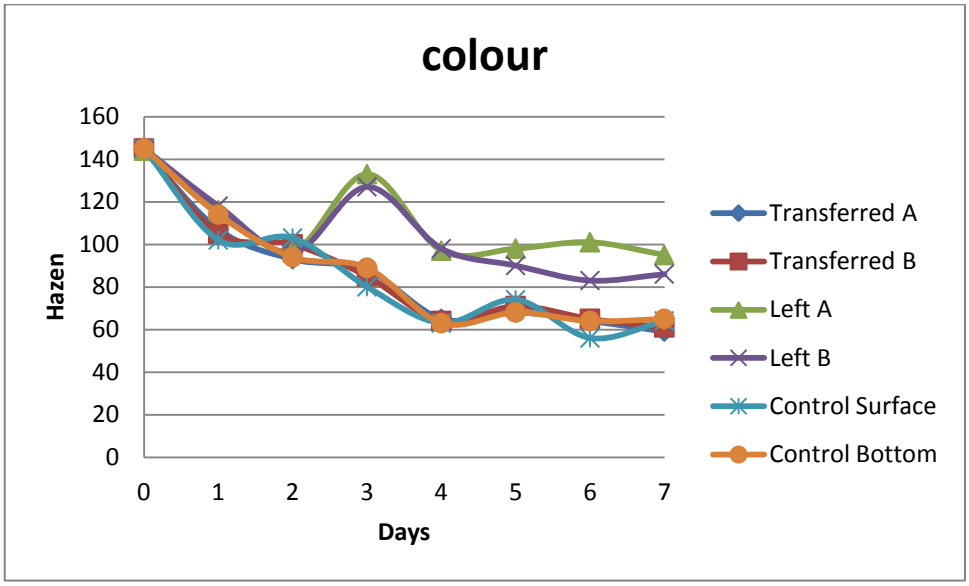
Graph 4.16: Temperature over time in experiment B-trial 1

Ambient (air) temperature is shown in this graph, since this was the only factor altering the water temperature. The containers are relatively small, thus temperature is stable through all the water body. Temperature is overall stable, with table 4.14 summarizing the average temperatures from all trials.

	Average (°C)	
	Raw water	**Final water**
Transferred	14,1	19,78
Left	14,1	19,78
Control Surface	14,1	19,20
Control Bottom	14,1	19,20

Table 4.14: Average temperature for all trials in experiment B

- Colour



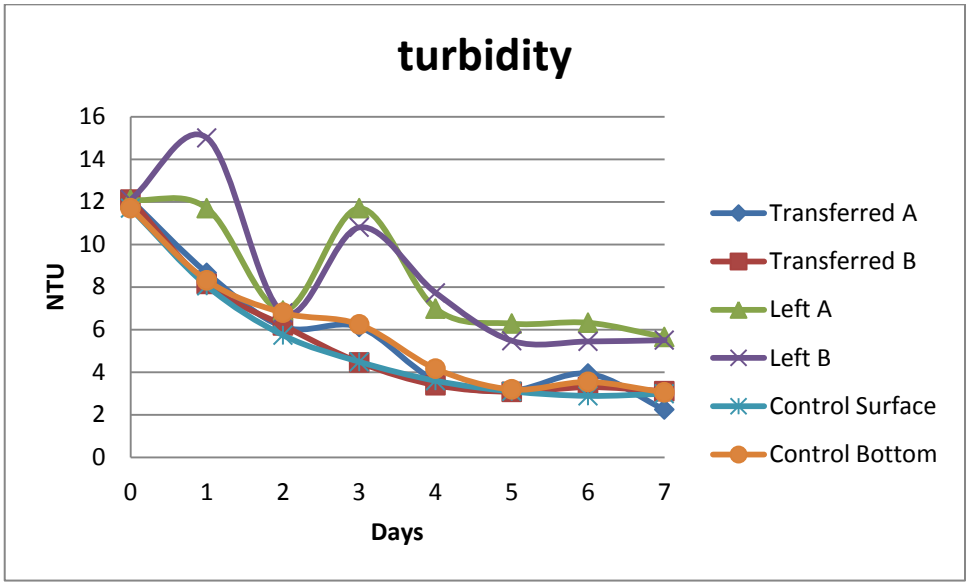
Graph 4.17: Colour reduction over time in experiment B-trial 1

Colour levels overall reduce, as suspended solids settle. The water left in the vessel contained more suspended matter, therefore the colour levels were higher and the reduction rates lower. It seems as if settlement occurred more significantly during the third day, if colour is connected only to the suspended solids. This is false proof though. At that point the “left” volume was altered from 1 litre to 0,5 litres. Therefore the water was more dense in suspended solids and they were captured in larger quantities from the syringe. Also, note that the random effect in experiment B was smaller, especially for the “left” water, which was less than 1 litre, since that allowed a more “representative” fluid entering the syringe. Table 4.15 shows the average colour reduction for all trials.

		Colour (Hazen)			
	Trial	**Raw water**	**Final water**	**Colour RR %**	**Average RR %**
Transferred A	1	144	59	59,03	56,06
	2	143	65	54,55	
Transferred B	1	145	61	57,93	
	2	146	69	52,74	
Left A	1	144	95	34,03	30,10
	2	143	109	23,78	
Left B	1	145	86	40,69	
	2	146	114	21,92	
Control Surface	1	145	64	55,86	56,20
	2	160	70	56,25	
Control Bottom	1	145	65	55,17	
	2	160	68	57,50	

Table 4.15: Average colour reduction for all trials in experiment B

- Turbidity



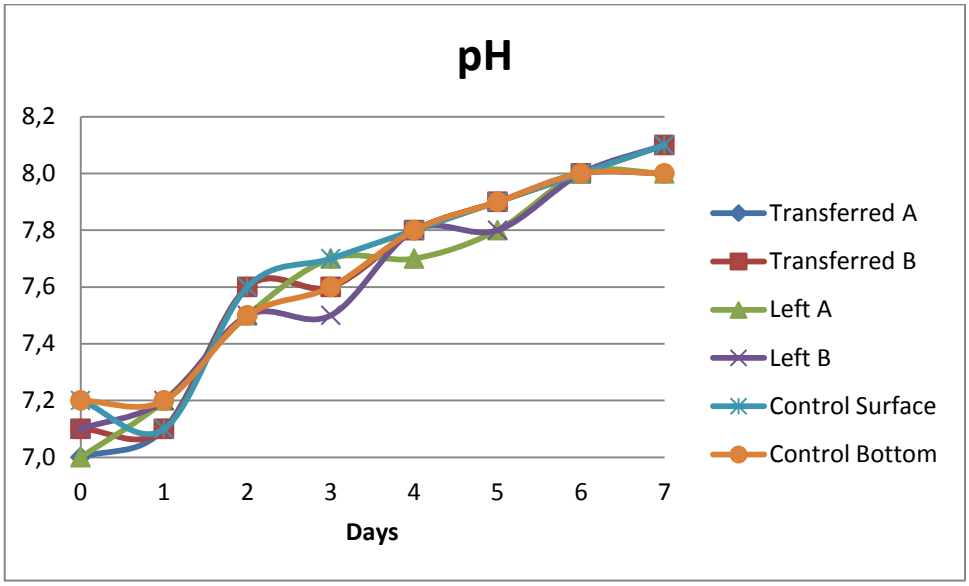
Graph 4.18: Turbidity reduction over time in experiment B-trial 1

Turbidity is inter-connected with the suspended solids, so it is logical for the turbidity levels to drop, along with the settlement of the suspended solids. Again the "left" samples with the higher content on suspended solids have higher turbidity levels and lower reduction rates. The more significant settlement seemed to take place on day 3 again, but again this is due to the change in the "left" volume, as explained before. The abnormal value of the "left B" curve in day 1 is probably due to some sort of procedural or laboratory mistake, since it doesn't seem to appear elsewhere indirectly. The two trial results are summarised in table 4.16.

		Turbidity (NTU)			
	Trial	**Raw water**	**Final water**	**Turbidity RR %**	**Average RR %**
Transferred A	1	12,1	2,24	81,49	75,26
	2	12,4	3,11	74,92	
Transferred B	1	12,1	3,10	74,38	
	2	11,8	3,51	70,25	
Left A	1	12,1	5,65	53,31	51,13
	2	12,4	6,18	50,16	
Left B	1	12,1	5,50	54,55	
	2	11,8	6,31	46,53	
Control Surface	1	11,7	2,98	74,53	73,04
	2	12,7	3,25	74,41	
Control Bottom	1	11,7	3,05	73,93	
	2	12,7	3,90	69,29	

Table 4.16: Average turbidity reduction for all trials in experiment B

- pH



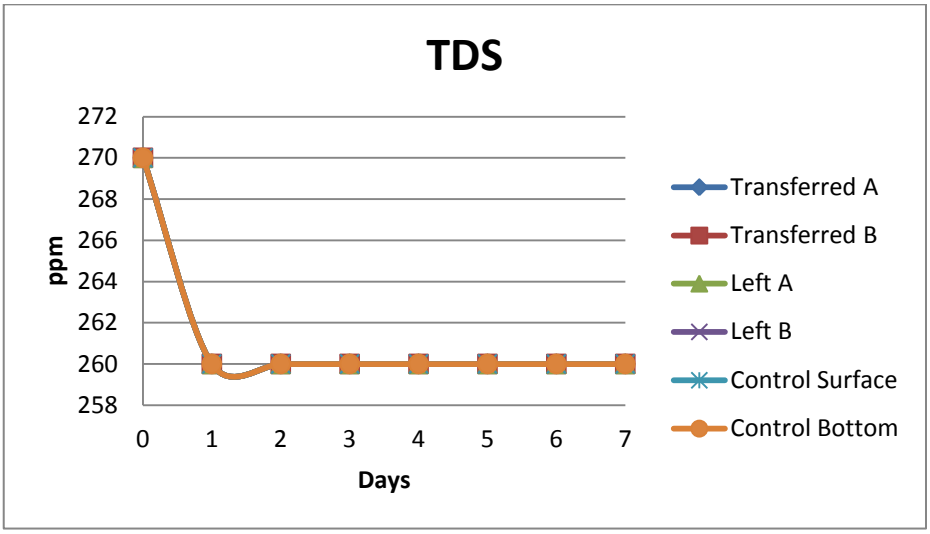
Graph 4.19: pH over time in experiment B-trial 1

pH in all trials slightly rises, around 1 pH degree. That could re-affirm the previously stated theory that (H^+) ions attach with the negatively charged *E. coli* and that can result in a rise of pH. In this experiment where the loading is higher, pH rises more than in experiment A. In table 4.17, the pH rise for all trials is shown.

		pH			
	Trial	**Raw water**	**Final water**	**pH rise %**	**Average rise %**
Transferred A	1	7,0	8,0	14,29	13,74
	2	7,1	8,1	14,08	
Transferred B	1	7,1	8,1	14,08	
	2	7,2	8,1	12,50	
Left A	1	7,0	8,0	14,29	13,74
	2	7,1	8,1	14,08	
Left B	1	7,1	8,1	14,08	
	2	7,2	8,1	12,50	
Control Surface	1	7,2	8,1	12,50	10,70
	2	7,3	8,0	9,59	
Control Bottom	1	7,2	8,0	11,11	
	2	7,3	8,0	9,59	

Table 4.17: Average pH rise for all trials in experiment B

- Total Dissolved Solids



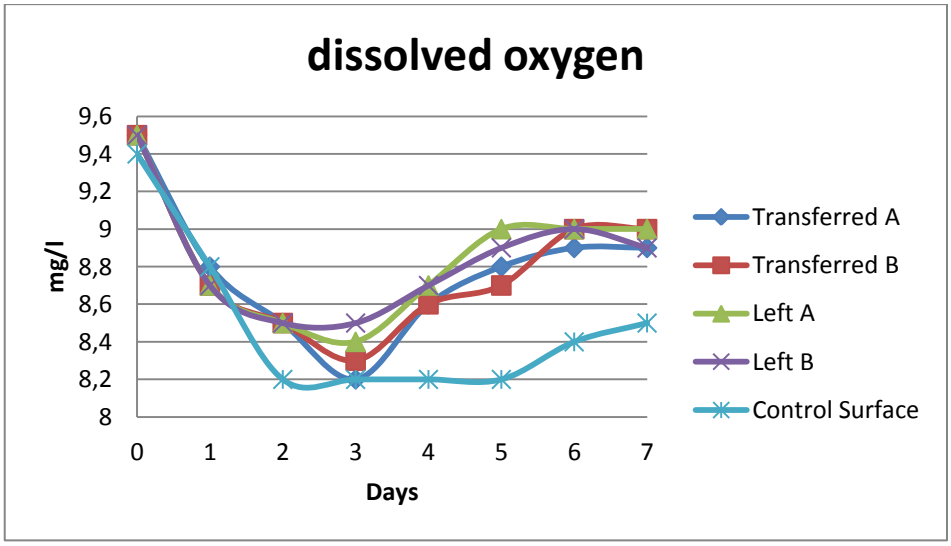
Graph 4.20: Total Dissolved Solids over time in experiment B-trial 1

Total dissolved solids drop from 270 ppm to 260 ppm and seem to remain stable through the days. As explained before, TDS should not be related only to sedimentation of suspended solids. If that was the case, the curve would follow the suspended solids one. Minerals, salts, anions and so forth, may be released or trapped through various procedures, therefore it is difficult to explain the TDS curves. Table 4.18 shows the average TDS results from all trials.

	TDS (ppm)		
	Raw water	**Final water**	**TDS RR%**
Transferred	270	260	3,7
Left	270	260	3,7
Control	270	260	3,7

Table 4.18: Average TDS values for all trials in experiment B

- Dissolved Oxygen



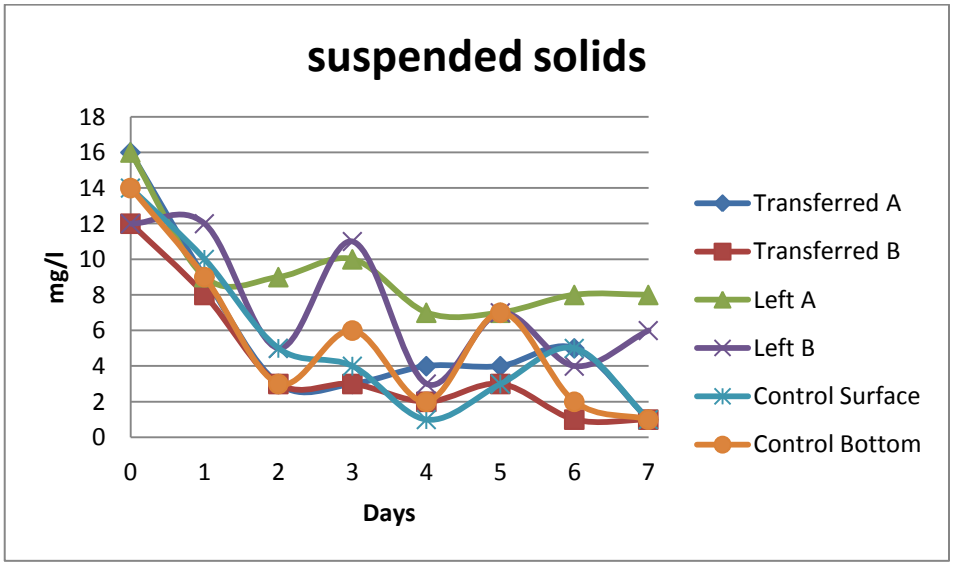
Graph 4.21: Dissolved oxygen over time in experiment B-trial 1

Note that in this graph “control bottom” is missing, since the DO meter probe wasn’t long enough to reach the bottom of the stationary water. Initially, DO was around 9,5 mg/l. As the first days passed, the DO levels dropped for the same reasons explained in experiment A. However, in experiment B, levels seemed to rise again after the third day. Transferred water became less in volume, since every day the settled water was thrown away. Therefore the column of water became smaller and it was easier for the remaining water layers to intermix after every pouring procedure. That assisted oxygen exchange with atmosphere. The smaller volume of the “left” water after day 3, allowed more oxygen to pass into the fluid as well, thus there was a rise in DO levels as well. Temperature rising and bacteria feeding, which resulted in oxygen reduction, may be applicable in this case as well, but they were not as strong as the aeration mechanism. Table 4.19 shows the DO reduction in all trials. Indeed, stationary “control” water with no aeration chances, dropped the DO levels most of all.

		DO (mg/l)			
	Trial	**Raw water**	**Final water**	**DO RR %**	**Average RR %**
Transferred A	1	9,5	8,9	6,32	6,05
	2	9,5	9,0	5,26	
Transferred B	1	9,5	9,0	5,26	
	2	9,5	8,8	7,37	
Left A	1	9,5	9,0	5,26	5,53
	2	9,5	8,9	6,32	
Left B	1	9,5	9,0	5,26	
	2	9,5	9,0	5,26	
Control Surface	1	9,4	8,5	9,57	9,04
	2	9,4	8,6	8,51	

Table 4.19: Average DO reduction for all trials in experiment B

- Suspended Solids



Graph 4.22: Suspended Solids over time in experiment B-trial 1

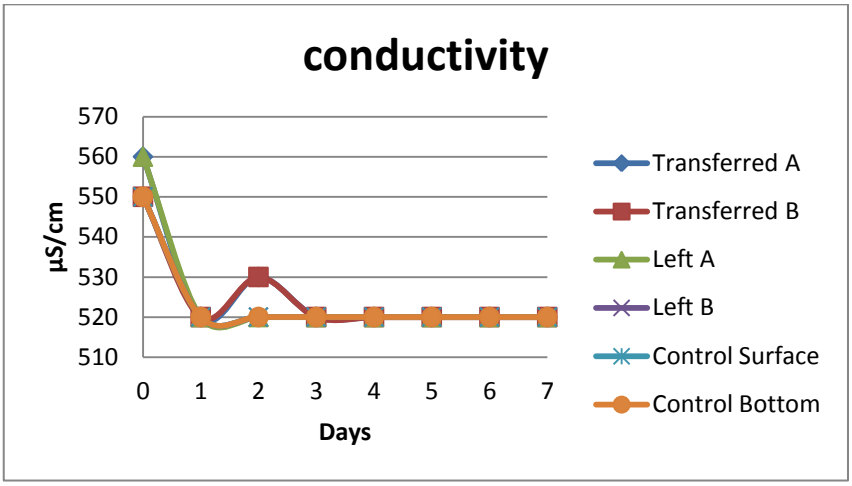
Suspended solids measurements and therefore the graphs again are not very uniform. The laboratory mistake of using unwashed filters for the SS measurement was not repeated this time. Day 3, where the SS level in “left” water became more dense can be seen. For the rest of the measurements, there is no clear explanation why they fluctuate. The author may think that since these figures are very small when measured in g/100 ml in the laboratory scale, 0,0001 g/100 ml will result in 1 mg/l in the graph. It is very easy to have 0,0001 g/100 ml fluctuation in the scale and on the SS, but on the graph this is reproduced with larger significance than it actually is. Overall though this time, the curves drop, since solids settle down. Table 4.20 summarises the reduction of the SS from both trials.

		SS (mg/l)			
	Trial	**Raw water**	**Final water**	**SS RR %**	**Average RR %**
Transferred A	1	16	1	93,75	90,08
	2	17	2	88,24	
Transferred B	1	12	1	91,67	
	2	15	2	86,67	
Left A	1	16	8	50,00	48,43
	2	17	9	47,06	
Left B	1	12	6	50,00	
	2	15	8	46,67	
Control Surface	1	14	1	92,86	88,10
	2	15	1	93,33	
Control Bottom	1	14	1	92,86	
	2	15	4	73,33	

Table 4.20: Average SS reduction for all trials in experiment B

As expected, transferred water has less SS as days passed, therefore higher reduction rates, compared to the “left” water, which gathered all the settled matter. Control water from the surface logically shows relatively high RR, since SS settled and moved away from the top. Note though that the RR of the bottom is false. By taking samples always from the centre of the container, SS were gradually removed from this area (see section 4.2.4). Therefore, SS seem falsely to reduce.

- Conductivity



Graph 4.23: Conductivity over time in experiment B-trial 1

Conductivity for both trials dropped from about 550 to 520 µS/cm within the first day and then remained relatively stable. As mentioned before, attachment of inorganic anions and cations with the settled solids, can significantly reduce conductivity. Moreover, it is affected by temperature, with warmer waters raising the conductivity. Also, there is a connection with TDS and pH since these are partly or totally anions and cations too. All these variables change in different ways, conductivity is a difficult parameter to examine separately and comment upon. However, it seems that whichever mechanisms reduced conductivity are dominant overall. Table 4.21 shows the average conductivity reduction from all trials, which is quite stable.

	conductivity (µS/cm)		
	Raw water	**Final water**	**Average conductivity RR%**
Transferred	552,5	520	5,88
Left	552,5	520	5,88
Control	550,0	520	5,46

Table 4.21: Average conductivity values for all trials in experiment B

4.1.3 Acceptability issues

Apart from colour, it is important to mention some more parameters affecting the acceptability by users. These are taste and odour. Taste and odour tests exist, either trying to detect specific substances in the chemical composition, or based on statistical analysis of subjective comments given by people actually consuming or smelling what it is to be tested. This obviously wasn't possible to be done within the laboratory. Only field data could produce such results but the researcher was able to make some subjective observations.

Applying to both experiments, one perceived the raw water to have a strong “damp” odour, like wet soil, which was expected since the water was collected from the stream. When water was decanted, by either siphoning or pouring, either for 3 or 7 days, this odour level dropped every day. It never disappeared completely, but it wasn’t discouraging any more. After the first two days, the reduction rate of this annoying odour, was thought to drop as well. Interestingly, in the control buckets, where water was stable, the odour remained almost as strong as it was initially. This supported the fact that aeration improves the water quality further and is an active mechanism in the three-pot system. Last point to mention, is that the exact moment the lid was taken off, the smell was a lot stronger. In that sense, the researcher thought that while the lid is necessary to prevent recontamination, it may be inhibiting the odour reduction. Of course, contamination of water is more important than the acceptability issue of odour, thus the lid is advised in any case.

The overall appearance of the pots as noticed through the experiments should be mentioned as well, when it comes to acceptability. Physical substances found in surface water, apart from suspended solids, were various organic matter like leaves and small pieces of wood, various small organisms, like dead-alive bugs and oils. Depending on their density, some sunk in the bottom and others remained floating at the surface. Before decanting the water, the floating substances were carefully removed. That can be performed by the user easily, so as to have more acceptable water finally. These observations generated the idea that floatation should be included in the purification mechanism as well.

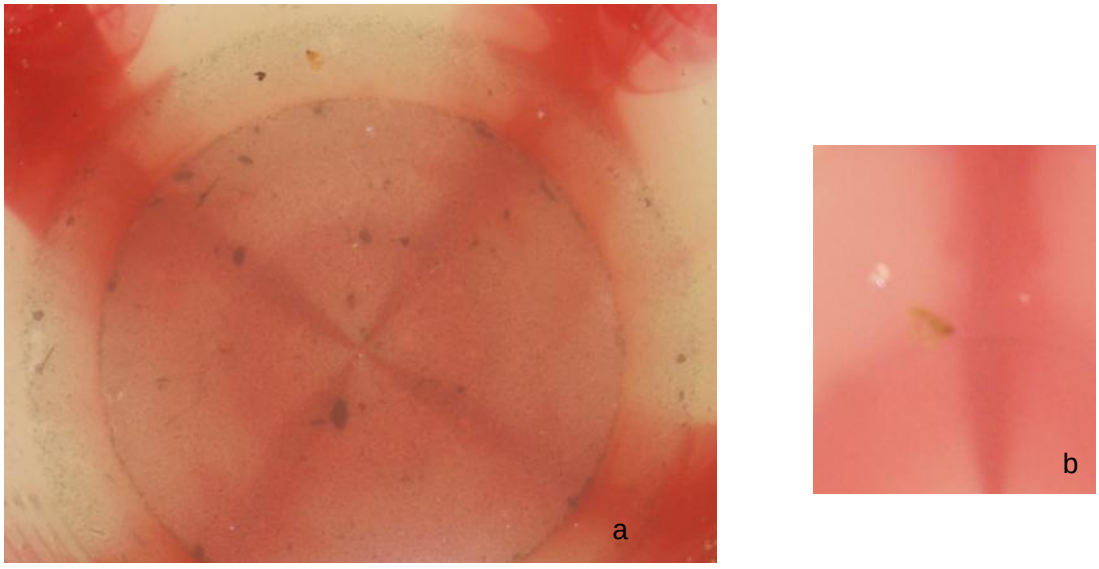


Figure 4.2: Small leaves (a) and a dead bug (b) floating on the surface (author 2012)

Moreover, according to the author’s perception, algae growth was noticed to a very small extent. This green substance didn't appear at the whole container with such sort retention times, but had the form of an algal ring at the border where the water met the edge of the

bucket. The formation of this ring kept reducing every day the water was decanted. On the control containers, the thickness of this ring was bigger, since water remained stagnant. Pots need periodical cleaning from algae as well, if they are to be used continuously for the three-pot system. Note, that no tests were carried out to confirm if that was algae indeed.

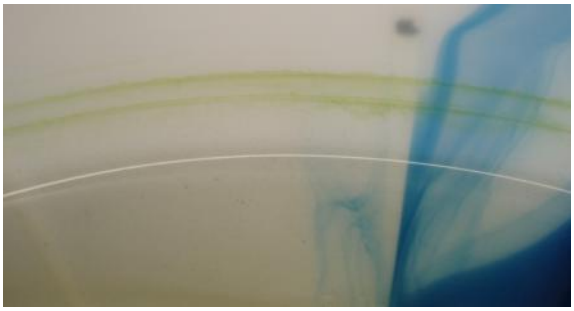


Figure 4.3: Algal ring near the surface (author 2012)

Last issue traced was the flotation of oils on the surface to a very small extent. Unfortunately, that couldn't be captured by the camera. It looked like a thin film with different sized circles which reflected the laboratory lights a bit differently than plain water, thus they were spotted. Initially, one thought that this were some sort of oils or even worse, this could be the initial stage of a biofilm formation (i.e. surface attached matrix composed of micro-organisms), concerned about *E. coli* floating instead of settling. (For details on biofilm formation, one may refer to the particular chapter in (Mara et al. 2003) on p. 337). Fortunately, this wasn't the case of a biofilm. It was observed, that this film wasn't present any more on day 2 when water was siphoned, but only when it was poured. If it was a biofilm formed from floating bacteria, it would most likely be re-formed in the next pot as well. However, the particular "film" seemed to be transferred rather than formed. When pouring, water falls from the surface into the next pot, so the "film" was carried along. When siphoning, water was sucked from the level where the siphon was placed and the procedure was stopped before surface water reached that level, so as not to suck air in. As a result, the "film" remained at the previous pot and thrown away with the rest of the bottom sediments. In that sense, this was most likely a film made out of oils present in the water that floated at the surface. That belief was confirmed after experiment B. In this case, the water that was collected from the stream was after having rained. The stream flow has increased and therefore the oils were diluted. With smaller oil content, the film wasn't formed this time. If it was a matter of biofilm, the bigger bacteria loading in experiment B, should have produced a thicker biofilm layer.

4.2 Discussion and Analysis

In this section, the five objectives will be answered in particular and that will lead to the discussion of the overall aim of the project.

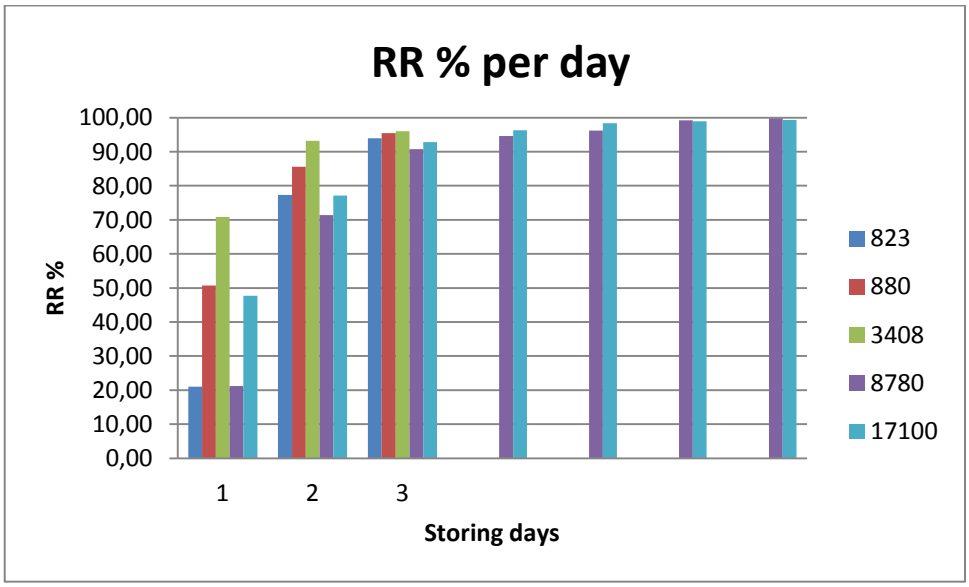
4.2.1 What is the bacteria removal effectiveness of the three-pot system?

In the literature review of the three-pot system, it is mentioned without further proof, that there is a bacteria reduction rate of about 50% with one day storage and it can be up to 90% with longer retention times.

Looking at experiments A and B, there are quite a few variables changing. In order to take results from both experiments to address this questions, data were chosen, which had most variables, if not all, in common. Looking at the methodology, comparable data were the "pouring A-B" results from experiment A with the "transferred A-B" results from experiment B. In both procedures water was decanted by pouring. The initial loading was different (823-880-3408-8780-17100 cfu/100ml) and the retention time as well (3 days-7 days). Also A-B results were added to give their average value. In that sense, table 4.22 was formed based on the Excels data in appendix 8.3. Graph 4.24 was formed based on table 4.22. The numbers (1)-(7) indicate 1-7 whole days (24 hours) of storage, so (1) means retention time from the beginning of day 1 until the beginning of day 2 or 24 hours, (2) means 48 hours and so forth.

	Average RR %						
Raw water (cfu/100 ml)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
823	21,02	77,32	93,93				
880	50,76	85,61	95,45				
3408	70,86	93,15	95,99				
8780	21,24	71,36	90,72	94,65	96,18	99,26	99,77
17100	47,74	77,17	92,79	96,34	98,39	98,91	99,27

Table 4.22: Average bacteria reduction rates per day in both experiments



Graph 4.24: Average reduction rates per day in both experiments

The 50% reduction rate with one day of storage is reached by the 880 and 3408 cfu/100ml samples, nearly reached by the 17100 cfu/100ml sample and is far from being reached by the 823 and 8780 cfu/100ml samples. It is difficult to comment with certainty on the results because of the large number of variables affecting the purification mechanisms. As mentioned within the literature review, it is difficult to predict every time the removal effectiveness based on theoretical models. Bacteria basically are reduced due to sedimentation and natural die-off. The variables on sedimentation mechanisms are: particle size and shape, particle density, particle surface charge, liquid density, liquid viscosity, liquid temperature, salt content, settling velocity, particles population, colloids and turbulence. Retention time and type of pathogen, affect the natural die-off rates, along with the environmental conditions. Which is the dominant variable or the particular inter-connections among them cannot be stated with certainty, as these are alive organisms and any relationships are changing dynamically. An attempt to conclude on some of these variables will be done, by keeping the rest constant to some extent.

The initial (raw) water quality characteristics in average are summarised in table 4.23, so that comparisons can be made, assuming of course that there are no laboratory and calculation mistakes.

	823	**880**	**3408**	**8780**	**17100**
SS (mg/l)	5	3,5	13	14	16
Temperature ($_o$C)	16,7	17,5	17	14,1	14,1
DO (mg/l)	8,4	8,5	8	9,5	9,5
pH	7,5	7,35	7	7,05	7,15
Conductivity (μS/cm)	710	660	673	555	550
TDS (ppm)	330	330	330	270	270
Colour (Hazen)	30	45	83	144,5	144,5

Table 4.23: Average water quality characteristics per sample in both experiments

Looking at the samples from experiment A and at two samples that reached the 50% limit (880-3408 cfu/100ml) in particular, their variables are quite similar, except for the suspended solids, where the difference is more significant. The bigger population of *E. coli* and of suspended solids could explain why the reduction rate is bigger in the “3408” sample. However, looking at the “823” and “880” samples, the bacteria loading and the suspended solids are almost similar, as are all the other parameters too. There is no obvious explanation why these two systems respond differently within the first day. One assumes that what is characterized “small” difference for the laboratory calculations and the researcher’s eyes, can play a significant role at a bacteria microscopic level, thus is very difficult to be captured. On the other hand, since water was collected on different days, the *E. coli* themselves are not the same. It may be just a case of finding the bacteria in a different stage of their growth cycle

(figure 2.6). The environmental conditions (oxygen, pH, temperature, nutrients, toxicity) just prolong or speed up their natural death.

Similarly, looking at the experiment B samples (8780-17100 cfu/100 ml), where water was collected in the same day and all the parameters are almost identical, the “17100” sample almost reached the 50% limit, while the other one only reached 20%. The bigger population of bacteria, actually assisting sedimentation, is one obvious explanation. However, it is very important that half of this population is artificially added with laboratory cultivated *E. coli*. As explained earlier, these bacteria may be less resilient, therefore dying faster than the natural ones.

Lastly, looking at experiments A and B together, the samples with naturally found bacteria are the “3408” and “8780” ones. In this case, bacteria loading doesn't seem to have the dominant role, since the “3408” sample performs better. Nor do the suspended solids which are almost similar. However, temperature is higher in the first sample, which can alter the water density or raise the thermal energy, which in turn will increase the collisions between particles (Brown’s law). Both phenomena assist flocculation and sedimentation. Moreover, oxygen is less in the first sample, therefore bacteria, as all aerobic organisms, will survive less without it. Also, TDS and conductivity figures are evidence of more anions, cations, salts and so forth. These charged molecules can attach with *E. coli* probably more easily and assist flocculation.

In an attempt to triangulate the one-day retention time on bacterial efficiency, it is worth mentioning the results found in (Singer, 2010, p. 73, table 4.11), even if that wasn’t the focus of the particular research. Again the reduction rates of *E. coli* for 24 hours vary from 20,30% up to 87,43% for different initial loadings, without necessarily the lower rates found in the less contaminated water.

All these observations apply only on the first day samples. It is obvious from the graph that by storing day (2), after 48 hours, even if all the variables are still different from one experiment to the other, all the reduction rates are higher than 70% and by day 3, higher than 90%. For the remaining days, the reduction rates rise slightly per day, reaching closer to 100% effectiveness. The “speed” of the reduction rate drops significantly after passing day (2) and keeps on reducing every extra day more. So the treatment process slows down after day (2).

Within each container, the conditions tend to be stabilized only after 24 hours of retention. That seems to be the time needed by the bacteria on a 10 litre vessel to realize their limited situation, thus start responding to that by dying-off (see figure 2.6) more quickly. Moreover, after one day of stagnant water, sedimentation processes have occurred more significantly,

therefore the reduction rates are increased. Whichever of the two mechanisms is dominant in the purification process, they both occur more significantly between 24 hours of retention (day 1) and 48 hours of retention (day(2)), thus the reduction rates are higher within that period.

Conclusion:

On the question of removal effectiveness, one day of storage doesn't necessarily lead to 50% reduction of the bacteria, as claimed. It can be higher or lower. For longer retention times, this figure is improved and it can exceed the claimed figure of 90%. The 90% figure is usually reached within three storing days, no matter the initial contamination. It is undoubted more effective to store the water longer than one day, but if this is the only drinking water available, questions on the efficiency of storing the water longer arise.

4.2.2 How many days should the retention time be?

In the literature it is claimed that the retention time can be from 24 hours, up to 6 days. This clearly leads back to question 4.2.1, but it was decided to be addressed separately, as it is found in publications without reference to the reduction rates.

One day retention time reduces the bacteria loading, but as shown earlier, this reduction may be quite low, not even close to 50% in some samples. The first day is the time needed for the conditions in the water to be uniform, therefore the bacteria start dying more significantly after that. One day of storage wouldn't be advised in order to be more certain that sufficient treatment has taken place. After two days of storage, the reduction rate has increased significantly in all samples. If the need to use the water is immediate and another day cannot be spared for treatment, two days of storage is advised, since it seems to be the minimum retention time with the highest possible results for all samples. After 48 hours, any more time/days are beneficial for the bacteria removal. Either this is 6 days as mentioned, either 7 as tested, either more, even if sedimentation ceases at some point, bacteria naturally keep on dying-off. Therefore, the longer the better as claimed in the literature. The reduction numbers for three days exceed 90% and after that period, reduction tends to reach 100%.

Note that in general, the“100%” figure needs attention. Percentages in the reduction rates are disconnected from the actual bacteria loading on the initial or final water. Therefore they can be misleading. 100% removal rate doesn't mean zero pathogens in the water. In addition, 100% rate is often 99,5% rate, rounded up. As one can see characteristically in tables 4.13, for transferred water the average removal rate is 99,27%, while the bacteria are still 125 cfu/100ml, far from being zero.

Conclusion:

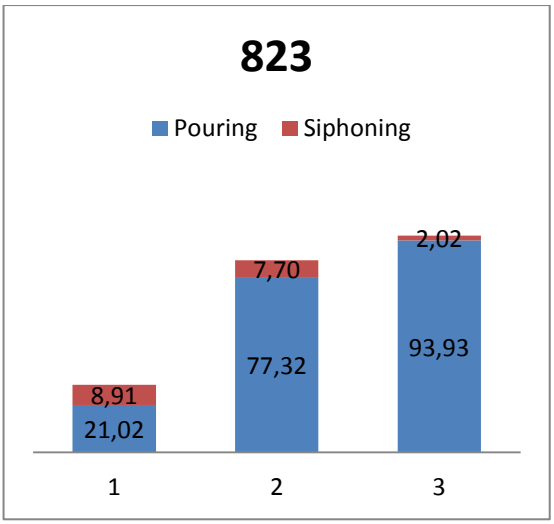
On the question of retention time days, treatment takes place every storage day, but the longer the storage period the better. One day is the minimum. Two days are advised since this is the minimum retention time with the maximum results, if one compares all the samples. Three days are optimum, since the reduction rates reach the level of 90% reduction. More days lead to further improvement. It is undoubted more effective to store the water longer than one day, but again if this is the only drinking water available, questions on the efficiency of storing the water longer rise. Acceptable levels of *E. coli* concentrations are commented in section 4.3.

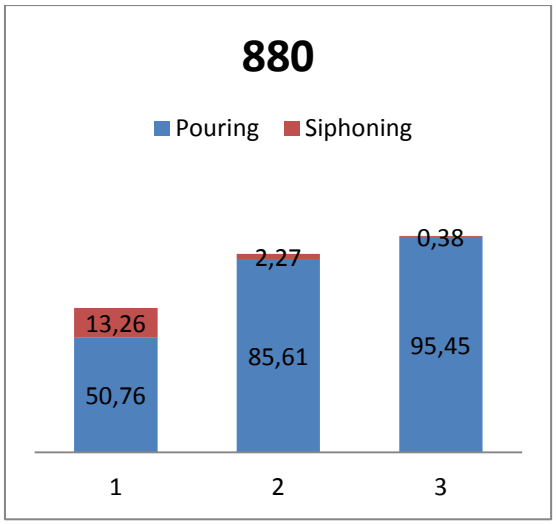
4.2.3 Is siphoning more effective than pouring?

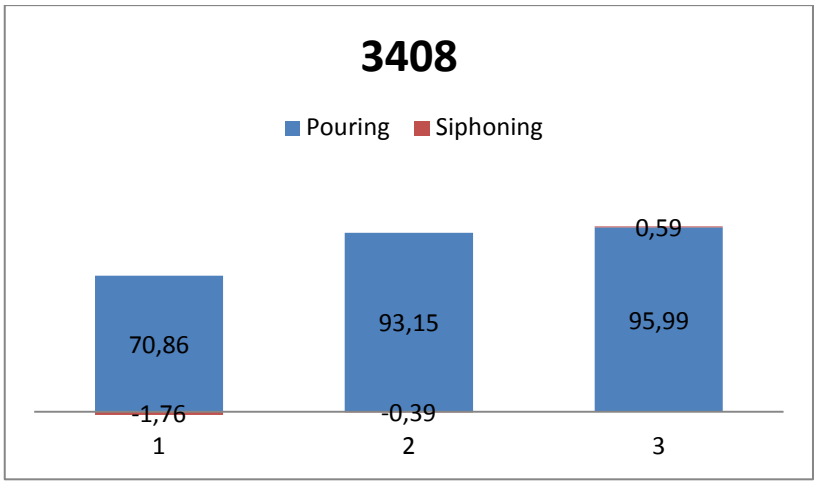
Within the literature it is claimed without further referencing that it is better to decant the water from one pot to the other by siphoning rather than pouring, because the sediments will be less disturbed. In experiment A siphoning and pouring was tested to see whether this is true. Table 4.24 summarises the average reduction rates for each bacteria loading, taken from appendix 8.3. Graph 4.25 is based on table 4.24, focusing on the difference between the rates.

		Average RR %		
Raw water (cfu/100 ml)	**Method**	**1**	**2**	**3**
823	Siphon	29,93	85,01	95,95
	Pour	21,02	77,32	93,93
880	Siphon	64,02	87,88	95,83
	Pour	50,76	85,61	95,45
3408	Siphon	69,10	92,76	96,58
	Pour	70,86	93,15	95,99

Table 4.24: Average reduction rate % for bacteria loading per method in experiment A







Graph 4.25: Difference in the E. coli reduction rates between siphoning and pouring per day and per sample in experiment A

In the first two samples, siphoning is more effective than pouring in the bacteria removal, while in the third sample things are opposite. The differences are not major and they tend to get smaller with more days of retention or as pointed in question 4.2.2, the longer retention time the better. Assuming that the figures are correct, the presence of the third sample, doesn't allow clear conclusion on the bacteria removal. In an attempt to rationalise this fact, one would think that it has to do with the higher bacteria loading and the suspended solids content as well, (the "3408" sample has double suspended solids compared to the other two). Both loadings, assist flocculation, thus sedimentation. If that is the case, in the first two samples, sedimentation takes place more slowly, so the bacteria are afloat for longer time within the water body. In that sense, when pouring is practiced in the first two samples, bacteria which are dispersed in the main water body, flow to the next pot. When siphoning is practiced, water is taken from the point where the siphon is placed and this is near the bottom (careful not in touch with the bottom, a few cm above). So in the first two samples, where sedimentation hasn't occurred in a great extent, the water near the bottom may be of better quality. On the contrary, on the "3408" sample, where sedimentation is faster, pouring water from the surface is of better quality, while siphoning water from the bottom is more contaminated. To sum up, the treatment is basically a matter of how much settlement has occurred in a sense and not of the disturbance caused to the suspended solids as stated in the literature. Besides, pouring was done in a gentle way as well, making sure that the sediments were not disturbed, so less likely to be carried over in the next pot.

Apart from the bacteria effectiveness, looking at the rest water quality parameters of the final water in section 4.1.1 and using the average figures for all three samples, table 4.25 was made.

	Siphoning	Pouring
Average E. coli RR%	96,12	95,12
Average colour RR%	46,98	33,32
Average turbidity RR%	81,15	76,70
Average pH rise %	3,25	5,34
Average DO RR%	19,38	18,33

Table 4.25: Average water parameters reduction rates per method in experiment A

In this table temperature was not included, as it has to do with the air temperature and not with the decanting method. Conductivity and TDS didn't produce uniform results, therefore in some cases there was a small rise and in others a small drop in the figures (see section 4.1.1). The differences were not significant anyway. Suspended solids, which is the argument for using a siphon instead of pouring, unfortunately cannot be trusted due to a laboratory procedural mistake, which was noticed during practice and couldn't be foreseen. The solid content drops in both methods though.

Apart from that, bacteria, colour and turbidity removal seem to be higher when siphoning the water. On the other hand, the oxygen content is bigger and pH rises more when pouring is practiced. Since colour and turbidity are mainly due to suspended solids, one could assume that solids are transferred to a smaller extent when siphoning, therefore it is better, looking at the significant differences between the two. *E. coli* though is only slightly better when siphoning and the difference doesn't follow the magnitude of colour-turbidity or of these indirect indicators of suspended solids. Dissolved oxygen was reported to be higher in the "pouring" method, in graph 4.10 as well. There it is pointed how pouring assists aeration better than siphoning. Last pH rise may imply better attachment between the negatively charged *E. coli* and the (H^+) in the water, which assists sedimentation of the bacteria.

As for acceptability issues (see section 4.1.3), odor was perceived to be the same. The only difference was that when water was siphoned, the oil film of the top water layer wasn't carried along, while when pouring, it was transferred with the water into the next pot. If one thinks of the bottom layer as the sedimentation zone and the top layer as the floating zone, a siphon placed properly in between, abstracts water only from the middle "safer" zone. Pouring on the other hand, carries water from the top and middle zone, so one may think that it cancels the effect of floatation in the treatment process. However, when water was poured from one pot to other, the oil film seemed to lower each day. Unfortunately, this idea couldn't be tested further within the laboratory, because there was no proper equipment to capture and analyse the oil content in so small concentrations.

As it is made obvious, siphoning can perform better with some variables, but pouring does so with some others. Since the purification mechanism of the three-pot system depends on many variables, it is difficult to conclude on which variable is most important, therefore decide on siphoning versus pouring. Besides, as already shown, each case is unique and theoretical models are difficult to be predicted covering each possibility. To one's personal opinion, both methods are similarly effective, especially to bacteria reduction, which is the primary concern. The rest parameters have more to do with aesthetic reasons and user acceptance. It is understood once more that "similar" reduction rates may not always refer to similar final water quality characteristics, as pointed in question 4.2.2. However, in this case the final bacterial loading is similar in each case along with the reduction rate, as shown in tables 4.3-4.4-4.5. Thus one can refer to these two methods having similar reduction effectiveness. The reduction effectiveness is becoming more identical when more retention days are given to the water, as explained in question 4.2.2

Conclusion:

On the question of whether is siphoning more effective than pouring, one would suggest that for bacteria reduction they are practically the same, especially after 48 hours of storage. For the aeration treatment process, pouring is slightly more effective and for turbidity reduction siphoning is better.

Since the purification mechanism of the three-pot system depends on many variables, it is difficult to conclude on which variable is most important, therefore decide on siphoning versus pouring. Personally, one concludes that both methods treat water significantly, so it is pointless dilemma the "siphoning versus pouring". It is similar to asking HWTS or centralized treatment method, as previously discussed. Since both improve water, they should both be adopted in the appropriate situation.

"Appropriate" raises some issues of efficiency worth to mention. Pouring is a simple procedure, easily performed by anyone, fast (10 litres were poured in about 25 sec), with no additional material needed. Siphoning requires some basic co-ordination skills, it is a slow procedure (10 litres were poured in about 3,5 min) and a siphon needs to be available or a flexible tube. A flexible tube, like a straw can be used to siphon the water out, initializing it by sucking the first water by mouth. Any siphon needs regular cleaning as well and careful handling to prevent recontamination of water. Sucking the water by mouth, may pose health risks to the person practicing it, if by accident swallows the contaminated water. On the other hand, if the containers are of great volume, lifting and pouring may be impossible and in this case, siphoning is needed or at least two people lifting the containers. Moreover, pouring needs to be done carefully, without much disturbance which can re-suspend the solids near the bottom

and any bacteria trapped in them. So, one point of view can be to use a siphon to prevent indirectly the user from practicing wrong the “pouring” method.

4.2.4 Is the surface water of better quality than the water at the bottom?

Within the literature it is claimed that water near the surface of the pot is of better quality than that of the bottom. In experiment B, measurements to test surface and bottom quality were done directly in the stable (control) buckets and indirectly in the other pots, by sampling the water left on the previous pot and the water transferred on the next pot.

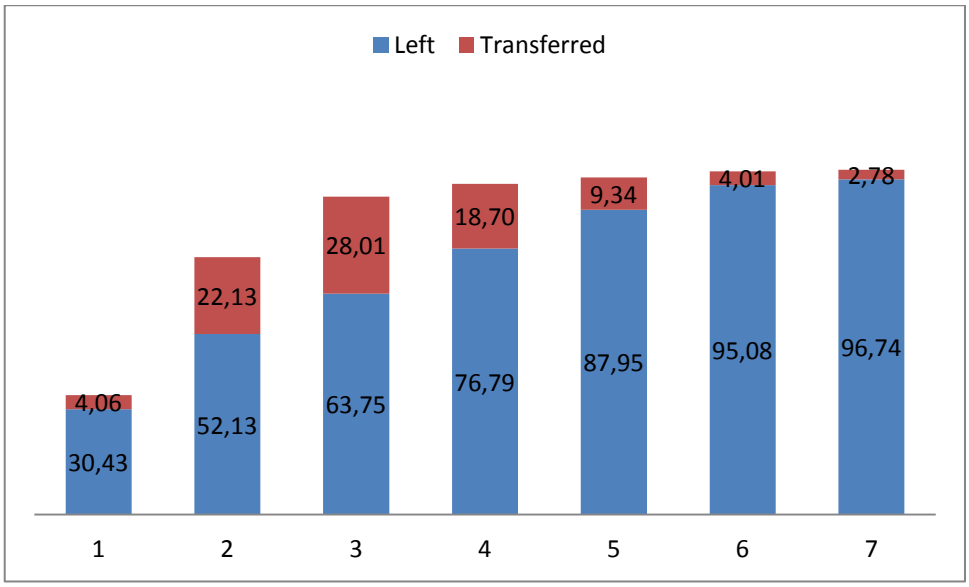
Looking at the *E. coli* counts and their reduction rates% in appendix 8.3.4 and 8.3.5 for the control surface and control bottom rows, will notice that they are similar for all days or in some cases the “bottom” sample has higher rates from the “surface” one. Since the indirect measurements did not agree not this fact appeared logical, it was concluded that these figures do not represent the real situation, therefore they are not worth presenting in this section. The cause for this false result was figured out. To sample the water from the control pot without disturbance a syringe was used. The syringe was always placed in the centre of the circular bottom of the pot, to assist procedural repetition. However, this proved to be faulty, because the syringe was gradually clearing the particular spot each day by sucking 100 ml out. This was noticed from the suspended solids which “disappeared” from the centre of the pot as well. Therefore, these results will not be used.

Figure 4.4: Syringe clearing out the centre of the pot (author 2012)

Looking at the *E. coli* counts in appendix 8.3.4 and 8.3.5 for the transferred and left water rows, the surface water is of better quality in both trials. Since the average reduction rates didn’t differ significantly between the trials, the mean values from trial 1 and 2 will be used to address this question. Thus table 4.26 was formed. Graph 4.26, based on table 4.26, focuses on the difference between the rates.

	Transferred	Left
Average RR% 1	34,49	17,25
Average RR% 2	74,26	37,13
Average RR% 3	91,76	45,88
Average RR% 4	95,50	47,75
Average RR% 5	97,29	48,64
Average RR% 6	99,09	49,54
Average RR% 7	99,52	49,76

Table 4.26: Average E. coli reduction rates per method in experiment B



Graph 4.26: Difference in the E. coli reduction rates between bottom and surface water per day in experiment B

It is obvious from the appendix that transferred or surface water has lower bacteria counts and the reduction rates are higher as well, compared with the bottom water. This verifies that sedimentation is part of the purification process of the three-pot system. Since bacteria tend to settle at the bottom, they exist in greater counts there. The difference in quality between them gets smaller as more days are given for retention. Since bacteria die-off, either found at the bottom or the surface, even if sedimentation ceases at some point, more retention days could theoretically lead to the same water quality at the surface and at the bottom. Moreover, in (Nath et al. 2006, p. 39) it is stated for another treatment method, that pathogens usually remain viable in the bottom and need to be separated from the upper cleaner water body.

As for the rest quality characteristics presented in section 4.1.2, most of them don't show significant differences, apart from the suspended solids. These are in higher concentrations at the bottom where they have settled. That leads to bottom water having higher turbidity and colour levels as well, compared to the surface. These average reduction rates for the final water, from both samples, summarised from section 4.1.2, form table 4.27.

	Transferred	Left
Average E. coli RR%	99,52	96,77
Average colour RR%	56,06	30,10
Average turbidity RR%	75,26	51,13
Average ss RR %	90,08	48,43

Table 4.27: Average water parameters reduction rates for surface and bottom water

When it comes to acceptability issues (see section 4.1.3), odor was perceived to be the same. Moreover, surface water retains the floating substances, while bottom water the settled ones. The floating matter though were less than the settled in this case and could be manually removed, thus transferred water was cleaner than the “left” one. Since bacteria tend to settle and not to float, bottom water could be more dangerous than surface water in any case, regardless of the appearance.

Conclusion:

To the question of which point has higher quality within the vessel, surface water is indeed better than the bottom one. Their difference gets smaller with more retention days. However, in order to be on the safe side, it is recommended always to abstract water from the near the surface. When sedimentation is part of the treatment method, it is not advised to use containers with a tap placed near the bottom, from where users will abstract water to drink. In that sense it is wiser for the user to pour the drinkable water from the surface when he wants to drink or to use an appropriately clean cup to collect water from near the surface.

4.2.5 How many pots should be used?

In the literature it is stated without further referencing that three-pots are advised, two-pots are considered as minimum, but even with one pot the treatment may work.

This is translated in days of retention basically. It is a way to make sure that the user will allow sufficient time for the treatment to take place before consuming the water. By suggesting three pots, one for each day, water settles for 72 hours before consumption, while two pots allow 48 hours for retention. Without giving further explanation or training to the user, by suggesting three or two pots safeguards indirectly, that significant treatment will have taken place. In that sense, one pot is not advised. However, it is stated that if no other pots are available, it can be used, but more days should be given for retention. One pot shouldn’t mean one day of storage. Even if treatment has occurred after 24 hours, it is always safer to allow more days for that (see questions 4.2.1 and 4.2.2 for details).

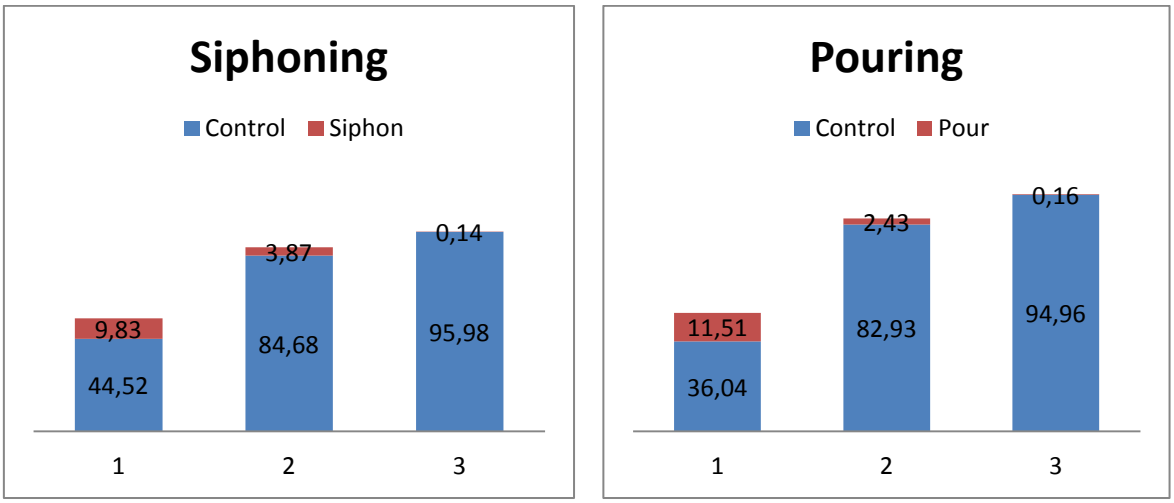
This question will not be addressed regarding the retention period, as this has already been covered. It generated the idea though to test the difference between water that is being decanted each day and stable water, given the same retention period. Or in other words, compare plain sedimentation with the three-pot system. If water is same in both cases, that will exclude aeration as part of the treatment mechanism. In that case, there is no need to use more pots, but the user can only make sure that he allowed the water to settle for some days. One pot could make the whole process much more efficient.

For that reason, in experiment A three pots were used, one for each retention day, along with one control pot with stagnant water. In experiment B two pots were used in rotation to cover the 7 days period, again along with a stable control pot. As explained in section 4.2.4, experiment B measurements on the control buckets cannot be trusted. Therefore, comparison between the water in the control buckets and the decanted one from experiment B, will not be included.

For experiment A, looking at appenndix 8.3.1-2-3, in all trials, one can see that *E. coli* in the control buckets are each day slightly higher than in the decanted water. As a result the reduction rates are lower as well. Here the average figures for the three trials will be presented. Table 4.28 shows the bacteria reduction rates and graph 4.27, focuses on the differences between the decanted water and the stable one.

	Average RR% 1	Average RR% 2	Average RR% 3
Siphoning	54,35	88,55	96,12
Pouring	47,54	85,36	95,12
Control Siphoning	44,52	84,68	95,98
Control Pouring	36,04	82,93	94,96

Table 4.28: Average E. coli reduction rates for siphoning and pouring in experiment A



Graph 4.27: Difference in the E. coli reduction rates between decanted and stable water per day and per decanting method in experiment A

It is obvious that stable water has lower reduction rates compared to the decanted one, either water is siphoned or poured in the next pot. It can therefore be concluded that aeration assist the treatment and is indeed part of the purification mechanism. On the other hand, bacteria counts in the appendices, tend to equalize as more days pass. Or as depicted here, the gap between the reduction rates once more tends to close. By day 3, the bacteriological quality in the control bucket, is very close to the decanted water.

As for the rest water quality parameters, referring to the final water in section 4.1.1 and using the average figures for all three samples, table 4.25 was made.

	Siphoning	Pouring	Control Siphoning	Control Pouring
Average E. coli RR%	96,12	95,12	95,98	94,96
Average colour RR%	46,98	33,32	37,89	40,61
Average turbidity RR%	81,15	76,70	82,19	83,37
Average pH rise %	3,25	5,34	6,25	6,25
Average DO RR%	19,38	18,33	26,67	20,88

Table 4.29: Average water parameters reduction rates per method in experiment A

Once more, temperature was not included, as it has to do with the air temperature and not with the decanting method. Conductivity and TDS didn't produce uniform results, therefore in some cases there was a small rise and in others a small drop in the figures (see section 4.1.1). The differences were not significant anyway. Suspended solids, unfortunately cannot be trusted due to a laboratory procedural mistake, which was noticed during practice and couldn't be foreseen. The solid content drops in any case though.

In the siphoning option, the stable bucket reduces colour less, reduces turbidity more, rises pH more, and reduces oxygen more than in the siphoned water. In the pouring option, the stable bucket reduces colour more, reduces turbidity more, raise pH more and reduces oxygen more than in the poured water. It is not easy to conclude from all these parameters if the stable pot is more effective, since these variables are interconnected and there are too many factors changing to be comparable. However, the oxygen content in both cases is reduced to greater extent in the control bucket, where no chances for re-aeration exist. Also, in both cases colour seems to be less in the control bucket

One uses the word "seems" deliberately. Suspended solids are responsible for colouration. Either siphoning or pouring, some disturbance within the water occurs. In the stable bucket though, there is no disturbance at all. Even though there are no reliable data for the suspended solids, in both cases colour "seems" to be less in the control bucket. Indirectly, this indicates less suspended solids. Water sampled from the middle-centre point of the stable pot,

may contain less suspended solids than the decanted water, but overall to the naked eye, water looks more dirty, with more suspended solids and of deeper colour. This is because solids settled at the bottom and remain there throughout all the treatment period, whereas when water is decanted, the last volume of water containing the settled matter, is thrown away. As a result, users perceive water to be cleaner and of better colour when they decant it. Figure 4.3, captures that difference with the naked eye.

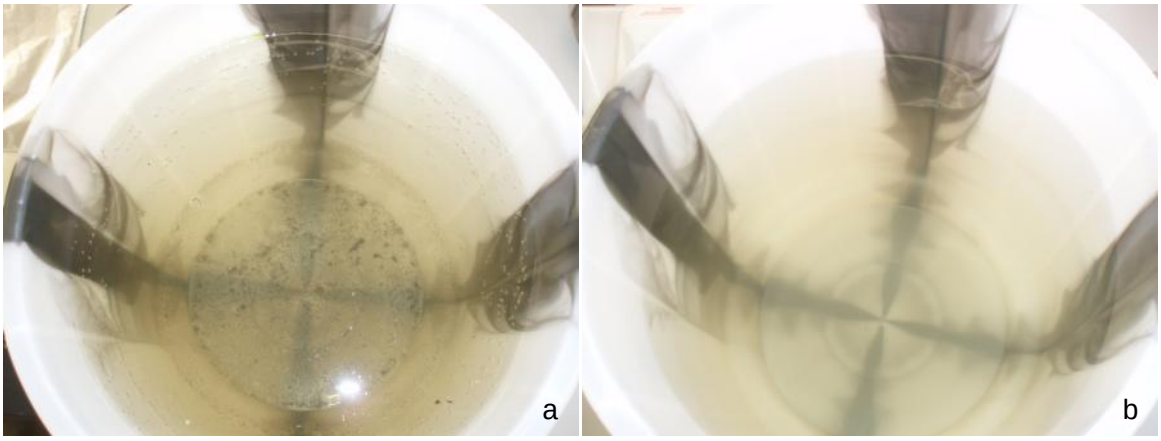


Figure 4.5: Colour with a naked eye in undisturbed (a) and decanted (b) water (author, 2012)

When it comes to acceptability issues, the overall appearance of water in the undisturbed buckets is worse (see section 4.1.3). Since water remains stagnant, algae growth is assisted. In this case, the algal “ring” on top of the container is thicker. Any oils present in the water or any other floating substance, remains on top of the water as well, worsening the appearance and maybe quality of the water which will be abstracted from near the surface for consumption. Last, the odour in the stable bucket doesn’t seem to improve, as it retains the initial smell of raw water. That supports that aeration assist the treatment mechanism.

Conclusion:

Answering the question of how many pots should be used, when this is not a matter of safeguarding that the user will allow sufficient number of days for the water to be treated, one could say that decanting water, therefore using more than one pot produces water of better bacteriological quality. Aeration takes place to support the treatment mechanism. Last, acceptability parameters are improved as well and the users will be more prone to use the water or consequently, adopt this treatment method. So the three-pot system is more effective than plain sedimentation.

Apart from the effectiveness, having more than one bucket is more efficient as well. That way pots can be cleaned on a rotational basis, without having to interrupt the continuity of supplying water to the household for cleaning purposes, as it would happen if one pot was

used. In similar sense, no interruption will occur if one pot fails and starts leaking, supposing that another container can be available within a day to carry on with the treatment process.

Practically, one pot will not be used. Even if the user chooses to have one stable container allowing water to remain stagnant for some days before consumption, once he starts using the water, after a few days, depending on his usage, the container will be empty. If he doesn't have a supplementary container treating water in parallel with the first, he will have to wait for some days for the water to be treated in his only pot. As a result, he will either interrupt his own supply of treated water or he may consume untreated water. So even when the users prefers plain settlement to the three-pot system, one pot isn't safe practice whatsoever.

4.3 Testing the effectiveness: Discussion

At this section further discussion will be promoted on the effectiveness of the three-pot system, but also on its efficiency as well.

- ✓ **Theories on bacterial reduction**

Trying to compare the results generated with theories on bacteria reduction rates (see section 2.2.4), as shown in the graphs for each case, the majority tends to follow a clear exponential curve. This follows the pathogen removal equation $C=C_oe^{-kT}$ (Feachem et al. 1983, p. 207). In experiment A-trial 3 (graph 4.3) and experiment B-trial 1 (graph 4.13), the curve gets exponential after a point only. In spite of that, the shape is still in accordance with the natural growth curve presented in figure 2.6. There is a possibility that this just a case where bacteria where “met” earlier within their growth cycle. As shown in the figure, there is a declining reduction following the declining growth, while the exponential reduction and the exponential growth are at the end sides of the graph. The environmental conditions (oxygen, pH, temperature, nutrients, toxicity) prolong or speed up this natural procedure. As the variables are not comparable in the two experiments, safe conclusions cannot be made.

Also, there was an attempt to compare the water from the stable pots with the water that is being decanted, as described in section 2.2.4, based on the theory of ponds in series (Marais, 1974). Unfortunately, the particular equations didn’t apply in experiment A, since the temperatures were outside the limit of 5-20 ^oC. In experiment B, even with temperatures being within the limit, the water from the control buckets was sampled from the surface, because that suited the purpose of the particular experiment. It would be a faulty simplification to assume that surface quality applies for the whole container in order to test the equations, as this experiment implies that quality may be changing depending on depth.

✓ **Drinking water quality**

In an attempt to safeguard drinking water quality, international standards have been set by WHO, as discussed in section 2.4.2. These guidelines, for each measured parameter within this project, were summarised in table 2.4. Starting with *E. coli*, the guideline suggests zero coliforms per any 100 ml sample. Looking at the tables showing the results for each experiment in section 4.1, table 4.30 was made, as a summary of all. According to the WHO standards, none of the final water should be considered safe for consumption.

Experiment A		
Raw Water		**Final Water**
823	Siphoning	33,5
	Pouring	50
	Control	50
880	Siphoning	36,5
	Pouring	40
	Control	40
3408	Siphoning	116,5
	Pouring	136,5
	Control	43,5
Experiment B		
Raw Water		**Final Water**
8780	Transferred	20
	Control	60
17100	Transferred	125
	Control	130

Table 4.30: E coli counts in final water in all experiments

As for the rest quality parameters of table 2.4, they are not of health concern, so no guideline is given. For some of them, desirable levels assisting user acceptance are suggested. Turbidity should be below 5 NTU and pH between 6.5-8.5. Final water from all experiments meet these levels. TDS should be between 600-1000 mg/l = 600-1000 ppm. Final water from all experiments are below this level. Note, that TDS content has to do with the source of abstraction basically, but also that through the experiments they remained relatively stable. So the low figures were like that within the raw water as well and they were not a result of the treatment process. Last, colour should be below 15 TCU (true colour units). The laboratory equipment measured colour in Hazen units. True colour is the actual colour of water, that is not due to suspended solids, thus it is measured only after filtration (Spellman, 2003, p. 371). In (EAC, 2009, p. 3) it is stated that 1 TCU after filtration is 15 Hazen. Other publications imply that 1 TCU=1 Hazen, but one thinks this refers to after filtration status of water. Since in this project, color was measured without filtration, the 1 TCU=15 Hazen will be used, so 15 TCU=225 Hazen. Final water from all experiments meet this level as well.

The applicability of these guidelines and especially the *E. coli* one, has been widely debated, as presented in section 2.4.2. To overcome that debate, comparing the *E. coli* levels with the infectious dose is more practical. Indeed for *E. coli*, for the commonest type-ETEC this can be 10^8-10^{10} organisms, while for EHEC (Enterohaemorrhagic) 100-10^6 (Hunter, 2003, p. 67-68). Three issues can be discussed on that. First, the infectious dose is expressed in number of organisms within the infected individual and not in cfu/100 ml, as measured in the laboratory. When counting bacteria in the lab, colony forming units (cfu) are distinguished. The assumption is that each viable bacteria will form a discrete colony, but in reality in each colony many more bacteria can be present (Reynolds et al. 2005, p. 1). With that assumption, 1 cfu/100 ml can be simplified into 1 bacterium/100 ml. Assuming again that the average drinking water quantity is consumed, which is 2 lcd (see section 2.4.1), 2 litres=2000ml. Taking the larger figure from table 4.30, this is 136 cfu/100 ml or 136 bacteria/100 ml, according to the first assumption and 2720 bacteria/2 litres. Second issue is that it is not certain which type of *E. coli* is found within the water each time. If it is the common type, the number of 2720 bacteria is way far from the infectious dose. However, if it is the more aggressive type, there is a chance of infection from most of the samples. Thirdly, drinking water isn't the only pathway for bacteria to enter the human system. Even if the previous assumptions can be accepted up to a point, it would be an oversimplification to assume that no other coliforms enter the body. This is one of the reasons that WHO guidelines are so strict, according to one's judgment.

Last, comparing the results form table 4.30 with the levels of safety presented in table 2.5, most samples fall in the third category of intermediate risk (11-100 cfu/100ml), characterized as polluted, but that can still be consumed as it is, if no treatment is available. This is even characterized as moderately good quality (Feachem et al. 1983, p. 210).

As concluded in section 2.4.2 as well, apart from guidelines and standards, the key idea is that of water quality improvement. "A moderately effective water treatment that raises the levels of the most important quality parameters – those that affect health – without meeting all the parameters and standards" may be perceived as an improvement in water quality (Heber, 1985, p. 13). Since all measured parameters in every experiment – not only those affecting health, no matter the initial variables or the final result, has been improved, treatment of water with the three-pot system is undeniable.

- ✓ **SHTEFIE approach**

In an attempt to analyse the three-pot method in a more holistic way, the SHTEFIE criteria, adopted from (Parr et all, 1999, p. 66), were kept in mind throughout the project. SHTEFIE stands for: Social, Health, Technological, Economic, Financial, Institutional and Environmental

criteria. These issues have already been mentioned within the previous chapters, but summarizing here to trigger further discussion:

- Social: The three-pot system is simple and easy to use, with no special skills required and very low cost. That makes it suitable for almost all social groups, therefore promoting equity. The user can have control of his own water treatment with local material, therefore promoting self-reliance. It doesn't require much time from the user, since the treatment is a natural self-purification mechanism of water, therefore he can spend this time more productively. It can be used both in emergencies and development. It addresses most acceptability parameters within the water quality and manages to improve significantly all of them, therefore the user can be willing to adopt it. The treatment itself doesn't seem socially or culturally insulting in any way, since it is using simple household material. Of course, acceptability in water quality and on a social level is subjective and cannot be guaranteed.
- Health: The three-pot reduces *E. coli* significantly. The reduction depends on many variables, but it can be basically controlled by prolonging the days of retention. Any water improvement, supports health of people. However, the three-pot hasn't been tested for other types of pathogens as well. Issues of algal or bacteria growth need to be taken into consideration when longer retention time is practiced.
- Technological: The "technology" involved in the three-pot system is simple and easy to use. There is no need for electrical power or chemicals. The use of 1-2-3 pots and of any kind of vessels, makes it flexible. Collection, treatment, storage and consumption of water can all be addressed with the same vessels. The materials can be found locally and basically these are the containers involved. In the case where siphoning is practiced, some sort of siphon has to be available, but the system works without it as well. For all that the system can be characterized adoptable and sustainable. The use of siphon may protect the system from misusing it, but it is quite slower than pouring. On the other hand if the volume of water is too large to be lifted, siphoning is opted. Too large volumes can be divided into smaller containers alternatively, but that would create a space problem within a household if 3 pots are used and not one.
- Economic: Local materials, even found within the household, don't require supporting the market supply chains, which is a common problem when material need to be imported in a country and if not addressed, water treatment and supply can be interrupted. Adopting the three-pot method which is low cost and having practically no recurrent costs, doesn't burden the economy of the household. Not much time is required from the user, which makes three-pot economic in that sense. The overall health improvement, leads indirectly to improvement of the house economy and one step further, of the local and country economy.
- Financial: The containers, if not already within the household, are low cost. This capital investment is small and the recurrent costs are practically zero. Practically, implies that there can be a minor cost for periodical cleaning of the pots and replacing the pots when their

lifespan is over. No power or purchase of chemicals is needed. Siphon can be one more small additional cost.

- Institutional: The three-pot needs to regarded as an option of the whole idea of HWTS, since it practically treats water at a household level and stores it safely. It can be used by stakeholders to scale up interventions on safe water, either alone or as part of another water treatment procedure. Field research is required to support the system as well. Since it can be practiced with any containers, market rules do not apply on it, therefore self-reliance is further promoted.
- Environmental: The improvement in health, improves the overall environment. The system itself, doesn't require chemicals, power or any constructions. It is a process practiced by nature anyway. The environmental impact therefore of the system cannot be negative. Only the material of the container needs to be considered, when disposed of. In cases of plastic, it is not friendly to the environment, but on the other hand, durability of plastic pots, give them a wide lifespan, so the amount of plastic disposed from the three-pot system cannot be that large.

These issues can characterize the three-pot system as an overall sustainable option, able to support the development of a household and consequently of an area and of a country in a larger scale. That fact should place the three-pot system among the rest HWT options. The simple and low-cost implementation of the three-pot system, makes it suitable for scaling up very quickly, therefore it is included in the emergency water treatment options as well. However, it should not be confused that this is its only suitable application.

4.4 Limitations

4.4.1 Limitations of the three-pot system

There are some limitations within the three-pot system, previously discussed within the chapters. They are worth re-mentioning here as issues one should be careful of when practicing or studying the system.

The three-pot improves all the studied water quality parameters and removes significantly the *E. coli* counts. However, the improvement rises more when the retention time is larger. It is safer to practice the method for three-days, thus called three-pot, before consumption of water. Even that though, cannot guarantee perfect results. The reduction rates are largely dependant on the initial loading. Unfortunately, this figure is not easy to be known on a household everyday level. Field tests or sanitary surveys are conducted by officials to identify that level on an everyday local scale. Basic principles borrowed from sanitary surveys can be passed to the users through training for safer practice of the three-pot as well. Another limitation rising from longer retention times, when water is decanted and the bottom volume is thrown away, is

that the water left for consumption finally is smaller than the initial water collected. That needs to be taken into consideration when calculating the household water needs.

Another issue is that water near the surface is of better bacteriological quality than that on the bottom. Users should be aware of that in order not to abstract water from taps placed near the bottom of the container, if placed there. Also, they should be careful not to decant all the water from one container to the other, including the bottom layer. This needs to be thrown away. When pouring is practiced, the pot should be tipped over gently, so as not to disturb the sediments and re-suspend them, thus transfer them in the next pot. Additional concern in that sense, is that how much water will be left behind depends on the user's eyesight or preference. There can't be a standard volume to be given as guidance, since it has to do with the loading of the suspended solids each time. Extra caution should be given when water "seems" clean because of the absence of suspended solids. Users need to be aware that pathogens are not seen with naked eye, so water needs to follow the three-pot system anyway.

Moreover, basic hygiene knowledge needs to be given if the users are not already aware of it. These are typical issues concerning every HWTS option. Vessels and the siphon, if used, need periodic cleaning. A lid prevents recontamination. Any utensil dipped in the consumable water needs to be clean as well. Users should avoid putting their hands in the water.

4.4.2 Limitations of the project

As in any task, here as well there were some factors limiting the project, worth to mention, so as to be addressed in any future similar work. Research method and personal calculations or observations, should always be considered as the first limitation. Even after careful consideration, there always seem to be issues or mistakes, not properly realized and addressed.

The idea behind the experiments was for them to be done as close to real field conditions as possible, thus stream water was collected. However, this produced too varying quality parameters, making results less easy to be compared. Instead, artificial water could be created, with better control over the parameters, but since there was a chance of bacteria acting differently in each case, the option of natural water was made.

In that sense, experiment A was repeated three times, but the initial water quality was different each time, although not intended. However, this random fact was exploited so as to understand better how bacteria act when they exist in different populations. Another issue in experiment A, was that the initial quality for each three-pot system was measured for two samples and assumed the same for the rest. That was due to time constrains within the

laboratory working hours. That wasn't repeated in experiment B, where one was given authorization to work above the official opening hours and days of the laboratory, thus each system was counted separately from the beginning. Last one more issue, addressed only in experiment B again, was the volume of water left in the previous pot after every decanting procedure. In experiment A, it was done approximately by looking at the sediments, thus the water transferred differed in volumes (see appendix 8.1). In experiment B, the volume transferred was kept constant by measurement and not by eyesight. Even when that volume was decided to change, that was applied to all systems at once.

Major limitation within this project was the issue with the suspended solids filters, basically on experiment A. As explained in methodology, when the loading isn't that big, higher quality filters are needed to capture the small differences in weight, but these were not available within the laboratory. On top of that, packets of filters already open, gather humidity from the atmosphere, adding weight to the filters. Then when the filters are placed in the oven, filtered water dries up along with the humidity. Since the suspended solids loading was minor and didn't contribute much on the filter's weight, the result was having lighter filters, even with the solids on them. That was just recording the loss of humidity actually. Thus the suspended solids were faulty and couldn't be trusted. In experiment B, this was addressed, by pre-wetting and drying the filters and keeping them in the oven until use, so as not to collect air humidity.

Last major procedural limitation was the syringe issue. The syringe was chosen so as to collect water from any depth without causing disturbance. This removable appliance was also opted to any permanent option of abstraction like taps, since edges can collect settled solids and bacteria more easily. Since the samples were relatively small (10 ml), there was the concern of these samples capturing the water quality of the particular edge and not of the whole container. The syringe was decided to collect water from the same point within the bucket, for repetition ease. For the samples taken straight from the bottom, the syringe seemed to clear off the area, so again the water quality of the particular spot, didn't seem to represent the whole container. Once more the results couldn't be trusted.

In general, sampling from any point within settling water is random, since settlement is affected by many variables, which cannot be controlled in total. In that sense, only large number of experiments and repetitions can provide a clear image of the situation in such a microscopic level. Therefore, more laboratory research is advised, since there doesn't seem to be enough on such a small scale level, like the three-pot system. Field studies should be going along laboratory studies, as they are supplementary and give useful feedback to one another. Only that combination can produce reliable results and promote actual development in the research area.

4.5 Review

The present chapter presented the results and attempted to comment and promote useful discussion on them. Reviewing the outcome from it, one could summarize in this section in shorter version.

Looking at the research questions:
Three days of treatment are advised to reach 90% bacteria reduction no matter the initial loading. Siphoning is slightly more effective than pouring in bacteria reduction, especially at smaller retention times, but doesn't assist aeration that much. Practical issues of efficiency rise as well with the siphon option. Surface water is indeed of better quality than that of the bottom. One pot produces only slightly worse quality water, but it is not advised because aeration doesn't occur and also for acceptability issues. All of the differences found within the systems seem to be minimized when more retention time is allowed. The longer the retention time, the better the water quality is the key rule for one to remember.

Overall, the three-pot system improves all measured parameters of water quality within this project. This means that it provides undoubted water treatment. Being practiced on a household level along with safe storage, attributes the title of HWTS. The three-pot system produces higher quality water than simple sedimentation, because aeration plays an important role. The exact purification mechanism or which parameters play more significant role than others is difficult to be concluded, since the relationships between the variables are complicated and even minor changes to the researcher’s eye seem to have major impact on a microscopic level.

Effective and efficient are two different issues. The effectiveness was tested, but the efficient could only be discussed. Measuring efficiency is more difficult, since more abstract and subjective term. Field surveys need to be done on the three-pot system to understand efficient issues further.

5.0 Recommendations

5. 1 Recommendations on the three-pot system

Looking at the limitations of the three pot system (section 4.4.1), consequently, some recommendations could be given for maximizing the benefits of that type of treatment.

The most important one, which safeguards that all water quality parameters will have improved is allowing at least three days of retention time. As previously repeated, the longer the retention time, the better. Moreover, It is advised that users abstract water from the surface when they need to consume it, since it is of better bacteriological quality. Decanting water should be done gently, so as not to disturb and re-suspend the sediments and minimize the possibilities of carrying them along with the transferred water in the next pot. Always a volume of water should be left behind to be thrown away. These two practices need to be followed even when the water “seems” clean from suspended solids, because pathogens are not visible, but they may still exist in the bottom of the water. The use of a clean cloth initially, when the raw water is poured into the first pot, could hold larger suspended matter visible to the naked eye.

Moreover, basic hygiene knowledge needs to be given if the users are not already aware of it. The vessels and the siphon, if used, need periodic cleaning. That can be done with boiling water and/or some sort of bleach solution. A safely tight lid always prevents recontamination. Any utensil dipped in the consumable water needs to be clean as well. Users should also avoid putting their hands in the water.

It is always difficult to safeguard that all users will be aware of these issues, therefore practice the treatment correctly. There is always the unknown factor of unpredictable human behaviour, that could cancel or minimize the benefits of the treatment. The best way to safeguard the benefits, even when users are not fully aware of the reasons, is to promote the use of three pots, where water is being decanted each day. This way water will remain in the pots for at least three days, which has been proved to give the best possible results in the shorter period of time for all systems. Three days are easy to remember, because they follow the name of the three-pot system. However, it has been proved within this project (see section 4.2) that even when three days or three pots are not practiced, less days and less pots still provide water treatment. Any improvement in the water quality parameters, even if it is smaller than the maximum that could be achieved, should not be neglected, since it is still an improvement.

Last recommendation would be on how the three-pot system could be scaled up. As mentioned earlier, all HWT options are promoted and researched further, because institutions and companies found opportunities through them to launch new products in the market. The

three-pot system on the other hand, consisting of any three containers available, doesn't give many opportunities for market expansion. The only HWT option which managed to be recognised and was scaled up without dealing with market terms was solar disinfection, known by the name SODIS. SODIS is practiced basically with the use of transparent bottles, mainly plastic. Therefore, it was scaled up mainly by promoting the method and not the materials needed for its implementation, like in the rest HWT options. Studying the case of SODIS, one could see how the three-pot technique could be promoted in a similar way.

5. 2 Recommendations for future projects

In the present section, an attempt to generate some ideas for prospective researchers will be done. These could be followed as they are presented or even better, just trigger their thinking and assist them in coming up with some genuine ones.

To start with, looking at the limitations in section 4.4.2, since it was decided to conduct the experiments with natural water so as to have more realistic conditions, one could suggest testing the three-pot system with artificial water replicating the natural one. This way it will be easier to have control over the water quality parameters and each time change strictly only one variable, so as to have a more clear picture of the role it plays. Water with exclusively artificially cultivated *E. coli* is worth to be tested, since there have been studies suggesting the different reaction they have compared to the natural ones. Also, within this project, there was an indication that the sample with the artificial added bacteria, showed different reaction as well (see section 4.2.1). Whether this has to do with these bacteria dying faster, since they are less resilient as previously suggested or whether because they settle less efficiently, since they are not attached to any solids, as natural bacteria, needs further research. In (Feachem et al. 1983, p. 60) it is suggested that in clean water bacteria may survive longer, since there is no competition or predation by other microorganisms, but on the other hand, some pathogens survive longer in dirty water, because they find protection attached to the solids. As a general rule though, it is said that “death rates are higher in natural waters with an active biological population, than in sterilized, filtered or other “dead” water (Feachem et al. 1983, p. 209). Last point to mention from section 4.4.2, is that care with any procedural and laboratory mistakes, is always recommended, to avoid limitations like the suspended solids or the syringe issue.

Next, looking at the design characteristics of the three-pot system (section 2.2.3), one could recommend future issues worth to be further researched. These could be:
1. a. Inlet water quality → alter the parameters to any extent, either alone or in combination. More interesting would be the suspended solids, since they play an important role in sedimentation, therefore in the purification mechanism of the three-pot system. Comparing characteristically, a sample with suspended solids and a sample completely free of it, both

with the same bacteria loading, would be really valuable. Suspended matter seem to be regarded negatively when present in water, but in case of sedimentation it can be beneficial in a sense. Another essential test would be testing the effectiveness of the three-pot system with other pathogens apart from *E. coli*.

b. Inlet water quantity → alter the quantities of the water treated, above the 10 l chosen to be tested here. It would be interesting to see if the purification mechanism depends on the volume of the water body. A comparison between smaller quantities with larger sedimentation tanks could be done, so as to test if the same theories apply to water, no matter the scale.

c. Use of cloth or not at the inlet point → compare the difference in the purification mechanism of the three-pot when a cloth is used at the inlet point. That leads back to the idea, whether the presence of more suspended solids is beneficial or not.

2. a. Size of vessel → that leads back to the water quantity recommendations, since the size depends on the quantity.

b. Shape of vessel → testing the three-pot system in different shaped vessels, using same quality water, could conclude on whether this can alter in any case the purification mechanism. The presence of corners characteristically, is claimed to facilitate the bacteria colonies to attach and grow (Oxfam, 2008, p. 4).

c. Material of vessel → testing the three-pot system in different materials of vessels, using same quality water, could conclude on whether this can alter in any case the purification mechanism again. Different materials are reported to alter the water parameters like pH, conductivity, TDS and therefore the bacteria die-off rates (Qi, 2007). Interesting suggestion by the supervisor was the use colloidal silver, since in the case of ceramic pot filters, enhanced with this metal, it has been reported to improve the microbiological effectiveness (Rayner, 2009).

d. Rest vessel characteristics (colour, opening, lid, handle, tap) → different coloured vessels using the same quality water, could test whether the presence of light could have an effect on the purification mechanism. Light in cases of solar disinfection, where the containers are transparent is reported to kill the bacteria, but on the other hand, light assists algal growth as well.

e. Number of pots in use → this was already addressed within this project (see section 4.2.5), but it can always be repeated with different parameters for confirmation.

f. Retention time (days of storage) → again this was already addressed within this project (see section 4.2.2), but it can always be repeated with different parameters for confirmation. Testing the difference on an hour scale not on a day scale could be interesting as well.

3. a. Method of decanting → again this was already addressed within this project (see section 4.2.3), but it can always be repeated with different parameters for confirmation. Stirring up the

transferred water, before allowing it to settle for a day, can test if that assists flocculation of bacteria, therefore helping their sedimentation and improve the water quality further.

b. Point of abstraction → this was attempted to be addressed for surface and bottom water (see section 4.2.4). Measurements along the depth of the water column, especially in larger volumes of water, could provide helpful information on how sedimentation differs with depth.

Last, looking at the "multi-barrier approach" idea, where the various HWTS options should be combined for better results in the pathogen removal efficiency (WHO, 2011, p. 143), some more suggestions can be given. Adding different coagulants in the raw water or Using other disinfection options like clay ceramic balls, chemical solutions and so forth, to test their contribution on the three-pot system could produce various new theories for testing. The key idea is to test the contribution of any other method to the three-pot system and not the other way around. Testing the contribution of the three-pot system on other HWTS options, could support arguments that place the three-pot system as a pre-treatment option only. Besides, the overall contribution of the project is to give appropriate recognition to the three-pot system as a HWTS option and not just as a pre-treatment one. Only then users could adopt it in a larger extent and allow to the three-pot system to play an active role to the universal goal of improving the quality of drinking water.

In general, additional research is always advised, especially in the HWTS options which are relatively recent and on the three-pot system in particular, as this scale of treatment hasn't been researched (see section 2.3.1). In that sense, even if the experiments of this project are repeated with not many alterations, it could be a good chance for the results to be confirmed or not. Field studies are always recommended along with laboratory experiments for more realistic results and for grasping efficiency issues better.

6.0 Conclusions

The present research aimed at testing the effectiveness of the three-pot water treatment system by answering five particular research questions (see section 1.2.3). Repeating here the review of the results (section 4.5):

Three days of treatment are advised to reach 90% bacteria reduction no matter the initial loading. Siphoning is slightly more effective than pouring in bacteria reduction, especially at smaller retention times, but doesn't assist aeration that much. Practical issues of efficiency rise as well with the siphon option. Surface water is indeed of better quality than that of the bottom. One pot produces only slightly worse quality water, but it is not advised because aeration doesn't occur and also for acceptability issues. All of the differences found within the systems seem to be minimized when more retention time is allowed. The longer the retention time, the better the water quality is the key rule for one to remember.

Overall, the three-pot system improves all measured parameters of water quality within this project. This means that it provides undoubted water treatment. Being practiced on a household level, attributes the title of HWT. The three-pot system produces higher quality water than simple sedimentation, because aeration plays an important role. The exact purification mechanism or which parameters play more significant role than others is difficult to be concluded, since the relationships between the variables are complicated and even minor changes to the researcher's eye seem to have major impact on a microscopic level.

The three-pot system is a simple, low-cost solution, easy to operate and maintain, which makes it efficient for the user. It basically exploits the self-purification processes that occurs in natural water bodies. Moreover, it can be practiced with any containers within the household. These features makes it able to be implemented without supply chains and market rules. Therefore, it promotes the user's self-reliance in a natural way. All these, can characterize the three-pot system a sustainable solution able to support the development of a household and consequently of an area and of a country in a larger scale. The simple and low-cost implementation of the three-pot system, makes it suitable for scaling up very quickly, therefore it is included in the emergency water treatment options as well. However, it should not be confused that this is its only suitable application.

Note though that effective and efficient are two different issues. The effectiveness was tested, but the efficiency could only be discussed. Measuring efficiency is more difficult, since more abstract and subjective term. Field surveys need to be done on the three-pot system to understand efficient issues further. Besides, field and laboratory research should be conducted in parallel, giving useful feedback to one another. This is even more necessary on

the relatively new area of HWT options and on the three-pot system in particular, which hasn't been tested before.

Looking at figure 1.1, in an attempt to depict the project's contribution, by including the three-pot system in the HWT "family", one could say that the long-term goal of development can be further assisted. However, if some people are not convinced and still perceive it as a pre-treatment or an emergency option, the present research can be of use to them as well, as a record of the magnitude of treatment provided by the system, regardless of where it is used.

In that sense, the three-pot can be seen as an "improved" sedimentation option. It has mainly the same principles with sedimentation, but aeration rises the positive effects further. Moreover, by suggesting the three-pot procedure, where water is being decanted each day, one safeguards the results of sedimentation and maximizes the health benefits for the user. This way water will remain in the pots for at least three days, which has been proved to give the best possible results in the shorter period of time for all systems. By naming the method "three-pot", the user will indirectly be lead to allow these three days to pass and it will be easier to remember. It is better to establish that name for the method then as a way of setting indirect guidelines for the sedimentation option.

However, it has been proved within this project (see section 4.2) that even when three days or three pots are not practiced, less days and less pots still provide water treatment. Any improvement in the water quality parameters, even if it is smaller than the maximum that could be achieved, should not be neglected, since it is still an improvement. That should be the general idea when considering if treatment options should be recognised or not. "A moderately effective water treatment that raises the levels of the most important quality parameters – those that affect health – without meeting all the parameters and standards" may be perceived as an improvement in water quality (Heber, 1985, p. 13).

"Appropriate technology doesn't imply modern and sophisticated technology versus basic technology, but on the contrary, out of a wide spectrum of possible methods, materials and systems, a choice must be made that is specifically tailored to a particular place" (Heber, 1985, p. 6). In that sense, the three-pot, could be an appropriate solution for many cases. Besides, it is wiser not to argue about it, but deal with the difficult issue of safe drinking water and consequently with the long-term goal of development from as many angles as possible.

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8.0 Appendices

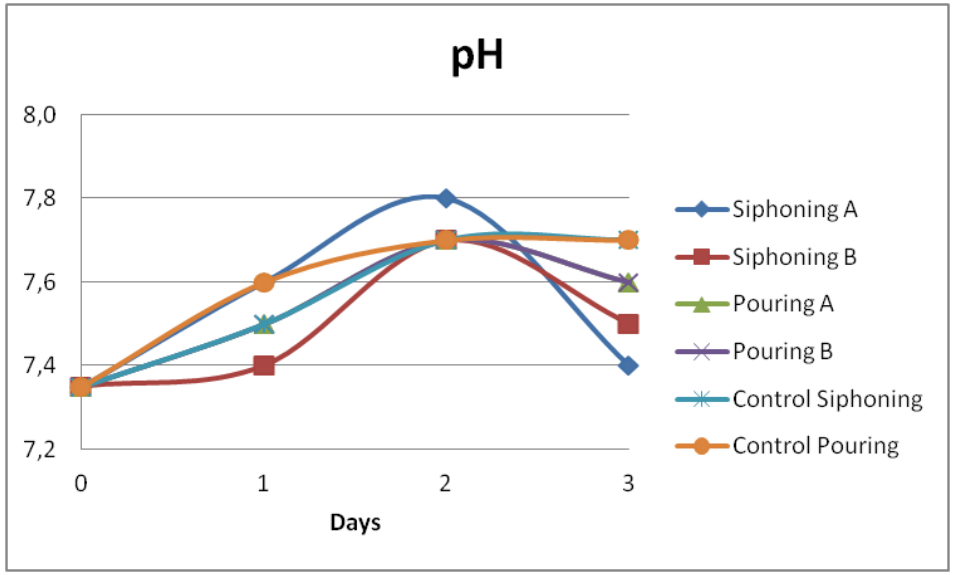
8.1 Experiment A raw data excel sheets

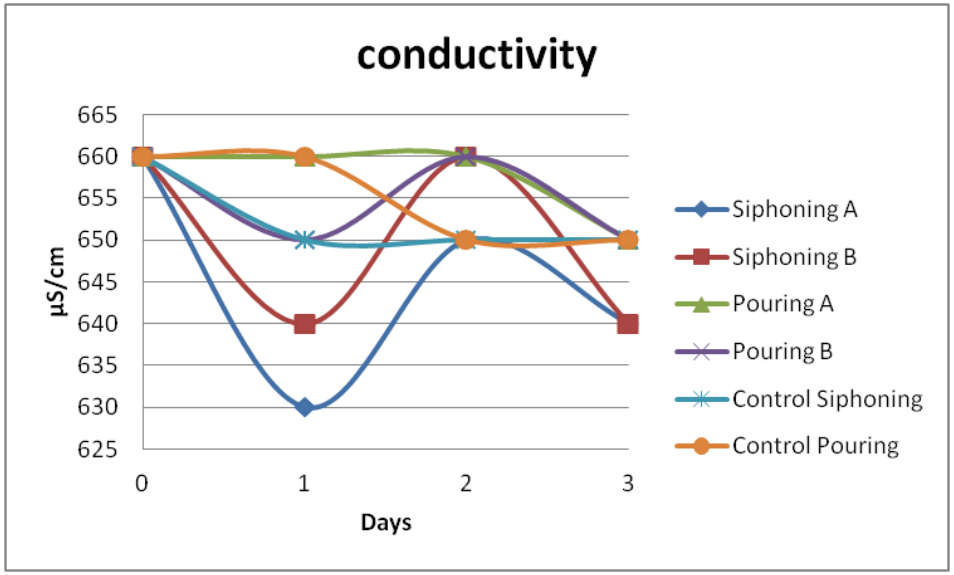
8.1.1 Trial 1

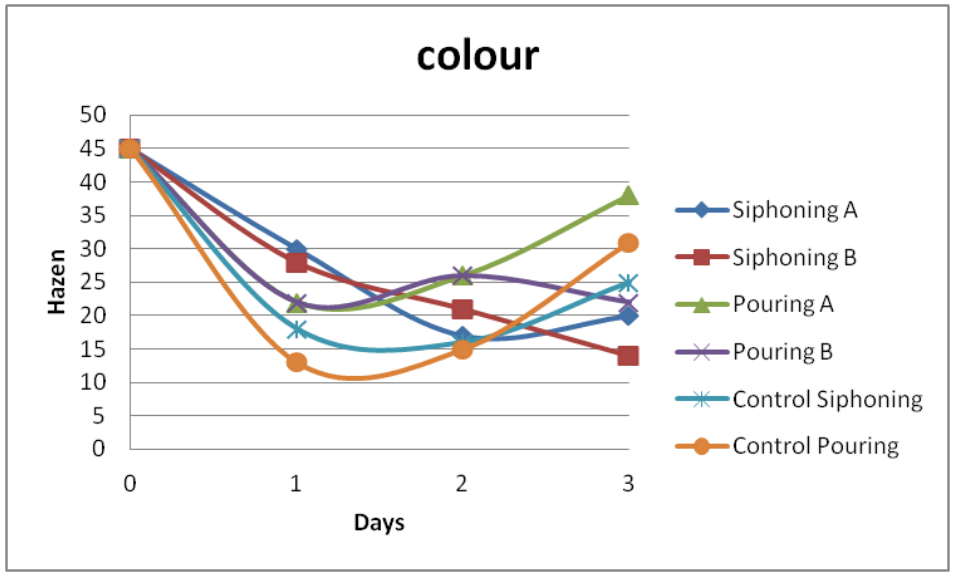
							SIPHONING								POURING								CONTROL							
		raw					A				B				A				B				Siphoning 1				Pouring 1			
		1	2	3	4	average	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
colour	(Hazen)	93	92	74	74	83	83	38	35	34	83	44	50	29	83	55	28	33	83	54	29	39	83	54	25	20	83	54	24	16
pH	()	6,9	7,0	7,1	7,1	7	7	7,5	7,6	7,3	7	7,5	7,5	7,5	7	7,4	7,5	7,6	7	7,5	7,5	7,7	7	7,5	7,5	7,7	7	7,6	7,5	7,7
conductivity	(µS/cm)	670	680	670	670	673	673	680	670	680	673	690	650	680	673	680	670	680	673	680	620	680	673	690	670	660	673	690	640	660
TDS	(ppm)	340	330	330	320	330	330	340	330	340	330	340	330	330	330	340	320	330	330	340	320	340	330	340	330	330	330	340	330	320
temperature	(oC)	17,1	17,1	17,2	17,1	17	17	24,8	25,1	24,9	17	24,3	24,6	24,6	17	24,3	25,0	24,6	17	24,1	24,2	24,4	17	24,0	24,5	24,6	17,1	24,0	24,3	24,5
turbidity	(NTU)	16	19,8	14,8	14,8	16	16	5,59	3,35	3,03	16	6,78	4,17	2,68	16	5,68	3,35	2,48	16	6,02	3,74	2,60	16	5,38	3,23	3,14	16	5,19	3,28	2,05
sus. solids (transferred)	(mg/l)	10	14	8	18	13	13	2	1	5	13	3	4	1	13	3	1	6	13	2	2	2	13	1	2	2	13	1	2	2
dis. oxygen (before)	(mg/l)	8,2	8,5	8,5	8,3	8	6,9	6,6		5,9	6,8	6,8		6,0	6,9	6,8		6,3	6,8	6,5		6,1	8	7,1	6,3	5,1	8	7,1	5,9	6,3
dis. oxygen (after)	(mg/l)						6,9	7,3	6,5	5,9	6,8	7,3	7,4	6,0	6,9	7,4	6,8	6,3	6,8	7,4	6,7	6,1								
E-coli (transferred)	(cfu/100ml)	3533	3440	3300	3360	3408	3408	1013	220	113	3408	1093	273	120	3408	1053	240	120	3408	933	227	153	3408	1227	227	60	3408	1253	167	27
volume (left)	(ml)						700	500			850	650			850	550			900	650										
volume (transfered)	(ml)							9300	8800			9150	8500			9150	8600			9100	8450								
flowrate	(ml/sec)							41,7	39,5			41,0	38,1			366	344			364	338								
air temperature	(oC)						22,9	24,3	24,4	22,3	22,9	24,3	24,4	22,3	22,9	24,3	24,4	22,3	22,9	24,3	24,4	22,3	22,9	24,3	24,4	22,3	22,9	24,3	24,4	22,3
	sus. solids (gr/100ml)																													
	clean filter	0,1952	0,1964	0,2012	0,1867			0,1924	0,1965	0,1976		0,2038	0,1941	0,1886		0,1952	0,1894	0,1919		0,1980	0,2005	0,2010		0,1932	0,2034	0,1923		0,1938	0,1922	0,1876
	used filter	0,1962	0,1978	0,202	0,1885			0,1926	0,1966	0,1981		0,2041	0,1945	0,1887		0,1955	0,1895	0,1925		0,1982	0,2007	0,2012		0,1933	0,2036	0,1925		0,1939	0,1924	0,1878
	E-coli (cfu)																													
	MLSB (a)	191	182	173	153			53	8	8		59	11	2		40	11	5		46	14	6		62	14	2		48	12	1
	MLSB (b)	171	184	157	175			50	8	5		45	17	5		65	14	7		45	10	6		59	10	2		73	7	1
	MLSB (c)	168	150	165	176			49	17	4		60	13	11		53	11	6		49	10	11		63	10	5		67	6	2

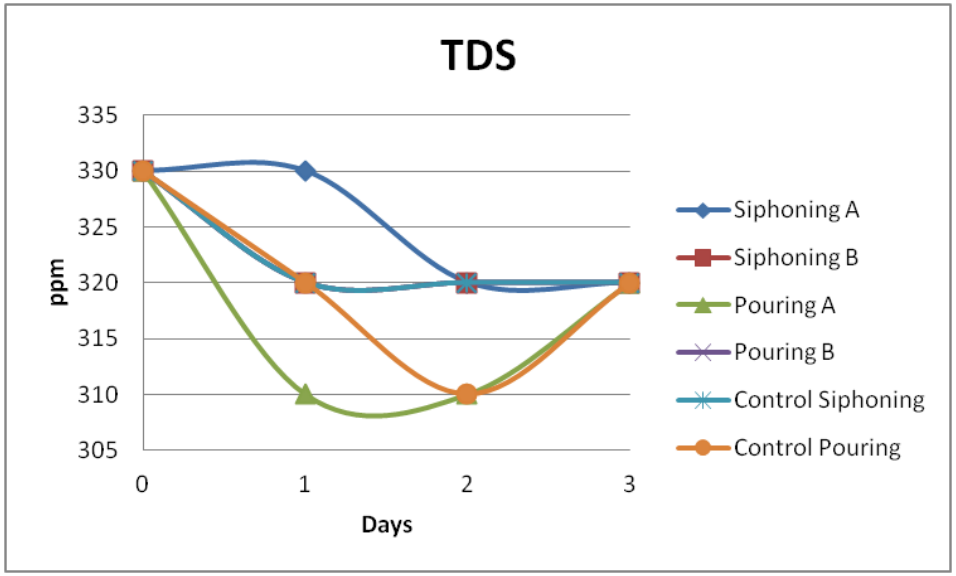
8.1.2 Trial 2

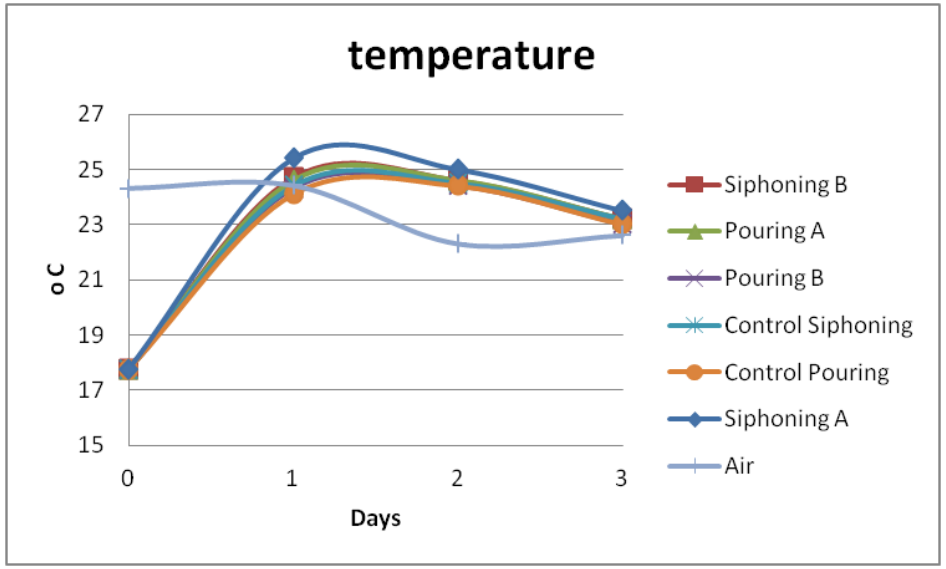
					SIPHONING								POURING								CONTROL							
		raw			A				B				A				B				Siphoning 2				Pouring 2			
		1	2	average	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
colour	(Hazen)	55	35	45	45	30	17	20	45	28	21	14	45	22	26	38	45	22	26	22	45	18	16	25	45	13	15	31
pH	()	7,3	7,4	7,35	7,35	7,6	7,8	7,4	7,35	7,4	7,7	7,5	7,35	7,5	7,7	7,6	7,35	7,5	7,7	7,6	7,35	7,5	7,7	7,7	7,35	7,6	7,7	7,7
conductivity	(µS/cm)	660	660	660	660	630	650	640	660	640	660	640	660	660	660	650	660	650	660	650	660	650	650	650	660	660	650	650
TDS	(ppm)	330	330	330	330	330	320	320	330	320	320	320	330	310	310	320	330	320	320	320	330	320	320	320	330	320	310	320
temperature	(oC)	17,9	17,6	17,75	17,75	25,4	25,0	23,5	17,75	24,7	24,6	23,2	17,75	24,6	24,6	23,2	17,75	24,3	24,4	23,0	17,75	24,4	24,5	23,2	17,75	24,1	24,4	23,0
turbidity	(NTU)	8,12	7,44	7,78	7,78	3,36	2,22	1,34	7,78	2,98	2,16	1,19	7,78	2,63	2,99	2,44	7,78	3,02	2,49	2,10	7,78	2,86	2,11	1,2	7,78	2,46	2,06	1,43
sus. solids (transferred)	(mg/l)	5	2	3,5	3,5	3	3	5	3,5	4	5	4	3,5	2	4	5	3,5	3	2	3	3,5	2	2	3	3,5	5	2	1
dis. oxygen (before)	(mg/l)	8,4	8,6	8,5	7,3	6,8	7,0		7,2	6,5	6,8		7,7	7,0	6,9		7,3	6,7	6,7		8,5	8,0	6,3	6,4	8,5	7,5	6,4	6,5
dis. oxygen (after)	(mg/l)				8,5	7,2	6,9	7,0	8,5	7,7	6,8	6,8	8,5	7,8	7,3	6,9	8,5	7,7	7,2	6,7								
E-coli (transferred)	(cfu/100ml)	847	913	880	880	340	87	33	880	293	127	40	880	453	140	40	880	413	113	40	880	407	153	33	880	567	187	47
air temperature	(oC)				24,3	24,4	22,3	22,6	24,3	24,4	22,3	22,6	24,3	24,4	22,3	22,6	24,3	24,4	22,3	22,6	24,3	24,4	22,3	22,6	24,3	24,4	22,3	22,6
volume (left)	(ml)				550	650			550	850			950	900			950	750										
volume (transfered)	(ml)					9450	8800			9450	8600			9050	8150			9050	8300									
flowrate	(ml/sec)					42,4	39,5			42,4	38,6			362	326			362	332									
	sus. solids (gr/100ml)																											
	clean filter	0,1906	0,2014			0,2059	0,2007	0,1967		0,1883	0,1934	0,1999		0,1973	0,2006	0,1980		0,2020	0,1939	0,2013		0,1934	0,2062	0,2007		0,1898	0,2118	0,2021
	used filter	0,1911	0,2016			0,2062	0,201	0,1972		0,1887	0,1939	0,2003		0,1975	0,2010	0,1985		0,2023	0,1941	0,2016		0,1936	0,2064	0,201		0,1903	0,2120	0,2022
	E-coli (cfu)																											
	MLSB (a)	58	41			19	4	1		19	7	3		23	6	1		21	5	4		20	7	0		21	10	1
	MLSB (b)	30	53			16	3	2		12	7	2		22	10	1		19	5	1		17	8	2		28	8	3
	MLSB (c)	39	43			16	6	2		13	5	1		23	5	4		22	7	1		24	8	3		36	10	3

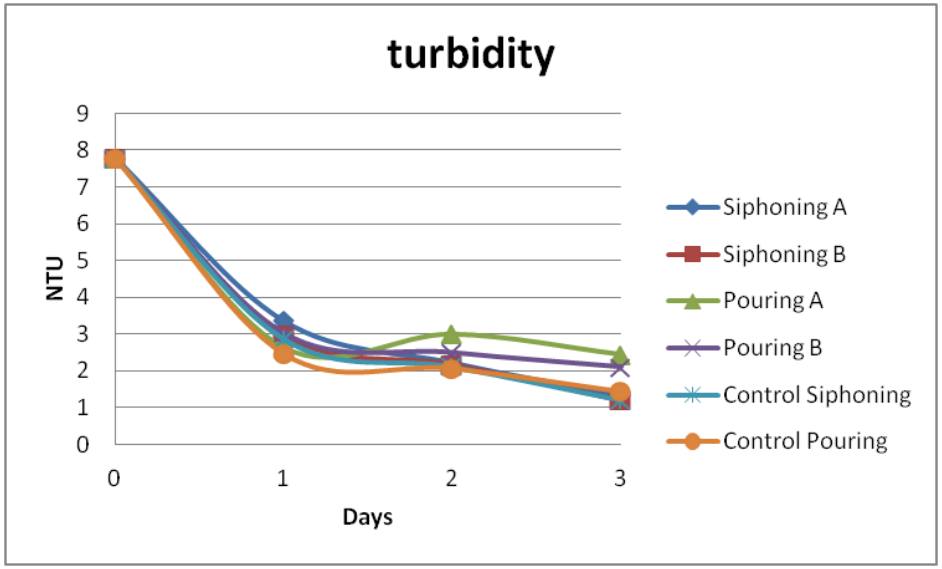

pH
8,0
7,8
7,6
7,4
7,2
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring

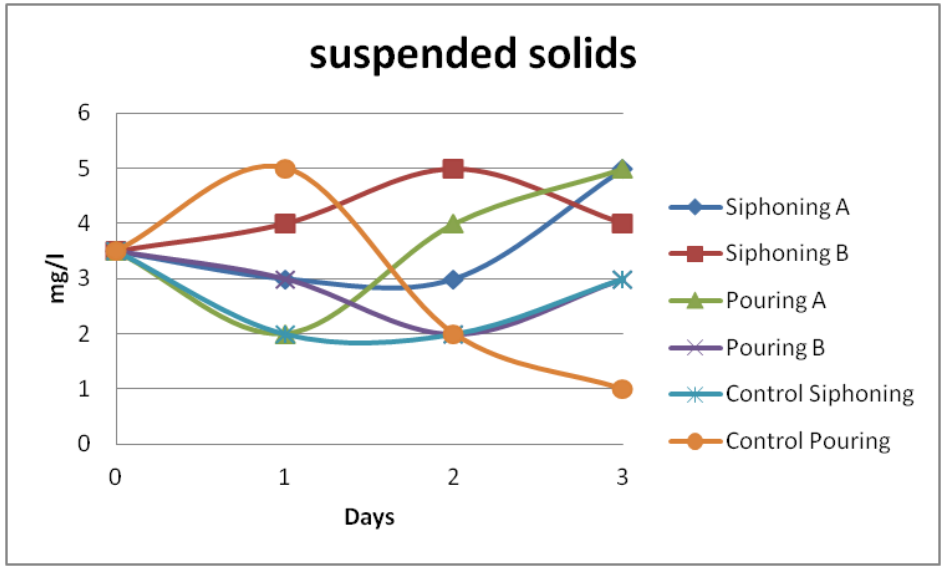

conductivity
665
660
655
650
645
640
635
630
625
µS/cm
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring

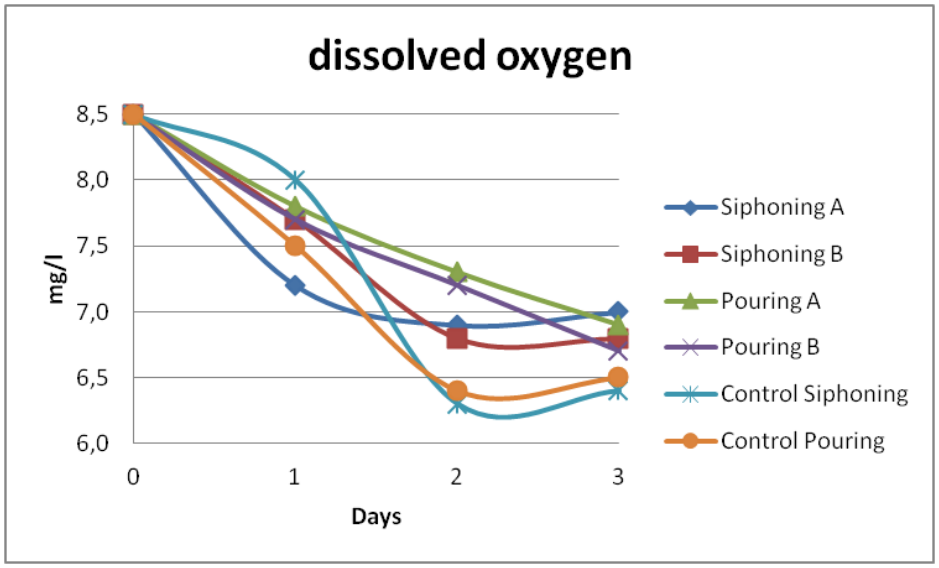

colour
50
45
40
35
30
25
20
15
10
5
0
Hazen
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring


TDS
335
330
325
320
315
310
305
ppm
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring


temperature
27
25
23
21
19
17
15
o C
0
1
2
3
Days
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring
Siphoning A
Air

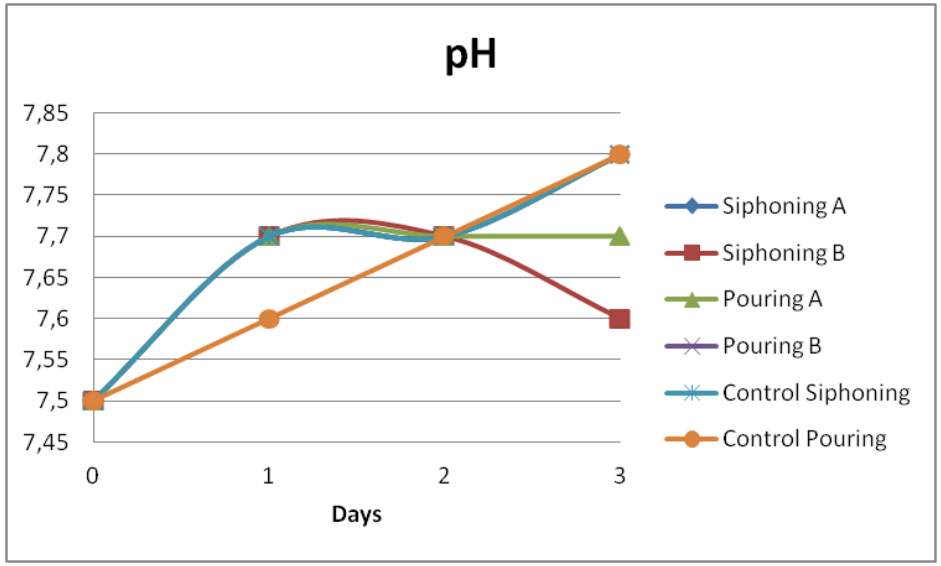

turbidity
9
8
7
6
5
4
3
2
1
0
NTU
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring

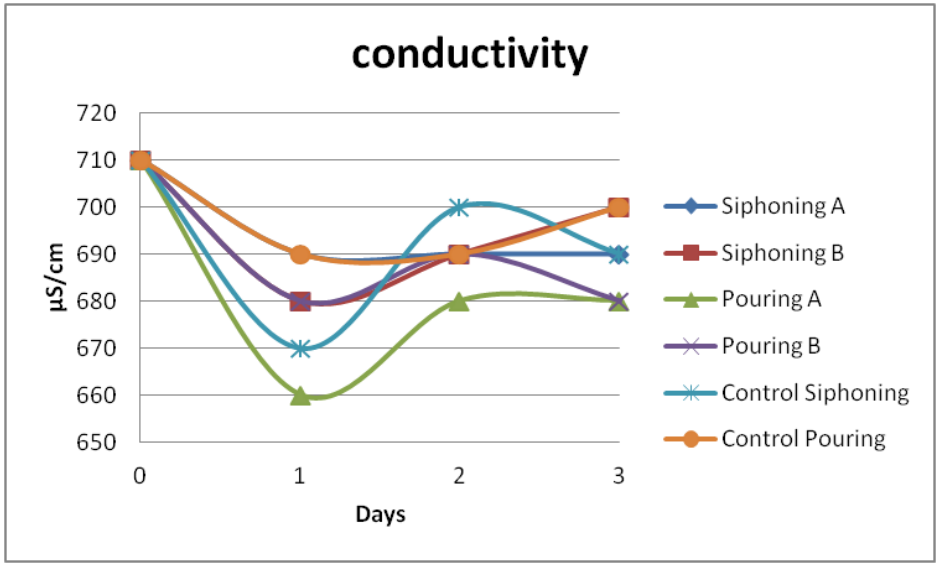

suspended solids
6
5
4
3
2
1
0
mg/l
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring

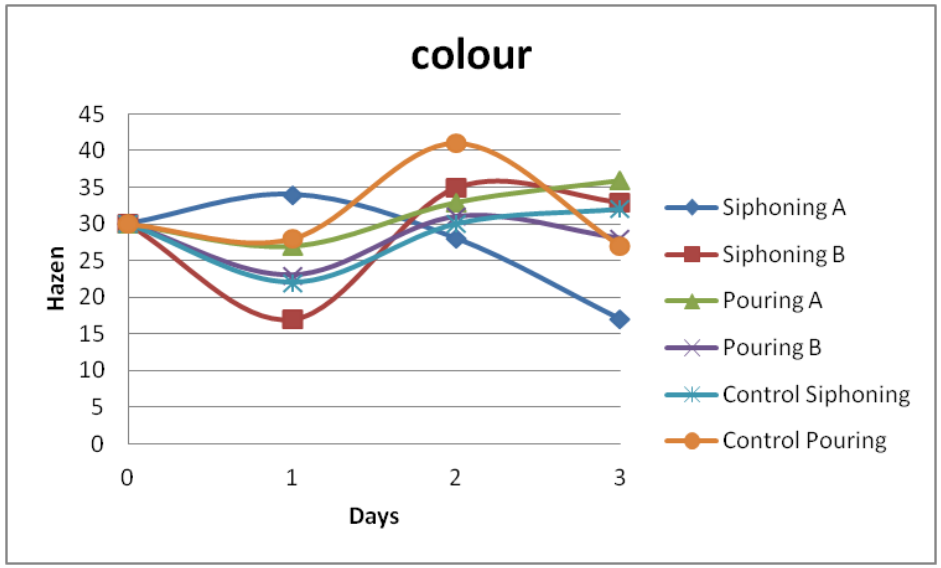

dissolved oxygen
8,5
8,0
7,5
7,0
6,5
6,0
mg/l
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring

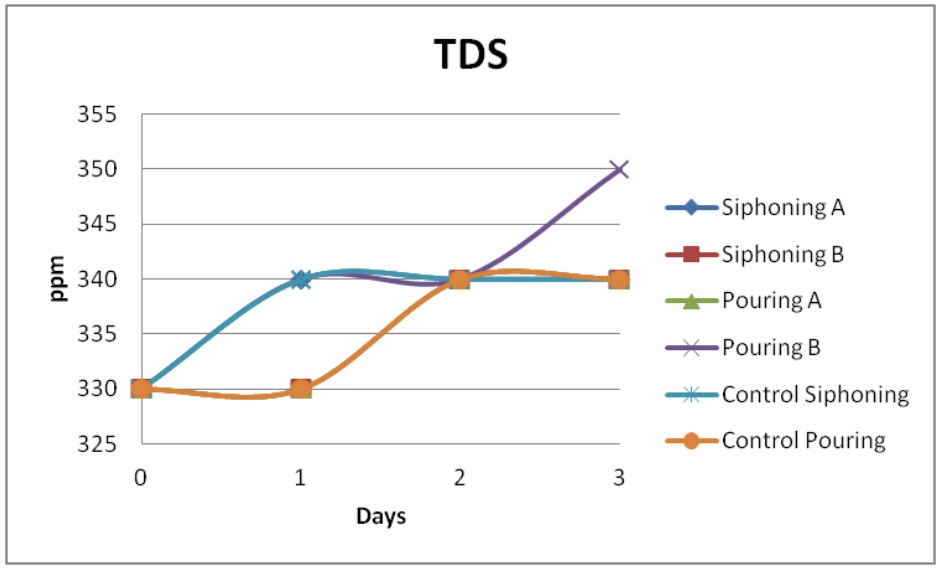
8.1.3 Trial 3

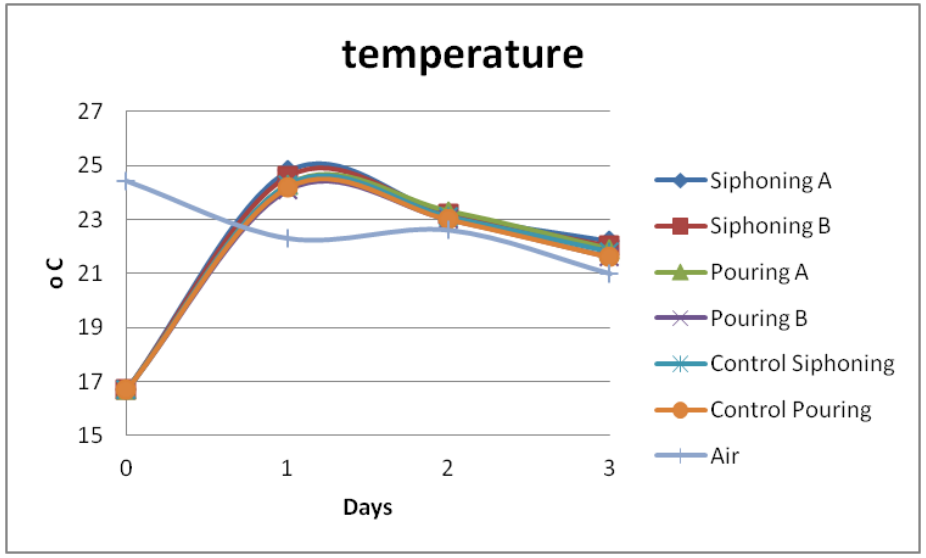
					SIPHONING								POURING								CONTROL							
		raw			A				B				A				B				Siphoning 3				Pouring 3			
		1	2	average	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
colour	(Hazen)	32	28	30	30	34	28	17	30	17	35	33	30	27	33	36	30	23	31	28	30	22	30	32	30	28	41	27
pH	()	7,5	7,5	7,5	7,5	7,7	7,7	7,8	7,5	7,7	7,7	7,6	7,5	7,7	7,7	7,7	7,5	7,7	7,7	7,8	7,5	7,7	7,7	7,8	7,5	7,6	7,7	7,8
conductivity	(µS/cm)	710	710	710	710	690	690	690	710	680	690	700	710	660	680	680	710	680	690	680	710	670	700	690	710	690	690	700
TDS	(ppm)	330	330	330	330	340	340	340	330	330	340	340	330	330	340	340	330	340	340	350	330	340	340	340	330	330	340	340
temperature	(oC)	16,7	16,7	16,7	16,7	24,8	23,2	22,2	16,7	24,6	23,2	22,0	16,7	24,3	23,3	21,9	16,7	24,1	23,0	21,6	16,7	24,3	23,1	21,8	16,7	24,2	23,0	21,6
turbidity	(NTU)	5,84	6,24	6,04	6,04	4,39	1,99	1,27	6,04	2,66	2,45	1,44	6,04	4,67	2,20	1,83	6,04	3,03	2,80	1,17	6,04	2,57	2,06	1,11	6,04	3,16	2,37	1,13
sus. solids (transferred)	(mg/l)	6	4	5	5	3	4	4	5	3	4	3	5	3	2	3	5	4	5	3	5	1	3	1	5	1	3	4
dis. oxygen (before)	(mg/l)	8,4	8,4	8,4	7,4	7,4	7,2		7,2	7,1	7,3		7,4	7,1	7,3		7,2	7,1	7,4		8,4	7,4	6,7	6,8	8,4	7,4	6,8	6,9
dis. oxygen (after)	(mg/l)				8,4	7,6	7,5	7,2	8,4	7,3	7,4	7,3	8,4	7,7	7,7	7,3	8,4	7,6	7,6	7,4								
E-coli (transferred)	(cfu/100ml)	813	833	823	823	607	87	27	823	547	160	40	823	687	207	73	823	613	167	27	823	693	180	40	823	747	207	60
air temperature	(oC)				24,4	22,3	22,6	21,0	24,4	22,3	22,6	21,0	24,4	22,3	22,6	21,0	24,4	22,3	22,6	21,0	24,4	22,3	22,6	21,0	24,4	22,3	22,6	21,0
volume (left)	(ml)				750	700			750	750			900	800			950	900										
volume (transfered)	(ml)					9250	8550			9250	8500			9100	8300			9050	8150									
flowrate	(ml/sec)					41,5	38,3			41,5	38,1			364	332			362	326									
	sus. solids (gr/100ml)																											
	clean filter	0,1968	0,1932			0,2031	0,2019	0,2224		0,1926	0,2049	0,2016		0,2005	0,2013	0,2230		0,1871	0,1992	0,2057		0,1876	0,1977	0,1962		0,2222	0,2034	0,1994
	used filter	0,1974	0,1936			0,2034	0,2023	0,2228		0,1929	0,2053	0,2019		0,2008	0,2015	0,2233		0,1875	0,1997	0,206		0,1877	0,198	0,1963		0,2223	0,2037	0,1998
	E-coli (cfu)																											
	MLSB (a)	36	35			29	3	1		28	9	0		36	9	3		31	6	0		31	7	2		36	10	2
	MLSB (b)	51	56			34	7	1		24	7	2		27	10	4		30	10	1		43	10	2		39	9	3
	MLSB (c)	35	34			28	3	2		30	8	4		40	12	4		31	9	3		30	10	2		37	12	4

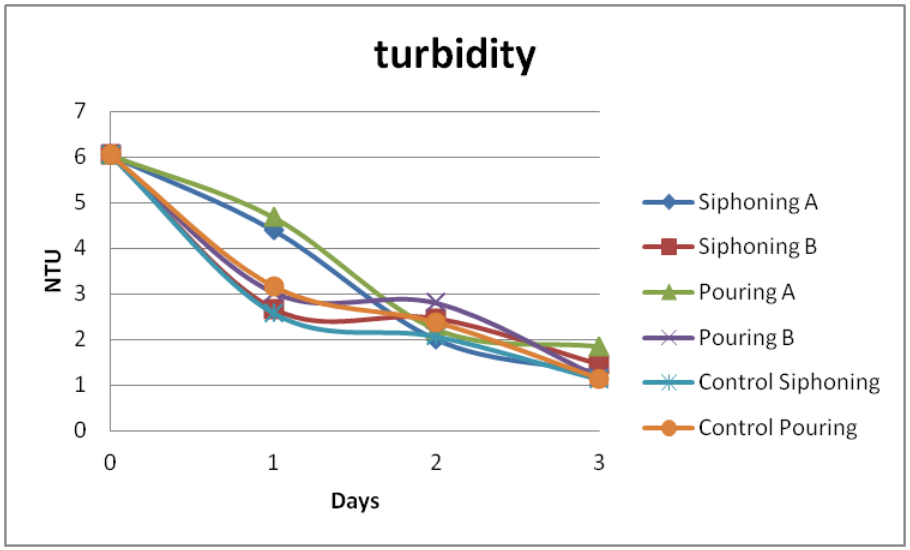

pH
7,85
7,8
7,75
7,7
7,65
7,6
7,55
7,5
7,45
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring

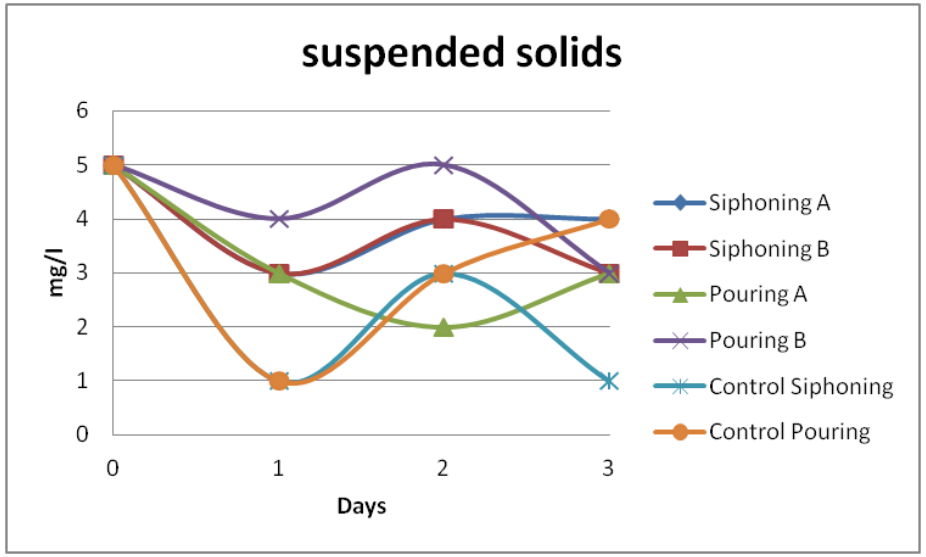

conductivity
720
710
700
690
680
670
660
650
µS/cm
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring

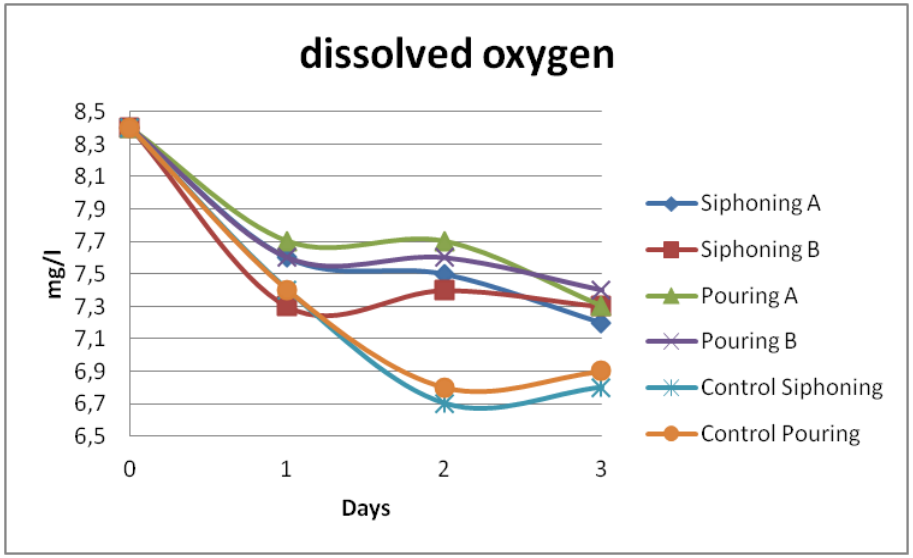

colour
45
40
35
30
25
20
15
10
5
0
Hazen
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring


TDS
355
350
345
340
335
330
325
ppm
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring


temperature
27
25
23
21
19
17
15
o C
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring
Air


turbidity
7
6
5
4
3
2
1
0
NTU
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring


suspended solids
6
5
4
3
2
1
0
mg/l
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring


dissolved oxygen
8,5
8,3
8,1
7,9
7,7
7,5
7,3
7,1
6,9
6,7
6,5
mg/l
0
1
2
3
Days
Siphoning A
Siphoning B
Pouring A
Pouring B
Control Siphoning
Control Pouring

8.2 Experiment B raw data excel sheets

8.2.1 Trial 1

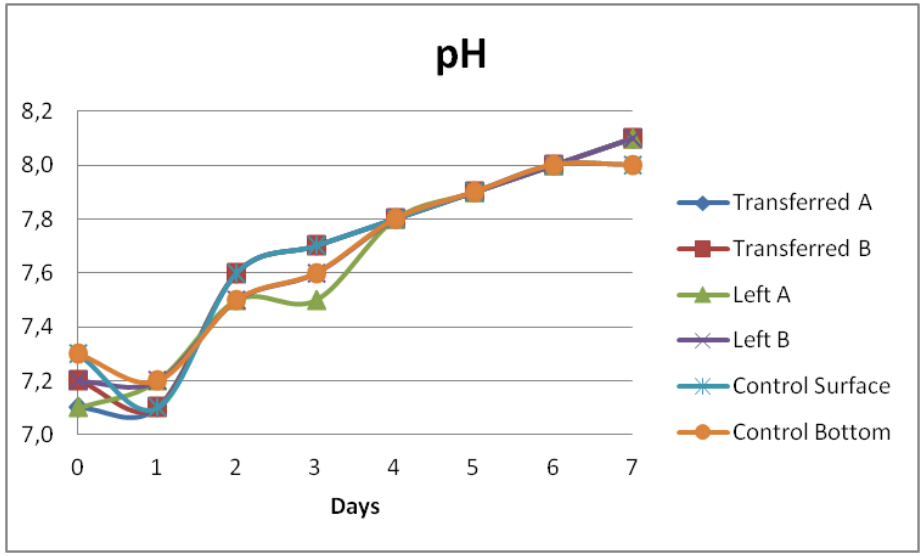
		transferred																					
		A								B								A					
		0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5
colour	(Hazen)	144	107	93	88	65	68	64	59	145	105	100	85	64	71	65	61	144	116	97	133	97	98
pH	()	7,0	7,1	7,6	7,6	7,8	7,9	8,0	8,0	7,1	7,1	7,6	7,6	7,8	7,9	8,0	8,1	7,0	7,2	7,5	7,7	7,7	7,8
conductivity	(µS/cm)	560	520	530	520	520	520	520	520	550	520	530	520	520	520	520	520	560	520	520	520	520	520
TDS	(ppm)	270	260	260	260	260	260	260	260	270	260	260	260	260	260	260	260	270	260	260	260	260	260
temperature	(oC)	14,1	19,3	19,7	20,9	19,4	18,9	19,4	20,3	14,1	18,7	19,3	20,5	19,0	18,4	19,1	19,6	14,1	19,3	19,7	20,9	19,4	18,9
turbidity	(NTU)	12,1	8,66	6,13	6,12	3,62	3,14	3,93	2,24	12,1	8,14	6,19	4,45	3,38	3,07	3,29	3,1	12,1	11,7	6,89	11,7	6,98	6,28
sus. solids	(mg/l)	16	9	3	3	4	4	5	1	12	8	3	3	2	3	1	1	16	9	9	10	7	7
dis. oxygen	(mg/l)	9,5	8,8	8,5	8,2	8,6	8,8	8,9	8,9	9,5	8,7	8,5	8,3	8,6	8,7	9,0	9,0	9,5	8,7	8,5	8,4	8,7	9,0
E-coli	(cfu/100ml)	8780	6920	2480	780	440	310	70	10	8780	6910	2550	850	500	360	60	30	8780	7210	3940	3430	2310	1600
volume (left)	(ml)		1000	1000	500	500	500	500	500		1000	1000	500	500	500	500	500		1000	1000	500	500	500
volume (transferred)	(ml)	10000	9000	8000	7500	7000	6500	6000	5500	10000	9000	8000	7500	7000	6500	6000	5500	10000	9000	8000	7500	7000	6500
air temperature	(oC)	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5
	sus. solids (gr/100ml)																						
	clean filter	0,2005	0,1988	0,1984	0,2015	0,2007	0,1987	0,2018	0,1998	0,1984	0,1983	0,2005	0,2019	0,2013	0,1995	0,2032	0,1988	0,2005	0,1981	0,2003	0,2004	0,2029	0,1998
	used filter	0,2021	0,1997	0,1987	0,2018	0,2011	0,1991	0,2023	0,1999	0,1996	0,1991	0,2008	0,2022	0,2015	0,1998	0,2033	0,1989	0,2021	0,1990	0,2012	0,2014	0,2036	0,2005
	E-coli (cfu)																						
	MLSB (a)	432	350	110	41	20	16	5	0	436	335	121	37	21	17	4	1	432	356	186	163	125	82
	MLSB (b)	446	342	138	37	24	15	2	1	442	356	134	48	29	19	2	2	446	365	208	180	106	78

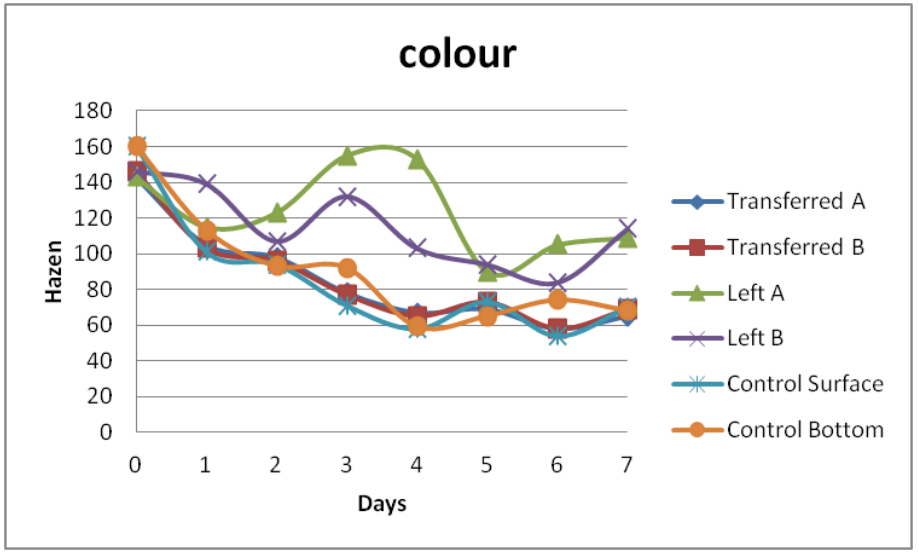
left										control															
		B								surface								bottom							
6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
101	95	145	118	96	127	98	90	83	86	145	102	103	80	63	74	56	64	145	114	94	89	63	68	64	65
8,0	8,0	7,1	7,2	7,5	7,5	7,8	7,8	8,0	8,1	7,2	7,1	7,6	7,7	7,8	7,9	8,0	8,1	7,2	7,2	7,5	7,6	7,8	7,9	8,0	8,0
520	520	550	520	520	520	520	520	520	520	550	520	520	520	520	520	520	520	550	520	520	520	520	520	520	520
260	260	270	260	260	260	260	260	260	260	270	260	260	260	260	260	260	260	270	260	260	260	260	260	260	260
19,4	20,3	14,1	18,7	19,3	20,5	19,0	18,4	19,1	19,6	14,1	18,7	19,1	20,2	18,9	18,2	18,5	19,3	14,1	18,7	19,1	20,2	18,9	18,2	18,5	19,3
6,32	5,65	12,1	15,0	6,78	10,8	7,72	5,47	5,44	5,5	11,7	8,05	5,73	4,48	3,59	3,09	2,88	2,98	11,7	8,31	6,79	6,24	4,16	3,19	3,54	3,05
8	8	12	12	5	11	3	7	4	6	14	10	5	4	1	3	5	1	14	9	3	6	2	7	2	1
9,0	9,0	9,5	8,7	8,5	8,5	8,7	8,9	9,0	8,9	9,4	8,8	8,2	8,2	8,2	8,2	8,4	8,5								
500	330	8780	7420	4260	2800	2170	1610	530	240	9500	7340	3170	870	280	250	100	60	9500	7090	2600	1350	490	290	80	60
500	500		1000	1000	500	500	500	500	500	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
6000	5500	10000	9000	8000	7500	7000	6500	6000	5500																
19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0
0,2018	0,2021	0,1984	0,2009	0,2016	0,1991	0,2016	0,2008	0,1991	0,2027	0,1969	0,1990	0,2010	0,2027	0,2009	0,2003	0,2005	0,1982	0,1969	0,1965	0,1998	0,1987	0,2014	0,2010	0,1989	0,1992
0,2026	0,2029	0,1996	0,2021	0,2021	0,2002	0,2019	0,2015	0,1995	0,2033	0,1983	0,2000	0,2015	0,2031	0,2010	0,2006	0,2010	0,1983	0,1983	0,1974	0,2001	0,1993	0,2016	0,2017	0,1991	0,1993
27	20	436	360	215	126	122	81	27	16	470	364	160	45	11	13	5	4	470	367	123	68	28	19	3	2
23	13	442	382	211	154	95	80	26	8	480	370	157	42	17	12	5	2	480	342	137	67	21	10	5	4

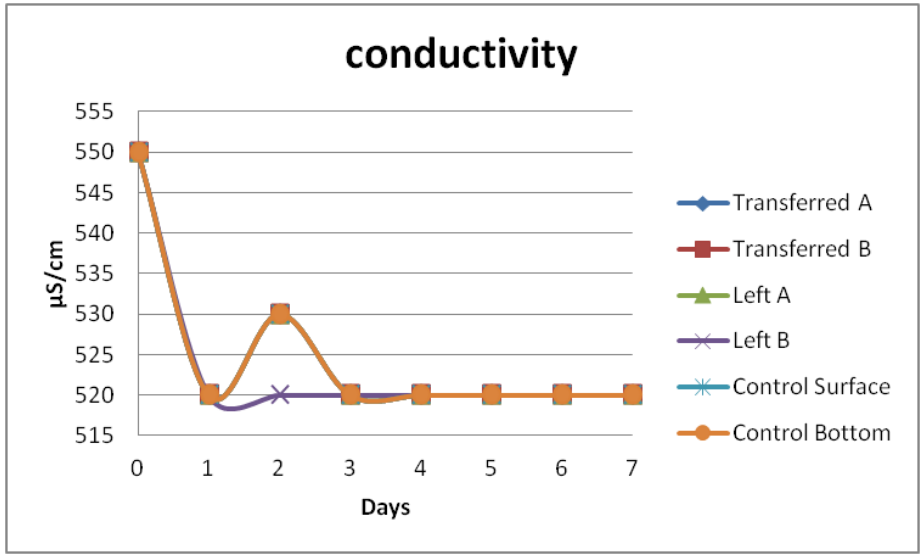
8.2.2 Trial 2

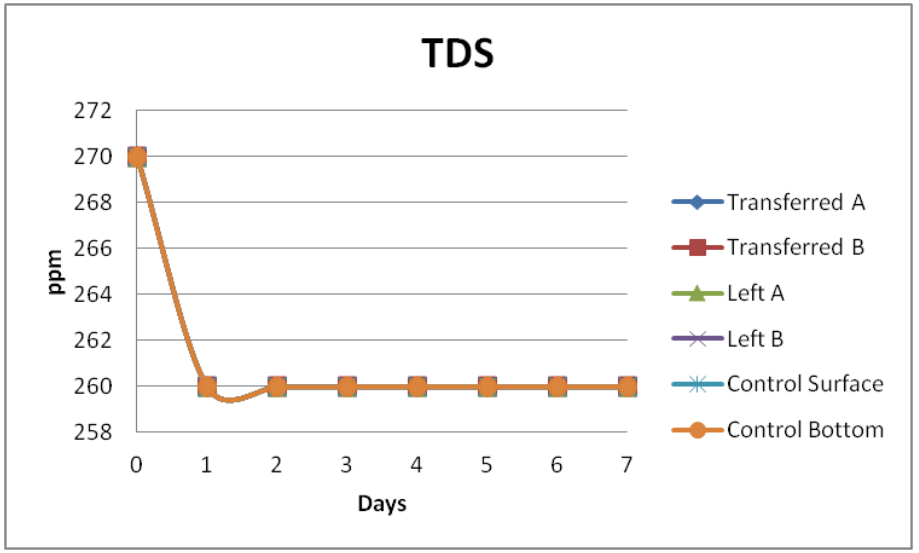
		transferred																					
		A								B								A					
		0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5
colour	(Hazen)	143	105	98	78	67	69	58	65	146	103	96	77	65	73	58	69	143	115	123	155	153	90
pH	()	7,1	7,1	7,6	7,7	7,8	7,9	8,0	8,1	7,2	7,1	7,6	7,7	7,8	7,9	8,0	8,1	7,1	7,2	7,5	7,5	7,8	7,9
conductivity	(µS/cm)	550	520	530	520	520	520	520	520	550	520	530	520	520	520	520	520	550	520	530	520	520	520
TDS	(ppm)	270	260	260	260	260	260	260	260	270	260	260	260	260	260	260	260	270	260	260	260	260	260
temperature	(oC)	14,1	19,1	19,4	20,3	18,9	18,2	19,1	19,7	14,1	18,8	19,3	20,1	18,8	18,1	18,6	19,5	14,1	19,1	19,4	20,3	18,9	18,2
turbidity	(NTU)	12,4	8,08	5,82	4,28	3,77	2,96	3,0	3,11	11,8	7,76	5,7	3,92	3,51	4,09	3,13	3,51	12,4	8,83	10,4	11,0	7,35	5,32
sus. solids	(mg/l)	17	11	4	6	4	3	5	2	15	11	3	4	4	2	3	6,5	17	11	7	12	11	4
dis. oxygen	(mg/l)	9,5	8,6	8,4	8,4	8,5	8,8	9,0	9,0	9,5	8,6	8,4	8,3	8,7	8,6	9,1	8,8	9,5	8,6	8,4	8,4	8,7	9,0
E-coli	(cfu/100ml)	17400	8750	3430	1110	630	260	140	120	16800	9110	4360	1350	620	290	230	130	17400	9650	8460	6610	3420	970
volume (left)	(ml)		1000	1000	500	500	500	500	500		1000	1000	500	500	500	500	500		1000	1000	500	500	500
volume (transfered)	(ml)	10000	9000	8000	7500	7000	6500	6000	5500	10000	9000	8000	7500	7000	6500	6000	5500	10000	9000	8000	7500	7000	6500
air temperature	(oC)	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5
	sus. solids (gr/100ml)																						
	clean filter	0,1977	0,1978	0,2003	0,2024	0,1989	0,1982	0,2027	0,2011	0,1973	0,1991	0,2000	0,2011	0,1996	0,2012	0,2026	0,20005	0,1977	0,1961	0,1995	0,2017	0,2019	0,2012
	used filter	0,1994	0,1989	0,2007	0,2030	0,1993	0,1985	0,2032	0,2013	0,1988	0,2002	0,2003	0,2015	0,2000	0,2014	0,2029	0,2007	0,1994	0,1972	0,2002	0,2029	0,2030	0,2016
	E-coli (cfu)																						
	MLSB (a)	870	425	157	57	31	13	9	8	880	431	219	60	33	14	12	9	870	485	436	302	165	48
	MLSB (b)	(x)	450	186	54	32	13	5	4	800	480	217	75	29	15	11	4	(x)	480	410	359	177	49

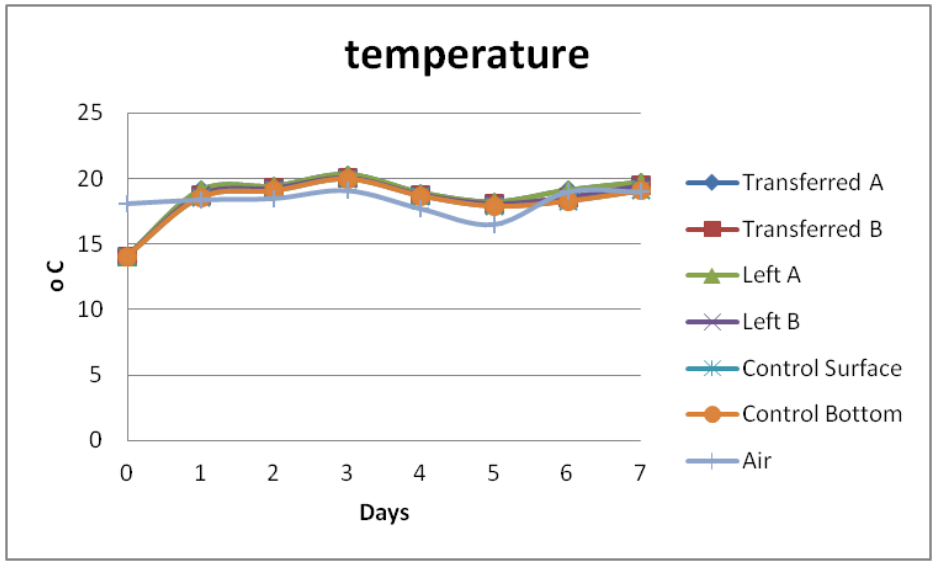
left		control																					
		B								surface								bottom					
6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
105	109	146	139	107	132	103	94	84	114	160	101	94	71	58	73	54	70	160	113	93	92	59	65	74	68
8,0	8,1	7,2	7,2	7,5	7,6	7,8	7,9	8,0	8,1	7,3	7,1	7,6	7,7	7,8	7,9	8,0	8,0	7,3	7,2	7,5	7,6	7,8	7,9	8,0	8,0
520	520	550	520	520	520	520	520	520	520	550	520	530	520	520	520	520	520	550	520	530	520	520	520	520	520
260	260	270	260	260	260	260	260	260	260	270	260	260	260	260	260	260	260	270	260	260	260	260	260	260	260
19,1	19,7	14,1	18,8	19,3	20,1	18,8	18,1	18,6	19,5	14,1	18,6	19,1	20,0	18,7	17,9	18,3	19,1	14,1	18,6	19,1	20,0	18,7	17,9	18,3	19,1
5,99	6,18	11,8	8,83	8,64	11,9	7,84	5,9	4,9	6,31	12,7	8,08	5,67	3,65	3,07	2,83	2,39	3,25	12,7	8,23	5,67	4,43	3,58	3,94	2,45	3,9
7	9	15	12	11	11	8	7	6	8	15	9	5	3	1	2	6	1	15	9	4	4	2	4	5	4
9,2	8,9	9,5	8,6	8,4	8,3	8,8	8,9	9,1	9,0	9,4	8,7	8,3	8,1	8,0	8,3	8,5	8,6								
710	510	16800	9440	8310	6060	3720	1020	650	610	16800	8850	4600	1510	480	390	170	130	16800	8840	3810	1660	740	560	230	210
500	500		1000	1000	500	500	500	500	500	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
6000	5500	10000	9000	8000	7500	7000	6500	6000	5500																
19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0	18,1	18,4	18,5	19,1	17,7	16,5	19,0	19,0
0,1994	0,2013	0,1973	0,1980	0,2001	0,2020	0,2029	0,2001	0,1976	0,1987	0,1988	0,1992	0,2010	0,2006	0,2016	0,1995	0,2023	0,1992	0,1988	0,1978	0,2008	0,2015	0,2028	0,2003	0,2007	0,1986
0,2001	0,2022	0,1988	0,1992	0,2012	0,2031	0,2037	0,2008	0,1982	0,1995	0,2003	0,2001	0,2015	0,2009	0,2017	0,1997	0,2029	0,1993	0,2003	0,1987	0,2012	0,2019	0,2030	0,2007	0,2012	0,1990
34	26	880	484	464	303	187	48	35	30	840	445	239	78	24	19	9	7	840	440	186	83	42	27	9	8
37	25	800	460	367	(x)	185	54	30	31	(x)	440	221	73	24	20	8	6	(x)	444	195	83	32	29	14	13

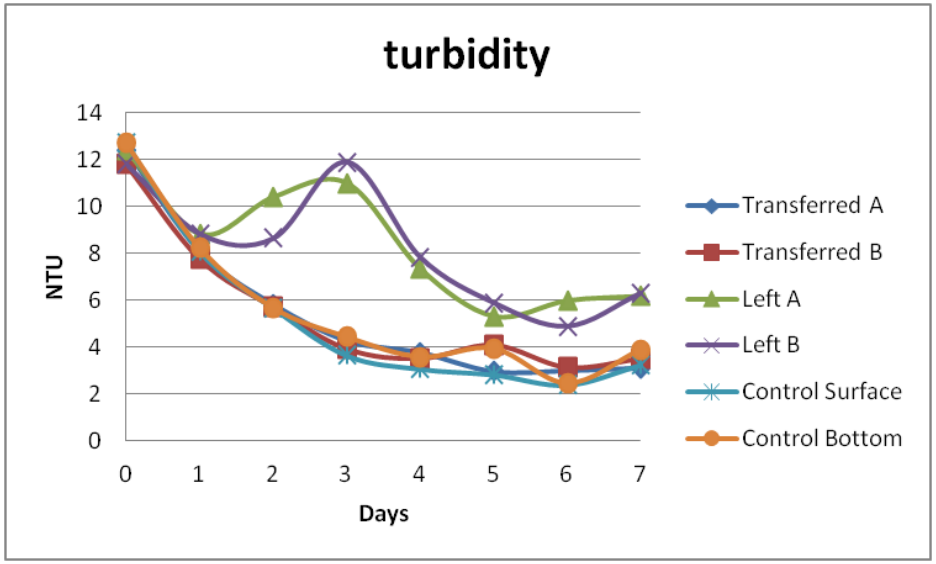

pH
8,2
8,0
7,8
7,6
7,4
7,2
7,0
0 1 2 3 4 5 6 7
Days
Transferred A
Transferred B
Left A
Left B
Control Surface
Control Bottom

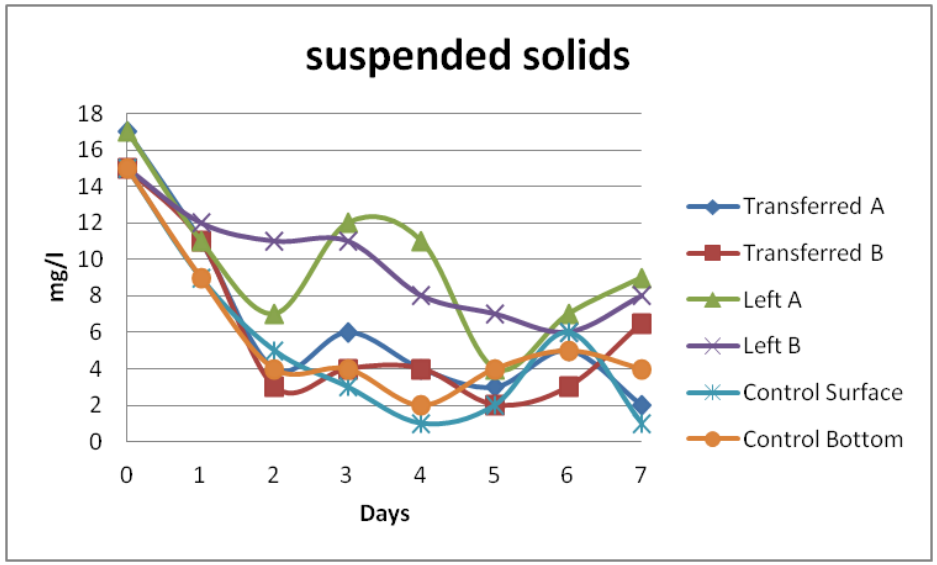

colour
180
160
140
120
100
80
60
40
20
0
Hazen
0 1 2 3 4 5 6 7
Days
Transferred A
Transferred B
Left A
Left B
Control Surface
Control Bottom

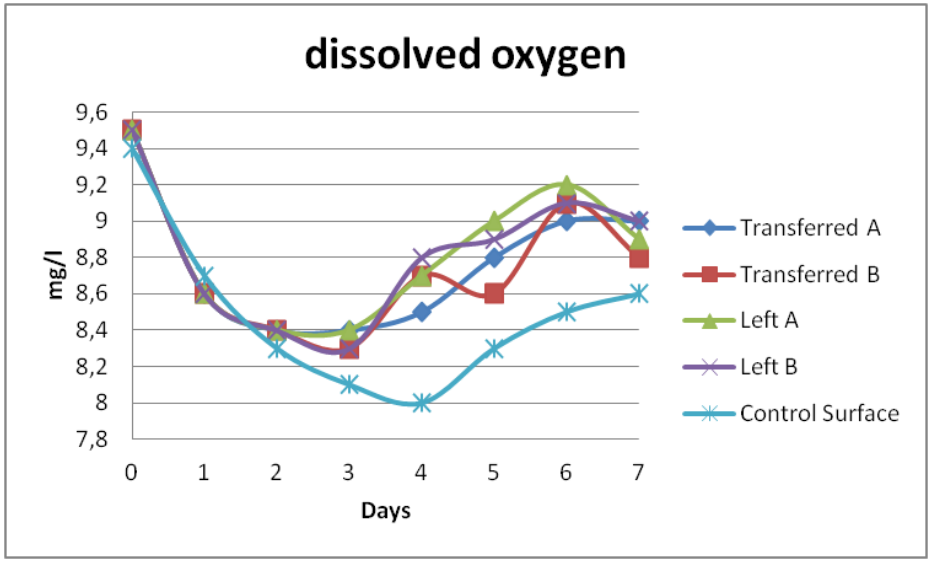

conductivity
555
550
545
540
535
530
525
520
515
µS/cm
0 1 2 3 4 5 6 7
Days
Transferred A
Transferred B
Left A
Left B
Control Surface
Control Bottom


TDS
272
270
268
266
264
262
260
258
ppm
0 1 2 3 4 5 6 7
Days
Transferred A
Transferred B
Left A
Left B
Control Surface
Control Bottom


temperature
o C
25
20
15
10
5
0
0 1 2 3 4 5 6 7
Days
Transferred A
Transferred B
Left A
Left B
Control Surface
Control Bottom
Air


turbidity
NTU
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7
Days
Transferred A
Transferred B
Left A
Left B
Control Surface
Control Bottom


suspended solids
mg/l
18
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7
Days
Transferred A
Transferred B
Left A
Left B
Control Surface
Control Bottom


dissolved oxygen
mg/l
9,6
9,4
9,2
9
8,8
8,6
8,4
8,2
8
7,8
0 1 2 3 4 5 6 7
Days
Transferred A
Transferred B
Left A
Left B
Control Surface

8.3 Experiment A and B reduction rates tables

8.3.1 Experiment A – Trial 1

	0	1	2	3	E. coli RR % 1	E. coli RR % 2	E. coli RR % 3	Average RR% 1	Average RR% 2	Average RR% 3
Siphoning A	3408	1013	220	113	70,27	93,55	96,67	69,10	92,76	96,58
Siphoning B	3408	1093	273	120	67,92	91,98	96,48			
Pouring A	3408	1053	240	120	69,10	92,96	96,48	70,86	93,15	95,99
Pouring B	3408	933	227	153	72,62	93,35	95,50			
Control Siphoning	3408	1227	227	60	64,01	93,35	98,24	63,62	94,23	98,73
Control Pouring	3408	1253	167	27	63,23	95,11	99,22			

8.3.2 Experiment A – Trial 2

	0	1	2	3	E. coli RR % 1	E. coli RR % 2	E. coli RR % 3	Average RR% 1	Average RR% 2	Average RR% 3
Siphoning A	880	340	87	33	61,36	90,15	96,21	64,02	87,88	95,83
Siphoning B	880	293	127	40	66,67	85,61	95,45			
Pouring A	880	453	140	40	48,48	84,09	95,45	50,76	85,61	95,45
Pouring B	880	413	113	40	53,03	87,12	95,45			
Control Siphoning	880	407	153	33	53,79	82,58	96,21	44,70	80,68	95,45
Control Pouring	880	567	187	47	35,61	78,79	94,70			

8.3.3 Experiment A – Trial 3

	0	1	2	3	E. coli RR % 1	E. coli RR % 2	E. coli RR % 3	Average RR% 1	Average RR% 2	Average RR% 3
Siphoning A	823	607	87	27	26,29	89,47	96,76	29,93	85,01	95,95
Siphoning B	823	547	160	40	33,58	80,56	95,14			
Pouring A	823	687	207	73	16,57	74,89	91,09	21,02	77,32	93,93
Pouring B	823	613	167	27	25,48	79,75	96,76			
Control Siphoning	823	693	180	40	15,76	78,13	95,14	12,52	76,51	93,93
Control Pouring	823	747	207	60	9,28	74,89	92,71			

8.3.4 Experiment B – Trial 1

	0	1	2	3	4	5	6	7
Transferred A	8780	6920	2480	780	440	310	70	10
Transferred B	8780	6910	2550	850	500	360	60	30
Left A	8780	7210	3940	3430	2310	1600	500	330
Left B	8780	7420	4260	2800	2170	1610	530	240
Control Surface	9500	7340	3170	870	280	250	100	60
Control Bottom	9500	7090	2600	1350	490	290	80	60
		E. coli RR % 1	E. coli RR % 2	E. coli RR % 3	E. coli RR % 4	E. coli RR % 5	E. coli RR % 6	E. coli RR % 7
Transferred A		21,18	71,75	91,12	94,99	96,47	99,20	99,89
Transferred B		21,30	70,96	90,32	94,31	95,90	99,32	99,66
Left A		17,88	55,13	60,93	73,69	81,78	94,31	96,24
Left B		15,49	51,48	68,11	75,28	81,66	93,96	97,27
Control Surface		22,74	66,63	90,84	97,05	97,37	98,95	99,37
Control Bottom		25,37	72,63	85,79	94,84	96,95	99,16	99,37
		Average RR% 1	Average RR% 2	Average RR% 3	Average RR% 4	Average RR% 5	Average RR% 6	Average RR% 7
Transferred A		21,24	71,36	90,72	94,65	96,18	99,26	99,77
Transferred B								
Left A		16,69	53,30	64,52	74,49	81,72	94,13	96,75
Left B								
Control Surface		24,05	69,63	88,32	95,95	97,16	99,05	99,37
Control Bottom								

8.3.5 Experiment B – Trial 2

	0	1	2	3	4	5	6	7
Transferred A	17400	8750	3430	1110	630	260	140	120
Transferred B	16800	9110	4360	1350	620	290	230	130
Left A	17400	9650	8460	6610	3420	970	710	510
Left B	16800	9440	8310	6060	3720	1020	650	610
Control Surface	16800	8850	4600	1510	480	390	170	130
Control Bottom	16800	8840	3810	1660	740	560	230	210
		E. coli RR % 1	E. coli RR % 2	E. coli RR % 3	E. coli RR % 4	E. coli RR % 5	E. coli RR % 6	E. coli RR % 7
Transferred A		49,71	80,29	93,62	96,38	98,51	99,20	99,31
Transferred B		45,77	74,05	91,96	96,31	98,27	98,63	99,23
Left A		44,54	51,38	62,01	80,34	94,43	95,92	97,07
Left B		43,81	50,54	63,93	77,86	93,93	96,13	96,37
Control Surface		47,32	72,62	91,01	97,14	97,68	98,99	99,23
Control Bottom		47,38	77,32	90,12	95,60	96,67	98,63	98,75
		Average RR% 1	Average RR% 2	Average RR% 3	Average RR% 4	Average RR% 5	Average RR% 6	Average RR% 7
Transferred A		47,74	77,17	92,79	96,34	98,39	98,91	99,27
Transferred B								
Left A		44,17	50,96	62,97	79,10	94,18	96,03	96,72
Left B								
Control Surface		47,35	74,97	90,57	96,37	97,17	98,81	98,99
Control Bottom								

8.4 Trial sampling prior to experiments

		Holywell 1	Holywell 2	Burleigh
colour	(Hazen)	75	72	39
pH	()	7,0	7,2	7,5
conductivity	(µS/cm)	680	690	990
TDS	(ppm)	340	340	490
temperature	(oC)	16,7	16,7	16,7
turbidity	(NTU)	7,14	6,59	2,04
sus. solids	(mg/l)	5	4	2
dis. oxygen	(mg/l)	8,5	8,6	9,2
E-coli	(cfu/100ml)	890	770	580
air temperature (oC)		21	21	21
	Holywell 1	Holywell 2	Burleigh	
sus. solids (gr/100ml)				
clean filter	0,1904	0,1927	0,2027	
used filter	0,1909	0,1931	0,2029	
E-coli (cfu)				
MFC (a)	30	65	76	
MFC (b)	50	75	92	
MFC (cfu/100 ml)	800	1400	1680	
MLSB (a)	47	45	30	
MLSB (b)	42	32	28	
MLSB (cfu/100 ml)	890	770	580	
	pour (sec)	siphon (min)		
flowrate	30,51	3,45		
	34,52	3,25		
	23,49	3,58		
	21,73	3,24		
	21,03	3,59		
	19,21	3,44		
average	25,08	3,43		
sec	25	223		