AN INDEPENDENT INVESTIGATION INTO THE PURIFICATION CAPACITY OF SMALL-SCALE WATER PURIFICATION UNITS SUPPLIED IN SOUTH AFRICA

Volume 1

Laboratory Testing of Home Water Treatment Devices

Report to the
WATER RESEARCH COMMISSION

by

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An Independent Investigation into the Purification Capacity of Small-Scale Water Purification Units Supplied in South Africa. Volume 2: Development and Distribution of Information Pamphlet
(WRC No. 1994/2/13);
To Buy a Water Filter or Not to Buy a Water Filter (WRC Report No. 1994/3/13 - available on WRC web site only).

EXECUTIVE SUMMARY

BACKGROUND AND RATIONALE

Recent outbreaks of cholera and other waterborne diseases in southern Africa have resulted in a perception among consumers that tap water is not safe for drinking purposes. As a result, the use of small-scale water purification systems in the domestic setting is increasing rapidly. Most of these units are sold over the counter and consumers buy the products in good faith, on the basis of claims of their efficiency made during marketing and advertising campaigns, and with the expectation that the units will remove at least 90-100% of all harmful microorganisms. However, very often the claims made in the manufactures brochures are not substantiated by independent research. Products are usually tested in-house by the manufacturer and often only for their capacity to remove traditional indicator bacteria.

Very few independent studies have been published on the capacity of these units to effectively treat water. The majority of publications refer to projects which only tested for a single organism or compound and/or a single product. To date, only two published studies have tested the units for removal of more than one compound simultaneously. Grabow and co-workers (1999) tested one product against indicator organisms, viruses, bacteriophages and *Cryptosporidium* and reported 99% removal of the organisms. In 2004 Herman and co-workers compared the purification efficiency of nine commercially available units in Finland against bacteria (*Escherichia coli*, *Clostridium perfringens*, *Klebsiella pneumoniae* and *Enterobacter cloacae*), enteric protozoans (*Cryptosporidium parvum*), viral markers (*F-RNA bacteriophages*) and microcystins. Their results indicated that only one of the nine devices tested was capable of decreasing the numbers of F-RNA bacteriophages to below the detection limit and decrease the levels of microcystins significantly. Units that used only filtration were not successful in reducing the numbers of viral indicators and chemicals.

The question arose: have the claims made by manufacturers regarding the water treatment efficiency of the supplied home water treatment devices been tested and reported accurately? A need therefore existed for an independent study to evaluate a representative number of units sold in South Africa against the claims that are made in sales brochures. This study focused on the testing of selected home water treatment devices according to the United States National Sanitation Foundation (NSF) guidelines and the results compared to the South African national Standards (SANS 241) requirements.

OBJECTIVES AND AIMS

The overall aim of this study was to assess home water treatment devices sold in South Africa for their capacity to provide safe drinking water for domestic, public and occupational use and to provide guidelines to enable consumers to make informed decisions when purchasing these units.

The study evaluated the performance capacity of tap mounted and jug-type purification systems currently available in South Africa for domestic use, particularly with regard to their ability to remove microorganisms under a variety of running conditions as prescribed by the National Standards Foundation and to compare our findings with the claims made by the manufacturers of the products.

The following specific objectives were determined for the project:

1. Obtain information about home water treatment devices sold in South Africa.
2. Obtain information about the claimed purification capabilities of home water treatment devices to be tested.
3. Test the claims about the purification capabilities of home water treatment devices made by the manufacturers.
4. Compare the claimed results with laboratory based results obtained in the first three objectives.

METHODOLOGY

This study was an exploratory, quantitative study relying on a combination of descriptive surveys, analysis of documentary evidence and analytical, quantitative laboratory experiments to evaluate the efficiency of home water treatment devices for the removal of microbiological, physico-chemical and chemical contaminants. An overview of selected home water treatment devices (HWTDs) currently available on the South African market as well as the purchase of the selected HWTDs included in this study were sourced from informal market retailers, direct marketers and retail stores within the Pretoria and Johannesburg areas (Gauteng Province, South Africa). Within this study the testing of HWTDs was limited to those that claimed to improve or enhance treated water supplied by the regular / local municipal water authorities. The HWTDs tested were divided into two groups, namely pour through / batch type devices (jug and counter top devices referred to as gravity fed) and flow through / in-line devices (plumbed in faucet type devices referred to as faucet devices).

Gravity fed and faucet devices were set up differently using the set-up recommended by the NSF. Three holding units of each type or brand of HWTD to be tested were purchased with three replacement filters / cartridges. The experiments to evaluate HWTDs were based on the established concepts as practised by SANS and the NSF. Thus the purchased HWTDs were tested using a combination of the SANS 1865:2006 (Point of use drinking water treatment units), SANS 241:2006 (Drinking Water Part 1: Microbiological, physical aesthetic and chemical determinants), NSF Protocol P231 (Microbiological Water Purifiers), NSF 42-2009 (Drinking Water Treatment Units – Aesthetic Effects), NSF 44-2009 (Residential Cation Exchange Water Softeners) and NSF 53-2009e (Drinking Water Treatment Units – Health Effects). In addition to testing the systems for deliverable water quality which should meet the required standards in SANS 241:2006, the individual systems were also tested in accordance with the reduction claims made by their manufacturers. Attention was also given to ensure that all tests and experiments conformed to SANS 5667-2:1991 (Guidance on sampling techniques), SANS 5667-3:1991 (Guidance on the preservation and handling of water samples), SANS 5667-5:1991 (Guidance on sampling of drinking water from treatment works and piped distribution systems) guidelines and included the techniques as described in “Standard methods for water and waste water samples” (Eaton et al., 2005), also all controls were included to ensure the validity and reliability of the reported results.

Each HWTD was equilibrated within the apparatus set-up to meet the manufacturer’s recommendation in terms of assembly, before use cleaning instructions, cartridge preparation/activation, initial flushing of the system before usage, maintenance, flow rate and pressure requirements in order for the system to operate optimally and the bed volume of each device was determined. The starting concentration of spiked contaminant NSF/ SANS 241:2006 “challenge test water” was determined using the appropriate test before being challenged / run through the unit. After the challenge the eluted “challenge test water” was collected and the final elution concentration was determined using the appropriate test as described in the section below. Data was used to determine the removal efficiency of each contaminant and so determine the HWTD removal capabilities. Experiments were repeated over a three day period for each HWTD, for each individual criterion of tests to obtain three separate data sets (24h, 48h and 72h after device calibration). All relevant controls were included in all the assays to ensure the validity and reliability of the results.

RESULTS

The overview of the available HWTDs in South Africa shows a wide variety of devices in South Africa. It was seen that attention should be paid to the claims made by the manufacturers in their information brochures to ensure that the devices are used correctly. This includes specific flow rates for the faucet mounted devices which in most cases do not translate to the normal opening of the tap. Possibly the greatest concern was the fact that all the devices tested as part of this study indicated that the device should only be used with municipal treated tap water that meets SANS241 requirements raising the question why there would be a need for the further treatment of the water.

An overall general pattern was observed that most of the HWTDs tested within this study potentially did improve the water quality in terms of its aesthetic attributes such as reducing scale, but in terms of taste, odour, heavy metal and microbiological removal claims the devices tested performed rather poorly. Considering that these were the most common claims made by the manufacturers (their devices could remove heavy metals and pathogens, as well as improve taste and odour); this potentially is their biggest “selling” point / “scare tactic” utilized to persuade consumers to purchase these devices. This is of great concern bearing in mind that their devices did not accomplish what they had claimed.

In terms of microbiological analysis, ultrafiltration and sediment filtration proved to be the most successful for removing bacteria and cysts; however none of the technologies tested successfully removed viruses. In terms of physic-chemical analysis most of the manufactures of HWTDs also claimed chlorine removal after treatment and most of the devices tested did succeed in reducing or removing chlorine. Devices which utilized ceramic, sediment, ultrafiltration (UF), kinetic degradation fluxion (KDF), and granular activated carbon (GAC) treatment technologies successfully neutralized both acidic and alkaline waters. In terms of turbidity, mechanical reduction and TDS assays, UF and sediment water treatment technologies were the most successful at excluding particles in water.

In terms of macro chemical determinant assays, none of the water treatment technologies tested reported any success in reducing fluoride in water. Water treatment technologies utilizing ceramic, sediment and organic carbon (OC) did indicate success at reducing zinc levels. In terms of chemical micro determinant assays, findings from the study suggest that HWTDs which utilize activated carbon (AC), ion exchange resin (IER), sediment, KDF and ceramic filtration (CF) technologies, in combination, effectively reduced copper contamination. None of the water treatment technologies tested, however, was effective at removing iron, manganese, and lead from tap water. The HWTD's technologies that utilize cationic exchange resins were successful at reducing aluminium contaminates in treated water; however the carbon based water filtration technologies were not. In terms of chromate reductions in tap water HWTDs technologies that utilize carbon and dense ceramic based water treatment technologies were successful at removing chromium contaminates from tap water.

In terms of organic chemical determinant assays finding from the study suggested that most of the HWTDs tested (especially those which utilized carbon based water treatment technologies) are infective at reducing total organic carbon (TOC), some of them actually added more carbon to the final treated water and this is a concerning factor as carbon is a substrate source for microbes which could lead to fouling of these devices (Matilainen *et al*., 2010 and Yue *et al.*., 2005). None of the HWTDs succeed at removing phenol from water after treatment to acceptable levels that would improve tap water aesthetically in terms of taste and odour. This leads to their manufactures claims, in terms of improving taste and odour or removing phenol contaminants, being unjustified.

The additional tests performed within this study were phosphate and silicate assays, and the overall findings suggest that all the HWTDs tested within this study that utilized AC, IER, sediment, GAC and KDF treatment mechanisms were effective at keeping / adding phosphate / silicate to tap water, to acceptable levels that would improve tap water aesthetically in terms of reducing scale. However, in terms of "softening" water by decreasing calcium carbonate none of the HWTDs tested succeeded.

Most of the HWTDs failed to comply with NSF P231, 42 or 53 and SANS 241:2006 POU water treatment device standards and most of them did not perform accordingly to the claims made by their manufacturers.

CONCLUSIONS

In summary, the following project objectives have been met:

1) An overview of HWTDs available in the Gauteng province and on the internet was successfully completed (Objective 1).
2) Information was obtained about the claimed purification capabilities of HWTDs that were selected and tested as part of this study (Objective 2).
3) The selected devices were tested using the NSF methodologies in terms of criteria specified by SANS 241 for the provision of safe potable water and claims made by the manufacturers (Objective 3).
4) All results were successfully compared with the claims made by the manufacturers and aligned with the recommendations of the NSF.

RECOMMENDATIONS FOR FUTURE RESEARCH

As many of the HWTDs available as possible should be tested to confirm the claims made by their manufacturers. The research team believe that this process should be done in consultation with the manufacturers or suppliers (if they are South African) to assist them with improving the quality of their products and by implication the water quality consumed by the public.

The results showed that although the required removal efficiency as stipulated by the NSF could not be met by several of the HWTDs for specific tests, there still was a reduction in most cases. The recommendation would be to do tests with treated tap water to evaluate the performance of these devices under normal conditions.

The negative impact that treatment technologies such as activated carbon could have on the water quality should also be investigated. The recommendation is to test HWTDs used with tap water for the claimed lifespan of the devices to ensure that the devices perform effectively during the whole lifespan, as claimed. In line with this it would be helpful to better understand what would happen to the water quality if the consumers did not follow suggested maintenance and replacement of HWTD parts, such as the filters.

THOUGHTS FROM THE TEAM

Water quality and supply in South Africa as a whole is a very touchy subject and has been the topic of strikes and protests in South Africa in the last few years. With this in mind the last thing we would want is for this report to be used to add to the fights and we as a team decided to voice our opinion in this section, something not usually done as part of WRC reports. This section links up with the Volume 2 of this report and deals with the public perception of water quality and the launch of a pamphlet to assist consumers with their knowledge about water quality in South Africa.

An overarching concern is that although people have concerns about water quality it seems that they do not always have access to trustworthy information or simply do not trust the information being supplied to them. This brings to mind brand failures reported by companies such as Coca-Cola, Pepsi and others linked to a specific product or advertising campaign. There are various books that deals with this and highlight an important questions that we as the water society needs to ask ourselves: Have the “brand” of water been tarnished in South Africa, why did this happen and how can we fix it? This in itself needs a lot of research but is important for the country. We do not have the answers for this but want to use this section to highlight some of our concerns and observations that does not have concrete scientific backing. Despite this we still believe it is important that we start talking about these topics.

We trust that the results we presented will be used properly to better the water sector and not to pass the blame. We need to interact with the public and put findings into perspective. We can easily say that almost none of the devices tested worked but you should keep in mind that the testing concentrations are well above the norm of what we would find in water and considering that most of the devices have a place if the users understand the limitations of the device. We need to engage the suppliers to ensure that make founded claims and rather help them to market their product for specific needs such as removing chlorine to meet the needs of the consumer. Most importantly we need to communicate with the public so that they understand why they are using these devices and to make them aware of what the devices can actually do.

This was only an exploratory study and much more research and testing is needed to test all the devices available so that we can engage the manufacturer to assist them with their needs and give advice for improving the devices. We trust that you as the reader accepts this and reads the document in the manner that is was intended to be used.

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LIST OF ABBREVIATIONS

AC	Activated Carbon
ANAB	American National Accreditation Board
ANSI	American National Standards Institute
Approx	Approximate
AS	American Standard
BDOC	Biodegradable Organic Carbon
BSF	Bio-sand Filter
CE	European Conformity
CF	Carbon Filter
Cl^-	Chlorine (Free)
CSF	Ceramic silver-impregnated Filter
DOC	Dissolved Organic Carbon
DPBs	Disinfection By-Product/s
DWA	Department of Water Affairs
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
FM	Faucet Mounted
GAC	Granular Activated Carbon
GF	Gravity Fed
HRS	Hours
HUS	Haemolytic Uraemic Syndrome
HWTD	Home Water Treatment Device
HWTDs	Home Water Treatment Devices
IER	Ion Exchange Resin
ISO	International Organization of Standardisation
KDF	Kinetic Degradation Fluxion
MCL	Maximum contaminant level
MF	Microfiltration
MRDL	Maximum residual Disinfection Level
N/A	Not Applicable
NC	No Claim
NF	Nano filtration
NHLS	National Health Laboratory Services
NOM	Naturally Occurring Organic Matter
NSF	National Sanitation Foundation
OC	Organic Carbon
POC	Particulate organic Matter
POE	Point of Entry
POU	Point of Use
RO	Reverse Osmosis
SABS	South African Bureau of Standards
SANS	South African National Standards
SI	Silver Impregnation
SUD	Technical Service Cooperation Certification
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TUV	Technischer Überwachungsverein
UF	Ultrafiltration
UJ	University of Johannesburg
UV	Ultraviolet
VOC	Volatile Organic Carbon
WHO	World Health Organisation
WRAS	Water Regulations Advisory Scheme
WRC	Water Research Commission
WQA	Water Quality Association

Units of Measurement	**Definition**
%	Percent
µg/L	micrograms per litre
L	Litre
mg/L	milligrams per litre
mS/m	Milisiemens per metre
NTU	Nephelometric Turbidity Units
µM	Micrometres

Note to the reader

For the purpose of this study the South African National Standards 241 (2006) document was used to determine the allowable levels of contaminants in potable water. Although the SANS 241 (2011) is available we were requested to use the 2006 values since the SANS 241 is currently being updated to include the new WHO values published in 201 shortly after the SANS241 (2011) was published.

1. INTRODUCTION

1.1 WATER QUALITY IN SOUTH AFRICA

1.1.1 Who is responsible for the quality of water in South Africa and the status of our water quality?

The primary responsibility for the provision of safe drinking water in South Africa rests with Water Services Authorities (Local or District Municipalities) (DWAF, 2008). Water Services Authorities have a legal responsibility to monitor the quality of drinking water provided to consumers to compare the results to national drinking water standards, and to communicate any health risks to consumers and the appropriate authorities (DWAF, 2008). This is described in the regulations for the Water Services Act (No. 108 of 1997) *Compulsory National Standards for the Quality of Potable Water*: The South African National Standard (SANS 241: 2006) *Drinking Water Specification* is the definitive reference acceptable limits for drinking water quality in South Africa and provides guideline levels for a range of water quality characteristics. This ensures bacteriological, appearance and chemical qualities of urban water are acceptable for the protection of human health (DWAF, 2009).

Other important role-players include the Department of Water Affairs (DWA) which is responsible for managing South Africa's water resources for its consumers. The DWA also regulates provision of drinking water by Water Services Authorities (DWAF, 2008). The Department of Health is responsible for coordinating responses to incidents of water-related diseases in South Africa and for providing interventions under emergency drinking water conditions (DWAF, 2008). Environmental Health Officers are responsible for empowering the community through the provision of health and hygiene education, as well as undertaking drinking water quality monitoring at the point of use (DWAF, 2008).

In 2009 the DWA released a press statement reassuring all South Africans that "tap water is safe for human consumption and that a country-wide system to assist with the overall management of drinking water was to be implemented" (DWAF, 2009). The DWA further reported in 2010 that 98% of samples collected nationwide, complied with health aspects of the national standard for drinking water quality (SANS 241:2006).

1.1.2 What does the public think about the water supplied in South Africa?

Of all the water in the world, only about 3% is consumed by human beings and of this small percentage the majority is either wholly or partially polluted by natural or manmade contaminants (Hodgson and Manus, 2006). The body requires water to survive, but not the contaminants found in most drinking water (Laurent, 2007). Most people in South Africa face limited choices of drinking water (Hodgson and Manus, 2006). They can either drink tap water provided by the municipalities they live in, or borehole water on their own land (Hodgson and Manus, 2006).

There is major concern amongst the South African public that the municipal drinking water is unsafe, and that there is widespread pollution of the water occurring naturally in the environment (van der Merwe-Botha, 2009). Since the recent Delmas diarrhoeal outbreaks that were reported within the Mpumalanga Province of South Africa, many citizens have started to question the quality of their tap water (Lang, 2007; Strydom, 2009). The public seems to mistrust governmental and municipal reports that state the water quality in South Africa is of an acceptable standard, and meets the World Health Organisation (WHO) water quality health standards (Lang, 2007; Strydom, 2009). Thus, many consumers still require peace of mind and assurance of their water quality, leading to large numbers of people investing in home water treatment devices (HWTDs) (Ahammed and Meera, 2010; Kaiser, 2010). Suppliers of such devices often use scare tactics and unjustified claims of poor South African water quality to mislead consumers into purchasing their products (Dungumaro, 2007; Fengyi *et al*., 2009).

1.2 HOME WATER TREATMENT DEVICES (HWTDS)

1.2.1 Is there a need for HWTDs in South Africa?

According to the consumer's guide on 'drinking water quality' released by government in 2009, people living in areas where the drinking water supplied meets national drinking water standards do not require an additional water filter to meet health requirements. In areas where safe drinking water is not yet supplied to consumers, commercially available point of use filters can be used, but these are relatively expensive (DWAF, 2008).

Currently, South African legislation requires that all water filtration device components installed at household level are approved by the South African Bureau of Standards (SABS) or local authority South African National Standard (SANS). It does not however explicitly prohibit the import and sale of such products (Buren, 2010; Unger, 2010). As a result, the South African market has been flooded with non-compliant water filtration devices (Buren, 2010; Unger, 2010). This raises concern as most of these products are not certified and inferior products increase the risk of waterborne diseases. This can also induce negative health impacts by reducing the quality of the current municipal tap water available to the public (Water Quality Management System, 2009).

1.2.2 Regulations for HWTDs in South Africa

The present SANS / SABS legislation for the implementation and testing of locally produced HWTDs is lacking, and the government itself does not regulate this particular market. This has led to consumers being misled by the products they are considering to purchase or install (Buren, 2010; Water Quality Management System, 2009). Currently, the only compliance required in South Africa to market and sell such devices is that they meet the requirements set out by the SANS 1865: 2006 “Point of use drinking water treatment units” standard (SANS 1865: 2006). This standard currently stipulates that the design and construction of HWTDs must meet SANS 9001: 2006 “Quality management system” standards for the integrated quality of the actual system (SANS 1865: 2006). The standard also states that the microbiological requirements must comply with the Authority Water Standard of SANS 241: 2006 for “Drinking and Potable Water for Human Consumption” (SANS 1865: 2006).

The SANS 1865:2006 “Point of use drinking water treatment units” standard is at the time of writing under review (SANS 1865, 2006), however the current matter of concern is that existing policy stipulates that the microbiological requirements of final filtered water product need only meet the SANS 241:2006 Authority Water Standard. This standard is of the same criterion that local municipal suppliers of tap water are required to meet in South Africa (Polasek, 2009). Thus, consumers are currently installing HWTDs to their taps that potentially purify tap water to perhaps a better standard than the local supply, yet both are meeting the same standards and requirements. So in effect if these water filtration devices have only SABS / SANS certification, they are not actually improving the tap water quality consumed by the public after municipal purification.

Another matter of concern is that the general public is led to believe that the current HWTDs available on the market will protect them from waterborne diseases, which might result from contamination of their municipal tap water supply. However, most of the suppliers of these devices state that their devices are only to be utilized with local municipally supplied tap water. Hence the issue in question is: do local suppliers of HWTDs depend on the notion that the local tap water supply will always meet the SANS 241: 2006 standard, or have they actually had them tested with additional contaminated water sources to ensure the removal of potentially harmful pathogens from a particular water source to the standard stipulated by SANS 241: 2006? Furthermore, should the local municipal supply of tap water fail to provide safe drinking water (that does not meet the SANS 241: 2006 Authority Water Standard) and there is an outbreak of waterborne disease in SA: will these current suppliers claims still stand, and would these purchased devices function effectively to produce potable drinking water by removing potentially pathogenic microorganisms? In order to protect the users who purchased these devices, with the intent of assured water quality and protection from potential water hazards and contaminants, HWTDs must be tested by an independent study such as this to verify the claims their manufacturers make.

1.2.3 International drinking water purification device standards

Only a few HWTDs available in South Africa have been tested and listed by the National Sanitation Foundation (NSF). The NSF is globally an international testing and certification program for drinking water purification devices. Although it is not a requirement by the South African government for suppliers of HWTDs to be registered with them, most European and American governments are making them the “golden standard” within their water policies to be registered and certified with, in order to market and sell water purification devices within their countries (NSF International, 2010). This is due to the fact that the NSF has developed and maintained consensus standards and certification programs in public health, safety and within the environment. This has resulted in them becoming the leading independent third party testing and certification organization within the water device purification market worldwide (NSF, 2010). Unfortunately, since it is not a legal requirement of home water treatment suppliers in Southern Africa to be registered with the NSF, most of them are not. The general public are unaware of the accurate standards of the NSF and therefore are still reliant on the SABS / SANS, which does not require these devices to meet any of the international standards unlike other countries (Buren, 2010; Unger, 2010).

The NSF certification requires that HWTDs meet the current prevailing Drinking Water Treatment Unit (DWTU) standards at all times. The device must also undergo strict evaluation in terms of structural integrity, material safety assessments, contamination reduction testing, packaging and literature review of all product data (NSF, 2010). The NSF also stipulates that the product must be supplied with a performance data sheet, and that the production facility of the device must be audited on a regular basis (NSF International, 2010). Since most of the water purification units supplied in South Africa lack adequate certification, there is a strong need for this study in order to evaluate the water purification capabilities of the devices currently supplied on the market.

1.3 STUDY RATIONALE

The information provided above can be daunting for the man on the street and could lead to customers being confused with the mass of information provided. Home water treatment devices have become popular with consumers as a tool to remove waterborne pathogens and chemicals from drinking water in their homes (Fengyi et al., 2009). There are a number of different HWTDs currently available, including AC, IER, sand filtration, UF, RO and nanoparticle disinfection (Fengyi et al., 2009; Varbanets et al., 2009). This leaves the consumer with a large variety of products available for over-the-counter purchase to choose from. Making informed decisions when purchasing units suitable for their specific needs thus become extremely difficult giving manufacturers and supplier the ideal situation to possibly use the information to their advantage when marketing home water treatment devices. The fact that sales people use home water testing regimes to their advantage is evidence of this and could be misused for the sale of HWTDs.

1.4 STUDY QUESTION

The study question that arose is if the claims made by manufacturers regarding the water treatment efficiency of the supplied home water treatment devices have been tested and is reported accurately. A need therefore existed for an independent study to evaluate a representative number of units sold in South Africa against the claims that are made in sales brochures.

1.5 STUDY AIMS

The overall aim of this study was to assess small home water treatment devices sold in South Africa for their capacity to provide safe drinking water for domestic, public and occupational use and to provide guidelines to enable consumers to make informed decisions when purchasing these units.

More specifically, the study aimed to evaluate the performance capacity of tap mounted and jug-type purification systems currently available in South Africa for domestic use, particularly with regard to their ability to remove microorganisms under a variety of running conditions as prescribed by the National Standards Foundation and to compare our findings with the claims made by the manufacturers of the products.

1.6 STUDY OBJECTIVES

The following specific study objectives were determined for the project:

1. Obtain information about home water treatment devices sold in South Africa.
2. Obtain information about the claimed purification capabilities of HWTDs to be tested.

3. Test the claims about the purification capabilities of home water treatment devices made by the manufacturers.
4. Compare the claimed results with laboratory based results obtained in the first three objectives.

An overview of how the objectives were organised approached during the study is shown in Figure 1.1. This figure includes the chapters that dealt with the objectives and should be read in conjunction with the figure in Appendix A that gives more details for the work process of each objective.

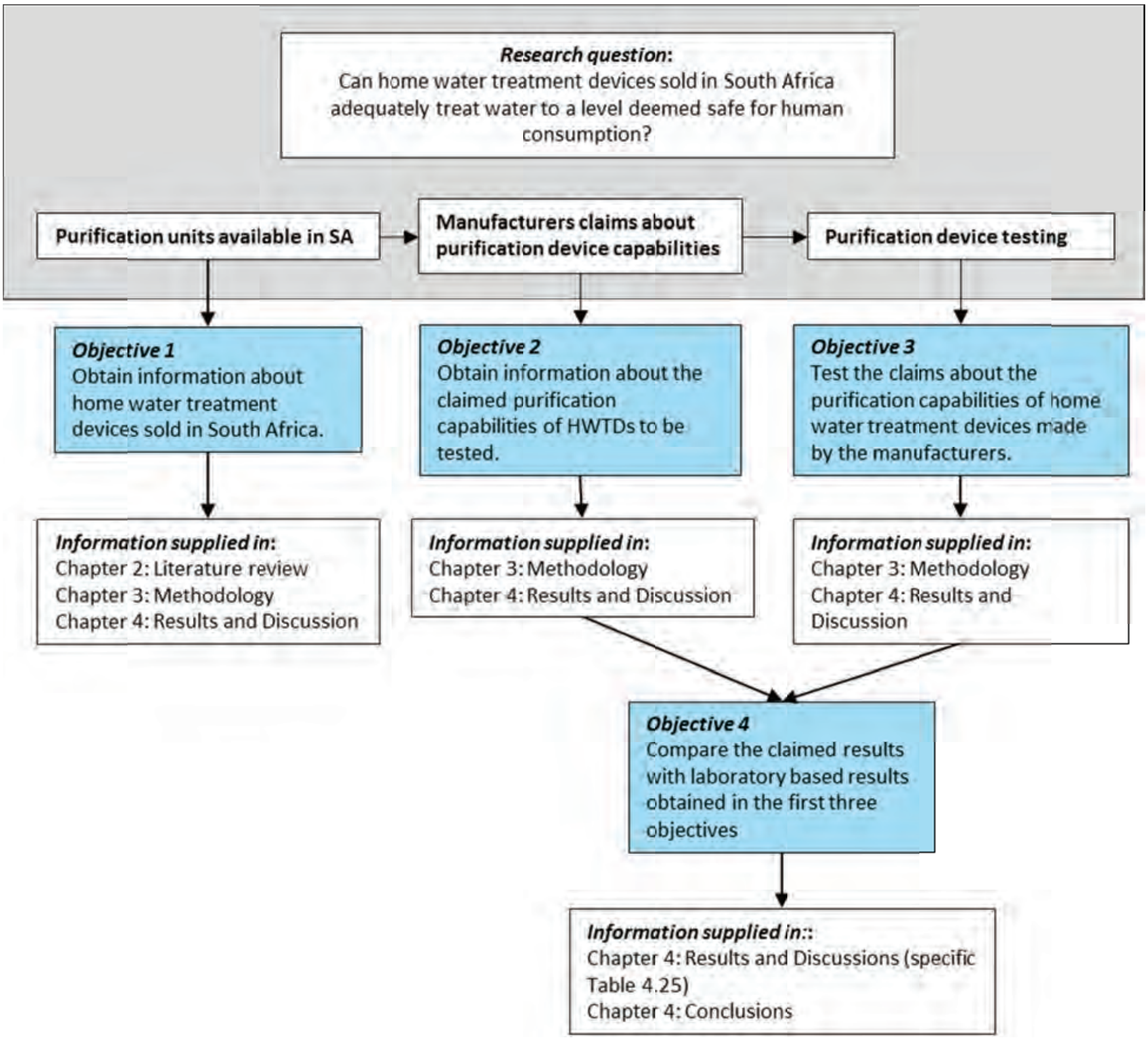

Figure 1.1 A flow diagram illustrating how the study was approached highlighting the four main objectives and the chapters that was used to deal with the specific objectives. Also see Appendix A for a more detailed version of flow diagram.

2. LITERATURE REVIEW

2.1 HOME WATER TREATMENT DEVICES AVAILABLE TO THE SOUTH AFRICAN MARKET

There are many different types of HWTDs combining various technologies currently available on the market in Southern Africa today. Most of these filtration devices have numerous advantages and disadvantages in terms of their ability to improve one's water quality. The main precursor to the application of decentralized technologies is to improve water quality of households, community leaders, local and national governments (Hunter *et al*., 2009). When the connection between water and waterborne disease is understood, the choice of solution depends on local customs, the availability of information and resources as well as the market and required scale (Varbanets *et al*., 2009). Some of the HWTDs currently available in Southern Africa are discussed below on the basis of their functioning technology and performance criteria.

2.1.1 Activated carbon filters

Activated carbon (AC) filtration is extensively used to produce potable water (Yepsakli and Çeçen, 2010). Activated carbon is used either as a powder (powdered activated carbon / PAC) or in a granular form (granular activated carbon / GAC (Delgado *et al*., 2012). These units are usually found in the form of pressed blocks, followed by UV disinfection or pre-coating with silver (Ag) pre-coating. They are generally used as table-top units for additional treatment of municipally supplied tap water. These systems, however, have a limited lifespan of approximately six months, which makes their running costs quite high (Varbanets *et al*., 2009). Most AC filters are tap-mounted and require a higher initial investment, but their running costs are low (Varbanets *et al*., 2009). They are easy to use, but do require regular maintenance. Overall these devices perform very well and produce a larger volume of filtered water than countertop filters (Varbanets *et al*., 2009). AC systems have received wide social acceptability (Filter Water, 2010).

Andersson *et al*. (2001) suggested that AC filters have been proven to effectively remove biodegradable organic carbon (BDOC), and so decrease the formation of undesirable chlorinated by-products and nitrification. In a study performed by Ahmedna *et al*. (2004), the use of carbon in drinking water filters was found to effectively remove metals, such as copper, lead and zinc.

However, in a study performed by Yoro *et al*. (2008), it was suggested that AC devices induce dissolved organic carbon (DOC) desorption into the water from the filter. In addition to this, it was suggested that bacterial utilization of the DOC resulted in severe microbial water contamination. In another study Lin *et al*. (2010), found that microbial degradation of pollutants occurs during AC filtration, and that bacterial colonisations cause the occurrence of biotic particles in water filters. These microorganisms were found to be resistant to chlorination disinfection and so, assumed potentially harmful (Kohnen *et al*., 2005). There have also been findings of increased microbial contamination within the water of home carbonation systems, and the gastrointestinal symptoms experienced by individuals utilizing these systems. Activated carbon filters have been reported to have poor removal efficiency of microbial contaminants (Bacteria and viruses) , calcium, magnesium, fluoride, nitrate, and many other compounds (Dvorak, 2008), and therefore often perform better in conjunction with other water filtration technologies. It is therefore suggested that these filters should only be considered as a pre-treatment device that can improve water taste and odour.

2.1.2 Ultra-Violet Sterilization

Ultraviolet (UV) irradiation has received renewed interest because of its well documented ability to extensively (99%) inactivate *Cryptosporidium parvum* oocysts and *Giardia lamblia* cysts, at relatively low doses (De Vet *et al.,* 2009). This being a remarkable discovery, UV lamp disinfection has some disadvantages at a household level (Bielefeldt *et al*., 2009). Studies by Varbanets *et al*. (2009), suggest that particles, turbidity and dissolved organic carbon (DOC) can interfere with, or reduce the efficiency, of microbial inactivation. This often affects their overall performance. A reliable and affordable source of electricity is required to power these UV lamps (SMI Analytical, 2009). Devices with UV lamps require periodic maintenance, especially in the case of submerged lamps; they have a finite lifespan and must be periodically replaced (SMI Analytical, 2009). The investment and running costs of UV-based systems are high and this impacts their environmental sustainability (Varbanets *et al*., 2009).

Laurent *et al*. (2007) found that UV lamp disinfection does not effectively remove Adenovirus which can cause respiratory illnesses and gastroenteritis. Laurent *et al*. (2007) also reported that UV sterilization does not effectively remove most chemical and other components from water. These include iron and manganese which gives water a metallic taste and odour, toxic heavy metal contaminates such as arsenic, as well as other organic substances and disinfection by-products. Even if UV lamp disinfection is considered to be a feasible technology for household water treatment, to date there are no epidemiological studies available describing field applications as well as its effects on human health.

2.1.3 Ion Exchange Resins

Ion exchange resins (IERs) are often used as pre-treatment in combination with other technologies, since they are a relatively inexpensive initial investment. These resins are also reusable due to current deionization methods available (Laurent, 2007). In studies performed by Varbanets *et al*. (2009), various ion exchange methods removed dissolved inorganics (minerals and metals) successfully. Heijman *et al*. (2009), however, reported that ion exchange did not remove particles, pyrogens or bacteria; and some ion exchange beds can become breeding grounds for potentially harmful bacteria. Ion exchange resins (IREs) are classified into four groups: strong-acid cation, weak-acid cation, strong-base anion and weak-base anion. The negatively charged cation exchange resins are used for calcium and magnesium removal, while the positively charged anion resins are less commonly used, and remove nitrate and other anions.

In accordance with studies performed by Heijman *et al*. (2009) IERs are often used as a softening pre-treatment, as they obtain almost complete calcium removal before ultrafiltration (UF) and nano filtration (NF). In recent studies reported by Batista, (2008) the successful removal of mercury and perchlorate from tap water has been achieved through the use of strong base resins. Newer technologies reported by Neumann (2009)\ suggest that the use of filter media based on ion exchange and adsorption resins, that use porous plastic beads, with diameters in the range of 0.3 to 1.2 mm, can remove a vast range of water contaminants.

2.1.4 Ceramic Filtration

The performance of ceramic filtration (CF) has been investigated over the years by an increasing number of researchers. Even though filters are manufactured in many countries, the Nicaraguan pot filters are most frequently investigated (Halem, 2006). Researchers have studied the water quality generated by these filters in both laboratory and field settings (Laurent, 2007). In general, the drinking water quality improvement by a treatment system is determined by the removal of pathogenic microorganisms, heavy metals, nitrogen, turbidity, colour and odour. In addition to this emerging organic micropollutants such as pesticides and pharmaceuticals are also indicators (Bielefeldt *et al.,* 2010; Halem *et al.,* 2009). In regions where CF are implemented the initial focus is to reduce the number of diarrhoeal cases; therefore the main function is to remove pathogenic microorganisms (Wegmann *et al.,* 2008). The removal efficiency of bacteria, protozoa and viruses is mainly tested using indicator organisms (Bielefeldt *et al.,* 2010).

One property of the ceramic silver-impregnated filter (CSF) is the addition of a colloidal silver layer (Wegmann *et al.,* 2008).The method of application and source of silver vary per manufacturing location. Commonly a solution of silver nitrate is brushed on the filters at most factories (Halem, 2006). Halem (2006) observed leaching of silver from the filter material at all the manufacturing locations sampled in that study. Previous research has shown that filters with this silver impregnation removed faecal coliforms and *Escherichia coli* (*E. coli*) K12 at a slightly better rate (Bielefeldt *et al.,* 2010; Halem *et al.,* 2009; Murphy *et al.,* 2009; Sobsey *et al.,* 2008). The colloidal silver is applied for assumed disinfecting purposes; however, some remarks have to be made on the sustainability of this application (Halem *et al.,* 2009). Ceramic silver-impregnated filters (CSFs) have shown a lifespan of over five years, but implementers recommend a life of one to two years (Bielefeldt *et al.,* 2010; Halem *et al.,* 2009). Either way, the leaching of silver will diminish after a few months of use, due to constant cleaning to prevent clogging and diminished flow rates (Varbanets *et al*., 2009).

Studies performed by Bielefeldt *et al.* (2010) and Halem *et al.* (2006; 2009) have measured the removal of viruses by ceramic filtration alone and with silver-impregnated pot filters, with little success. Since filters are made from ceramic material, their overall porosity varies considerably, and these filters are prone to cracking. This results in viruses, which are minute in size, passing through with ease. It is very likely that the initial observation was better removal of coliforms caused by contact with the silver in the receptacle (Murphy *et al.,* 2009; Sobsey *et al.,* 2008). The silver concentrations in the receptacle decrease in the course of the first week of filter runtime but this may not be assumed a sustainable disinfection step (Murphy *et al.,* 2009 and Sobsey *et al.,* 2008). In addition to this, Bielefeldt *et al,* (2010) and Halem *et al.* (2006; 2009) are sceptical about the improvement of CSFs by the addition of a colloidal silver layer based on the following: the removal of *E. coli* K12 was already found to be very high without the application of silver, the retention of sulphite reducing *Clostridium* spores was equally effective by filters with and without silver, and the retention of MS2 bacteriophages was observed to be better by filters without the silver application. This final observation suggests that additional research on the effect of silver and other potential additives, for the removal efficiency of viruses in ceramic filtration is in need. However, studies performed by Tsetsekou *et al.* (2008) and Wegmann *et al,* (2008), impregnating ceramic filters with hybrid hyperbranched polymers and colloidal zirconia, respectively have shown some success in absorbing viruses from water.

In general the effectiveness of ceramic filters may vary, due to different production methods and porosity (Halem, 2006) and user cross-contamination (Sobsey *et al.,* 2008). Also, the average flow rate of these filters is about 1-3 litres per hour, which is very slow and can decline with use and accumulation of impurities on the filters' element surface (Murphy *et al.,* 2009). Ceramic filtration, however, has been proven to remove turbidity, organic matter, and microbes. Once purchased there is no on-going cost except for the replacement of broken parts due to the fact that they require no source of energy (Varbanets *et al*., 2009). Overall it may be concluded that CFs can improve drinking water quality (Sobsey *et al.,* 2008).

2.1.5 Bio-Sand Filtration

A Bio-Sand Filter (BSF) proves to be as effective as traditional slow sand filters, in both laboratory and field tests (Varbanets *et al*., 2009). The filter has been tested by various government, research, and health institutions, as well as by non-governmental agencies (Laurent, 2007). They are relatively cheap to manufacture and produce, with low investment and running costs. This is a result of them functioning on gravity filtration (De Vet *et al.,* 2009). Bio sand filters have a high flow rate of approximately 36 litres per hour, and are easy to maintain. They occasionally clog up due to high turbidity, but can easily be unblocked (De Vet *et al.,* 2009). The only disadvantages are that they need to be continuously used in order to maintain the biofilm, and are relatively large in size (Sobsey *et al.,* 2008).

In recent studies performed by Varbanets *et al*. (2009) and Laurent (2007), BSF have shown to successfully remove bacteria consistently if not completely. Evincing a removal efficiency range of between 81-100%, BSFs also have a high removal percentage of protozoa (99-100%). The viral removal efficiency however, is limited. De Vet *et al.* (2009) reported an 85-99% removal of faecal coliforms, 100% of protozoa and helminths, 50-90% of organic and inorganic toxins, and most suspended sediments. Nemade *et al.* (2009) reported successful removal of iron, arsenic and coliform bacteria from contaminated water, with improved taste and less turbidity.

These filters are an appropriate, simple, and low cost technology for rural community water treatment in developing countries (Sobsey *et al.,* 2008). However, they are not recommended for individual households because of their relatively large size, and the need for proper construction and operation (especially sand scraping, replacement and cleaning) by trained individuals (Laurent, 2007). Such demands seem to be unrealistic, because they are beyond the capacities and capabilities of most households (Sobsey *et al.,* 2008).

2.1.6 Membrane Technology

Some membranes, and fibre filters (reverse osmosis, nano filtration, microfiltration and ultrafiltration) are able to proficiently remove parasites, bacteria and viruses (Laurent, 2007). In accordance with Laurent (2007), however, they require advanced production methods, filter holders, and the use of pressure to force the water through the filter media. In addition, Varbanets *et al*. (2009) reports that these filters are readily available, but their costs preclude them from widespread use to treat household water in many areas.

With regards to the production of safe drinking water, it is important to assess membrane technologies in relation to waterborne contaminants. In accordance with Pryor *et al.* (1998) the pore size of ultrafiltration (UF) membranes is small enough to ensure high log-removal of microbial hazards, such as *Cryptosporidium*, *Giardia* and total bacterial counts. Microfiltration (MF) is also claimed to have these properties, but some doubts have been reported by Wang *et al,* (2007) with the respect to bacterial retention by these membranes. Studies by Li *et al.* (2010) have reported that substantial virus removal can be attained with UF membranes, since the size of viruses range from 30-300 nm. Nano filtration (NF) and reverse osmosis (RO) can be used to remove inorganic contaminates from water (Polaczyk *et al.,* 2008). Polaczyk *et al.* (2008) reports that most NF membranes are effective in removing bivalent ions, but RO membranes are required for monovalent ions.

In comparison to conventional water treatment, the main advantage of membrane processes is that water can be treated at one stage without chemicals, while the treatment footprint is relatively small (Lenntech, 2010). The developments in membrane technology in the last decades have resulted in a significant decrease of membrane costs and energy requirements (Varbanets *et al*., 2009).

2.1.6.1 Reverse Osmosis

Reverse osmosis (RO) systems can be fitted to a single tap. They require high investment costs, and their running costs can be fairly high as they require maintenance annually and may require electricity (although most function on tap pressure). These units are easy to use and generally perform well. Studies performed by Varbanets *et al*. (2009) have shown that RO units can effectively remove all types of contaminants to some extent (particles, pyrogens, microorganisms, colloids and dissolved inorganics). However, they do not remove viruses, have slow flow rates, and require large volumes of water to produce filtered drinking water. In another study performed by Ahmed *et al*. (2008) the incorporation of novel biocidal polymers in RO systems was investigated to determine if bacterial growth rate was reduced on the membrane itself, reporting promising results. Reports by Pure SA (2010), suggest that RO systems are only required where the water source has a severe salt problem, and 90% of South Africa’s water does not have this problem since the water comes from municipal suppliers or chlorinated wells. Pure SA (2010) also report that RO systems are very costly and very dangerous since they do remove unwanted chlorine, lime and bacteria, but also filter out mineral and nutrient requirements the body needs, leaving the water “dead” in terms of nutritional benefits.

2.1.6.2 Nano filtration

Nano filtration (NF) is an inexpensive method when compared to conventional methods. Studies reported by Polaczyk *et al.* (2008) indicate that they effectively remove most particles, pyrogens, microorganisms, and colloids. These filters tend to soften water and produce the highest quality water for the least amount of energy investment. However, Polaczyk *et al.* (2008) also reports that they will not remove dissolved inorganic compounds. These filters require constant cleaning and replacement of cartridges, as they can become breeding grounds for bacteria. They only have a moderate retention for univalent salts and they require source water pre-treatment, to prevent clogging of membranes. They are also subject to scaling and fouling. Nevertheless, within a recent study performed by Li *et al,* (2010) results have shown that Nano alumina fibre filters have been successful in removing viruses from environmental waters. Newer technologies are currently being investigated by Senftle *et al.* (2007) where super magnetic nanoparticles in membranes have shown promising results in tap water purification.

2.1.6.3 Ultra Filtration

Ultrafiltration (UF) can produce the highest quality of water for the least amount of energy investment, as they are gravity fed (Laurent, 2007). They perform very well and in accordance with studies performed by Varbanets *et al*. (2009) they effectively remove most particles, pyrogens, microorganisms, viruses, and colloids. This technology is also cost effective as these membranes are re-generable. However, Varbanets *et al*. (2009) report that UF will not remove dissolved inorganics, and filters require constant replacement as they can become clogged and form breeding grounds for bacteria. Also, studies performed by Li *et al.* (2010) show that UF can effectively remove viruses, microorganisms, fine particles, and sediments from contaminated water sources as they have a relatively small membrane size. Polaczyk *et al.* (2008) reported that UF was successful in removing multiple microbe classes from various tap samples. Three low-pressure ultrafiltration membrane systems have been tested, in South Africa, for rural community water supply (Pryor *et al.,* 1998). Pryor *et al.* (1998) reported that they were tested on surface waters containing high levels of suspended matter, algae blooms and diffuse pollution with great success. With regret, the implementation of this technology was impractical due to high investment and operational costs.

2.1.6.4 Micro Filtration

Microfiltration (MF) requires minimal maintenance and is easy to use. Unfortunately, they have potentially high expandable costs for large scale use, and they are not generable (Laurent, 2007). Reports by Varbanets *et al*. (2009) suggest that these membrane filters can successfully remove all particles, viruses and microorganisms larger than the specified pore size. However, Varbanets *et al*. (2009), also reports that MF, will not remove dissolved inorganics, chemicals, pyrogens or all colloidal. Due to constant clogging, from the relatively small pore size, they can become a breeding ground for bacteria. In a recent study performed by Ahammed and Meera (2010) successful removal of bacteria and heavy metals from natural waters was reported with the use of metal oxide / hydroxide – coated dual media micro filtration systems. Although reports made by Wang *et al.* (2007) indicate that bacterial retention occurs within these filter systems and that they only partially remove some viruses.

2.2 FEED TYPES OF HOME WATER TREATMENT DEVICES

Point of use (POU) and point of entry (POE) devices are systems that typically treat water in batches and deliver water to a single tap, such as a kitchen sink faucet or an auxiliary faucet mounted next to the kitchen sink (NSF, 2009). Point of entry devices are used to treat of all of the water you use in your home. Point of use devices are often used as additional treatment after the use a POE system to further treat the water at a particular output such as a drinking water tap (Heiden, 2012). Several types of water treatment devices are available on the market today. The most common considerations when choosing a water filter are the capacity, type of capacity, water source, cost and type of filtration system used versus potential type of contaminant found within the local water supply (NSF, 2009). Three main styles of household POU filtration units: Tap countertop or under sink units.

2.2.1 Tap Filters (faucet mounted)

Tap filters, also called faucet mounted filters, are designed to screw onto a tap fitting. They generally use an AC or microporous filter that traps impurities as the water flows through the tap (Filter Water, 2010). They are inexpensive, portable, easy to install and can be used in any home. The only pitfalls are that they result in slow water flow, only one filter can be used per tap, and replacing these filters over time can get expensive (NSF, 2009).

2.2.2 Gravity Fed (countertop)

Countertop water filters sit on your kitchen counter by the sink. They are generally connected by a hose to your water tap. Most have a storage tank, and use both an AC filter and a reverse osmosis filter to remove up to 99.9% of the contaminants in tap water (NSF, 2009). Some countertop units even include a UV light source to disinfect water. The advantages of such units are that they are easy to install, inexpensive, can be used in any home and remove up to 99% of contaminants. Problems can arise due to their slow and limited capacity, as well as the amount of space they require (NSF, 2009).

2.2.3 Under the Sink

Under sink water filters are installed in line with household plumbing (NSF, 2009). Most use a combination of technologies including AC filtering, RO, and IER to filter water of impurities and to soften it. The advantage of this type of POU device is that it has a larger storage tank which is fitted under the sink (out of sight) therefore does not require countertop space and is easy to maintain (NSF, 2009). Some disadvantages of these devices are that they are more expensive than other types and may require professional installation.

2.3 HEALTH IMPACTS OF WATERBORNE PATHOGENS

Microorganisms that are found in water can potentially cause waterborne diseases. These waterborne diseases are transmitted through drinking water and pathogens can originate from leaking sewer lines or septic systems (Kaufman *et al*., 2011). Waterborne pathogens can pose a major health risk to humans (Abbaszadegan *et al.*, 1997). Microbial contaminants of particular concern include Adenovirus, Rotavirus, Hepatitis A, and Norovirus; enteric bacteria, such as the pathogenic strain of *Escherichia coli* O157:H7, *Salmonella*, *Campylobacter*, *Vibrio cholerae* and *Shigella* spp.; protozoan pathogens, such as *Cryptosporidium* and *Giardia* (and their environmentally resistant oocysts and cysts) (Bielefeldt *et al*, 2009, Deirgaardt *et al*., 2004; Huffman *et al*, 2000; Wegman *et al*., 2008).

2.3.1 Viruses

More than 140 different enteric viruses are known to infect man (Laurent, 2007). They are excreted in the faeces of infected individuals and may directly or indirectly contaminate drinking water (Wright *et al.,* 2006). Once in the environment, they can survive for long periods of time (Wright *et al.,* 2006). The enteric viruses include enteroviruses, rotaviruses, hepatitis A and E, Norwalk and Norwalk-like viruses, adenoviruses and reoviruses (Li *et al.,* 2010). They are transmitted by the faecal-oral route, infect the gastrointestinal or respiratory tracts, and are capable of causing a wide range of illness, including diarrhoea, fever, hepatitis, paralysis, meningitis, and heart disease (Wegmann *et al.,* 2008). Viral gastroenteritis occurs with two epidemiologic patterns, diarrhoea that is endemic in children; and diarrhoea outbreaks that affect people of all ages (CDC, 2009). Viral diarrhoea in children is caused by the group A rotaviruses, enteric adenoviruses, astroviruses and the human caliciviruses (predominantly Noroviruses) (CDC, 2009). The illness affects all children worldwide in the first few years of life, regardless of their level of hygiene, quality of water, food or sanitation or type of behaviour (Drinking Water Contamination, 2010).

2.3.1.1 Rotaviruses

Rotaviruses are the most common cause of severe diarrhoea in infants and children, the elderly, and immunocompromised (CDC, 2009; Ehlers *et al.,* 2005; Wegmann *et al.,* 2008). Symptoms are characterized by vomiting, watery diarrhoea for three to eight days; dehydration, fever and abdominal pain occur frequently (Waterborne Diseases, 2008). Although it occurs worldwide, the mortality rate is highest in developing countries, where up to 870 000 per year have been reported (CDC, 2009). Rotavirus is one of the major causes of viral gastroenteritis worldwide and several waterborne outbreaks have been documented in Southern Africa (Ehlers *et al.,* 2005).

2.3.2 Bacteria

Waterborne bacteria are pathogenic microorganisms which can cause diseases such as cholera, campylobacterosis, shigellosis and salmonellosis (Wright *et al*., 2006). Although most of the well-known pathogenic waterborne bacteria are relatively easy to detect and identify, newly emerging and re-emerging bacteria are continuously recognised. *Escherichia coli are* a subset of total and faecal coliforms that are normally found in human and animal intestines. These microorganisms are not only a cause of human disease, but are the most reliable indicators of contamination by faecal matter and other contaminants (Talon *et al*., 2005). *Escherichia coli* O157 can cause human disease (Jones, 1999). Clinical manifestations include symptomatic excretion, mild non-bloody diarrhoea and haemorrhagic colitis. Severe complications, such as haemolytic uremic syndrome (HUS) with acute renal failure sometimes resulting in death, can also occur. People of all ages may be affected, pregnant women and the elderly are at a higher risk of developing HUS (Bolton and Aird, 1998).

Most public water treatment plants use chlorine or other biocides to kill the traditional indicator organisms, but these methods of disinfection are not successful for all bacteria that may be present (Bielefeldt *et al*., 2009; De Vet *et al*., 2009).

2.3.3 Parasites

Waterborne protozoan parasites can be potentially harmful to humans (Hunter *et al.,* 2009). Commonly encountered parasites include the hard shelled cysts of *Giardia* and *Cryptosporidium*, both of which affect the intestines cause diarrhoea, nausea, and stomach cramping (Waterborne Diseases, 2008). They can be life threatening for those with low resistance (Drinking Water Contamination, 2010). They are not killed by chlorine and can pass through well-functioning water treatment and filtration systems (Bielefeldt *et al.,* 2010).

2.3.3.1 *Cryptosporidium parvum*

Cryptosporidium parvum is a leading cause of persistent diarrhoea in developing countries, and is the most highly infectious enteric pathogen (Exotox, 2010). This protozoan parasite is found in untreated surface waters, in swimming and wade pools, day-care centres, and hospitals (Water Sanitation, 2009). It is resistant to chlorine, small and difficult to filter, and ubiquitous in many animals (Bielefeldt *et al.,* 2010). Numerous water sources have been found to be infected with *Cryptosporidium parvum* (DMACC, 2008). Infection begins when a person ingests the chlorine-resistant, thick-walled oocysts (Exotox, 2010). Infection may occur with ingestion of as few as 30 oocysts (some have occurred with just one) (DMACC, 2008). Even if there is evidence that modes of transmission for *Cryptosporidium* other than drinking water exist, removal of cysts from the water is important (Water Sanitation, 2009). Due to the resistance of cysts to chlorination, their eradication from drinking water depends on adequate flocculation and filtration rather than chlorination (Bielefeldt *et al.,* 2010).

2.3.3.2 *Giardia lamblia*

Giardia lamblia is a protozoan parasite that infects numerous mammals (domestic and wild animals), including humans (Water Sanitation, 2009). In infected persons or animals *Giardia* is found in the lumen of the small and large intestine, thus making it an enteric parasite (Water Sanitation, 2009). Once in the host's intestinal tract, Giardia will produce a resistant, dormant, transmission form, which is referred to as a cyst (DMACC, 2008). Cysts are then excreted by the infected host (Kempster, 2003). The cyst is round to oval with dimensions ranging from 8-18 μm long by 5-15 μm wide (DMACC, 2008). It can survive for long periods outside the host, especially in cold water (Exotox, 2010). *G. lamblia* has a worldwide distribution and is the most common intestinal parasite of humans worldwide (Water Sanitation, 2009). The gathering of young children in day-care centres provides the ideal setting for the transmission of this parasite (DMACC, 2008). Bad hygiene is a major cause for this phenomenon and *G. lamblia* is transmitted in food and water (Exotox, 2010). Giardiasis is a major public health concern especially in developing countries, and waterborne outbreaks often occur (DMACC, 2008).

Filtration processes, including diatomaceous earth filtration, slow sand filtration, and coagulation-filtration, when applied appropriately can remove *Giardia* cysts at levels of 99% or more (Bielefeldt *et al.,* 2010). Chemical disinfectants such as free chlorine are known to inactivate them, when appropriate conditions of pH, temperature, disinfectant concentration and contact time are used (Bielefeldt *et al.,* 2010). A multiple-barrier approach to water treatment is the most prudent policy (De Vet *et al.,* 2009).

2.3.4 Particle Size Exclusion

Particles in water play an important role in all kinds of water quality and treatment issues (Verberk *et al*, 2009). Since the beginning of centralized water production and treatment, the main goal of water purification was primarily to remove water turbidity in order to produce clear water, free from visible particles (Lundquist *et al.*, 2011). Removal of particles from water is crucial for safe potable water production (Lundquist *et al.*, 2011). If particles are present in a water source, it is the primary issue of all purification techniques to eliminate or inactivate the particles (Verberk *et al*, 2009). Many contaminants are strongly associated with particles in water such as hygienic contaminants and adsorbed chemicals (Lundquist *et al*, 2011).

Various studies by Nieuwenhuijzen and Graaf (2010); Polaczyk *et al.* (2008) and Verberk *et al.* (2009), have been performed to gather knowledge on particle characterization, in order to understand the role of particles in water quality evaluation and water purification treatment processes. These particles include bacteria, viruses, protozoan cysts and many organic and inorganic substances (Verberk *et al*, 2009). Various removal treatment processes for such particles have been reported by Nieuwenhuijzen and Graaf, 2010 which could potentially exclude these particles according to their size, such as sedimentation, granular and membrane water treatment technologies (Varbanets *et al*, 2009).

Nieuwenhuijzen and Graaf (2010) and Polaczyk *et al.* (2008) have gone further to assess the exclusion capabilities of these water treatment technologies. However, since most of these water treatment technologies remove these contaminating particles by size exclusion and don't destroy or disinfect them; particles of similar sizes could be utilized to mimic microbes in water. This can assist in assessing water treatment technologies and their size exclusion capabilities without having to cultivate or grow these pathogens. Studies performed by Bielefeldt *et al.* (2010), Lin *et al.* (2010), Lundquist *et al.* (2011) Nieuwenhuijzen and Graaf, (2010) and Polaczyk *et al.* (2008) have gone as far as utilizing ISO standardized fine and coarse test dust particles, fluorescent labelled carboxylated-coated polystyrene microspheres or colloidal particles for size exclusion studies. These particles are similarly sized to water contaminating pathogens such as viruses, cysts and bacteria. These mimic particles are then spiked into water and passed through a water treatment technology. The exclusion capabilities of the technology are determined by either measuring the turbidity or using a particle counter which detects fluorescence. This is done to determine the concentration of particles before and after treatment (Verberk *et al.*, 2009). These studies have allowed the exclusion capabilities of many different water treatment technologies to be established (Lundquist *et al.*, 2011).

2.4 HEALTH IMPACTS OF CHEMICALS AND OTHER WATER CONSTITUENTS

Certain constituents found in water do not have a direct effect on health, but their presence or absence can be considered as a sign of the quality of water (Kohnen *et al.,* 2005). Indeed, aesthetic colour (iron-manganese), presence of deposits (turbidity) and organoleptic criteria (taste and odours) are the main, and often the only way consumers evaluate the quality of drinking water (de França Doria *et al*., 2009). Drinking water must be acceptable to consumers from the aesthetic and organoleptic point of view (APEC International, 2010). This acceptability relates indirectly to health, since the rejection of unacceptable water may lead consumers to use alternative water sources (de França Doria *et al*., 2009).

2.4.1 Chemical Contaminants

2.4.1.1 Minerals

Toxic minerals are harmful inorganic materials. That is, they do not originate from plant or animal matter, and they include metals as well as rock, sand, and clay matter (APEC International, 2010). Although not all are harmful to human health, some cause unpleasant effects when present in water. Calcium and magnesium add to water hardness, iron and manganese causes discolouration of water (Nemade *et al.,* 2009). Fluoride is a mixed blessing since there is much disputed as to whether it is beneficial or harmful to health (APEC International, 2010). Fluoride comes from multiple sources such as normal surface or ground water, industrial waste, water run-off from urban and agricultural areas, and from plumbing (APEC International, 2010; Devi *et al.,* 2008).

2.4.1.2 Heavy Metals and Trace Metals

There are a host of heavy metals that are harmful to human health. In particular, arsenic, mercury and lead are highly toxic (Ahammed and Meera, 2010).

2.4.1.2.1 Arsenic and Mercury

Arsenic may contaminate water systems via several routes and occurs worldwide (Devi *et al.,* 2008; Laurent, 2007). Arsenic enters into the environment through both natural processes as well as human activity (Smedley and Kinniburgh, 2002). Leaching from soil into groundwater systems is the most common factor contributing to dissolved arsenic (DeMarco *et al*., 2003). Long term exposure to arsenic in drinking water may cause skin damage, circulatory problems and cancer (Nemade *et al.,* 2009). Mercury contaminates various water sources through the erosion of natural deposits, discharge from refineries and factories and runoff from landfills and crop lands (Nemade *et al.,* 2009). Consuming excessive amounts of mercury can cause severe kidney damage (Ahmedna *et al.,* 2004).

2.4.1.2.2 *Lead*

Lead typically leaches into drinking water through the corrosion of household plumbing systems (Kim *et al*., 2011). Dominant sources include lead pipes, lead-based solder, brass fittings and plumbing fixtures (Lasheen *et al*., 2008). The major factor influencing lead leach into water passing through these plumbing systems is the corrosiveness of the water. Soft, acidic water is more corrosive to lead and iron than hard water (Lasheen *et al*., 2008). Lead may also enter water systems through the erosion of natural deposits in the environment (Deshommes *et al.,* 2010). Lead pipes and plumbing fittings have been banned since August 1998 (APEC International, 2010). This is due to the fact that lead is highly toxic and can be carcinogenic (Muhammed *et al*., 2011). Health effects may include headaches, irritability, abdominal pain, nerve damage, kidney damage, blood pressure, lung cancer, stomach cancer and gliomas (Steenland *et al*., 2000). Pregnant women, children and infants who consume water contaminated with lead are most susceptible to adverse health effects (Laurent, 2007). Infants and children present with delays in physical or mental development; deficits in attention span and learning abilities, whereas adults usually present with kidney problems and tend to suffer from high blood pressure (Laurent, 2007). Water contaminated by lead may be toxic, but SANS 241 has established a maximum contaminant level of ≤ 0.01 mg/L in municipally supplied water, as at this level there is no risk of health problems (SANS 241: 2006).

2.4.1.2.3 *Aluminium*

Aluminium is an abundant metal found in the Earth's crust (Pereira *et al.*, 2004). Aluminium enters into our soil and water as a result of the development of modern industry (Wang *et al*., 2010; Gerhard *et al*., 2002). Acid precipitation has led to a large amount of aluminium dissolving from the soil into our natural waters and so increasing the concentration in drinking water (Kim *et al.*, 2011). In addition to this, aluminium salts are used as coagulants in treatment processes for drinking water (Wang *et al*., 2010). Increased aluminium in water has been shown to cause high turbidity in drinking water (Kvech and Edwards, 2001). Low levels of aluminium (within acceptable standards) have not shown any acute health effects, but several studies of long term exposure have been published showing a connection to neurological disorders such as Alzheimer's disease (Verissimo and Ghomes. 2008; Campbell *et al*., 2004). The South African maximum contaminant level for aluminium is ≤ 0.3 mg/L (SANS 241: 2006) at which it does not pose any health risks.

2.4.1.2.4 *Manganese*

Manganese enters into water supplies through rock and soil erosion (Sarin *et al*., 2004). Manganese in drinking water is necessary for human health as it is an essential micronutrient (Herman, 1996; Kim *et al.*, 2011). It is however only required in small amounts. High concentrations found in drinking water (> 0.4 mg/L; WHO 1998) have been associated with aesthetic problems such as discolouration and an unpleasant metallic taste (Cerrato *et al*., 2010). At high concentrations manganese may also cause brownish-black precipitate and stains on clothes or household fixtures (Kim *et al.*, 2011; Muhammad *et al*, 2011). Although these effects may be observed by the general public, the concentration of manganese may be high but the water is still safe for consumption (Ferretti *et al.*, 2007 and Muhammad *et al.*, 2011). At excessive concentration though, Mn may cause human health effects such as a severe neurological disorder known as manganism, as well as Parkinson's disease (Caruso *et al*., 2011). The maximum permissible level for manganese at which there is no concern for health risks in South Africa for municipally treated water is ≤ 0.1 mg/L (SANS 241:2006).

2.4.1.2.5 *Chromium*

Chromium (Cr) is found abundantly in the Earth's crust and water (Azizullah *et al*., 2011). Chromium (III) is an essential trace element and important for human metabolism as it aids in the metabolism of carbohydrates (de Almeida Pereira *et al*., 2004). However, the toxic form Cr (VI) can cause carcinogenic effects in humans (Abdolmohammad-Zadeh and Sadeghi, 2012). Chromium (VI) is more toxic than Cr (III) due to its high water solubility and mobility. The most soluble and toxic forms include chromate and dichromate (Mohan and Pittman, 2006). Hexavalent chromium enters into our environment as a result of it being widely used for its anti-corrosive properties (Dalcin *et al*., 2010) It is used in many industries such as steel industries, metal work, textile industries (Barnhart, 1997) and so gains entrance into drinking water sources. Ingestion of Cr (VI) via any exposure route is hazardous (Mohan and Pittman, 2006). These compounds are easily absorbed by the digestive tract, lungs and skin (Baruthio, 1991). When chromium (VI) accumulates at high levels it can have major health implications including nausea, skin ulcerations and lung cancer. It has also been reported that when the concentration reaches 0.1 mg/g body weight, it can be lethal (Tziritis *et al*., 2012). South African standards established a maximum contaminant level (MCL) of ≤ 0.05 mg/L for chromium in drinking water, which does not pose any chronic health risks (SANS 241:2006).

2.4.1.2.6 Copper

Copper enters drinking water as a result of corrosion of copper pipes in household plumbing (Vargas *et al*., 2010). In addition, copper may also be found in mining areas (Chrosniak *et al.*, 2006; Vargas *et a*l., 2010). At low concentrations, copper may cause no health effects as the human body does require small amounts of this micronutrient (Vargas *et al.*, 2010). Ingestion of copper at greater concentrations and long-term exposure can lead to acute and chronic health effects. These include gastrointestinal diseases and liver damage (Dietrich *et al*., 2004). High concentrations may also cause aesthetic effects as it causes a bitter, metallic taste in water and result in blue-green stains on plumbing fixtures (Vargas *et a*l, 2010). South African regulations around the acceptable concentrations (Maximum contaminant level) for copper in drinking water have been established and implemented by SANS 241, the allowable concentration being ≤ 2 mg/L (SANS 241: 2006) at which it does not cause any health problems.

2.4.1.2.7 Iron

Iron can enter into drinking water via iron containing minerals that are dissolved by water percolating through rock and soil (Sarin *et al.*, 2004). Iron corroded from water distribution systems is the most common cause of water contamination. The presence of iron in drinking water is not harmful to human health (WHO: Guidelines for drinking water quality, 1996). It is however, undesirable, as it results in aesthetic problems. These include bad taste, odour, and staining of water (Vasudevan *et al*., 2009). In addition to aesthetic problems non-pathogenic bacteria feed off of iron in water and accumulation results in a reddish- brown slime in toilet tanks which can clog distribution systems and production of a bad odour(Sarin *et al.*, 2004). Municipally supplied tap water in South Africa allow a maximum contaminant level of ≤ 0.3 mg/L for iron, that is aesthetically pleasing is supplied to the South African public (SANS 241:2006).

2.4.1.2.8 Zinc

Zinc occurs both naturally in the environment (ore deposits) and may enter into the environment through anthropogenic influences (Chrosniak *et al*., 2005; Rice, 1999). Increased levels have also been associated with the use of fertilizers, manures, sewage-treatment plants, or emissions from power generation, which can contaminate water sources (Vargas *et a*l., 2010 and Lucentini *et al*., 2007). Zinc is an essential micronutrient found in the human body in many enzymes and proteins. Excess levels of zinc in drinking water can have adverse effects including damage to cells and elevated risk of Alzheimer’s disease (Cuajungco *et al*., 2000). In addition elevated levels of zinc have been shown to cause gastrointestinal effects in the elderly and sideroblastic anaemia (Lucentini *et al.*, 2007). Zinc may also have aesthetic effects on drinking water which include a bitter metallic taste and can affect the clarity of drinking water (Ahmedna *et al.*, 2004). In South Africa municipally supplied tap water must comply with an established maximum contaminant level for zinc of ≤ 5 mg/L to ensure safe drinking water that is aesthetically pleasing is supplied to the South African public (SANS 241: 2006).

2.4.2 Organic Matter and Chemicals

Natural organic matter (NOM) in the aquatic environment consists of a number of organic compounds that are derivative from the decomposition of plant and animal residues. Presence of NOM in water sources is of major concern to environmental scientists and engineers, specifically in water treatment. Natural organic matter can cause aesthetic problems in water by contributing to offensive taste and odour in drinking water. It may also act as a carrier for metals and various harmful organic chemicals (Joseph *et al*., 2012). Naturally occurring organic matter consists of dissolved organic carbons (DOC), or hydrophobic fractions; and hydrophilic fractions composed mostly of aliphatic carbon and nitrogenous compounds (Matilainen *et al*., 2010). Humic substances are the primary compounds making up the group of hydrophobic NOM (Matilainen *et al*., 2010). Humic substances account for more than half of the total organic carbon (TOC) compounds in water.

2.4.2.1 Volatile Organic Carbons

Volatile organic carbons (VOCs) belong to a class of chemicals that contain carbon. They are found in many commercial, industrial, and residential products. Volatile organic carbons that enter into the environment are usually a result of human activity, and once they soak into the ground they can enter into groundwater. Volatile organic carbons have potential health effects if they reach drinking water sources. They are carcinogens which may adversely affect the liver, kidneys, spleen, and stomach. They can also have effects on the nervous, circulatory, reproductive, immune, cardiovascular, and respiratory systems (Rowe *et al*., 2007).

2.4.2.2 Total Organic Carbon

Total Organic carbon is a measure of the total amount of organic matter in water, both DOC and particulate organic matter (POC). Both of these terms are used routinely to describe organic carbon in water (Ledesma *et al*., 2012). In natural waters, not polluted, TOC is mainly due to partially degraded animal and plant matter. On the other hand, in polluted waters TOC contamination can be due to solvents such as fertilizers, pesticides and surfactants (Visco *et al*., 2005). Total organic carbons are used as dependable indicators for organic pollution in water (Shi *et al*., 2010), even though it may not directly, negatively affect human health (Visco *et al*., 2005). These materials can often be associated with discolouration of drinking water as well as bad taste and odour. In addition to this they can also lead to the formation of harmful DPBs after reactions with disinfectants (Volk *et al*., 2002). Other problems associated with organic matter contamination include interference with removal of other contaminants, membrane fouling, contribution to corrosion and provision of a substrate for bacterial growth in the distribution system (Matilainen *et al*., 2010). Total organic carbon levels in South Africa are strictly monitored according to SANS 241: 2006 which have established a maximum contaminant level (MCL) of ≤ 10 mg/L for TOC (SANS 241: 2006).

2.4.2.3 Phenol

Phenols are generated in the preparation of many industrial products such as papers, metals, resins, plastics, and pharmaceuticals (Saitoh *et al*., 2011; Keith *et al*., 1979).These compounds may also be found in the wastewater of industries such as oil refineries, phenol production industries and dye manufacturing industries, to name a few (Chen *et al*., 2010; Adak *et al*., 2006). Environmental pollution by phenol may be due to agricultural runoff and domestic waste. Due to the fact that these compounds are highly soluble in water, they are likely to reach sources of drinking water downstream from their original discharge point (Adak *et al*., 2006). Because these substances are toxic, and they have the potential to accumulate in the environment, phenols in water have to be removed (Saitoh *et al*., 2011). Entrance into drinking water can cause aesthetic problems as well as health effects.

Addition of disinfectants into drinking water (e.g. chlorine) may alter the organoleptic characteristics of certain chemicals already present in the water. Chlorine reacts with organic matter to form disinfection by-products (DPBs). One of these by-products is halophenols, and this compound can impact on taste and odour of the water (Criittenden *et al*., 2012). Ingestion of phenol at high concentrations may have adverse health effects on humans. These include comas, convulsions, cyanosis and even death, when exposed to high concentrations (Busca *et al*., 2008). The South African National Standard (SANS 241) has established a maximum contaminant level for phenol at ≤ 0.01 mg/L within municipally supplied tap water (SANS 241: 2006).

2.4.3 Phosphates and Silicates as Corrosion Inhibitors

Phosphates and silicates are added to drinking water treatment as corrosion inhibitors of drinking water distribution systems (Batte *et al*., 2003; Rushing *et al*., 2003). Phosphates are usually added to prevent corrosion and the release of lead, copper and iron into circulating drinking water (Gouider *et al*., 2009). Silicate, on the other hand, is involved in the reduction of 'red-water' due to its ability to reduce iron corrosion and release into drinking water (Rushing *et al*., 2003).

Although phosphates can be used to reduce contamination by metals in drinking water, it has negative effects too. Addition of these compounds may result in proliferation of the biofilm since phosphorus can provide an additional nutrient for micro-organisms (Gouider *et al*., 2009). Previous research has suggested that addition of phosphates in high amounts may inhibit microbial growth by limiting the biofilm (Romprle *et al*., 1999; Batte *et al*., 2003). Studies have shown that water treated with low levels of phosphorous have increased microbial growth (Sathasivan *et al*., 1997; Batte *et al*., 2003). The growth of bacteria on these biofilms can enter into the drinking water causing adverse health effects. Although it is well known that an adequate phosphorus intake is needed for normal bone growth in children and maintenance of bones in adults (Pravst, 2011), animal studies have shown that high phosphate intake caused secondary hyperparathyroidism and bone loss (Pravst, 2011; and Calvo and Park., 1996). This being said, not many studies have been conducted with regards to effects of high calcium intake on bone density.

Silicon enters drinking water through weathering of rocks and from soil minerals (Jugdaohsingh, 2007). Although silicon is associated with normal bone health, ground silicate minerals that have eroded from acid granite and entered into drinking water can be toxic. Such contamination has been linked to inflammation of the kidneys (Jugdaohsingh, 2007; and Dobbie *et al*., 1986).

2.4.4 Additives and Disinfectants

2.4.4.1 Chlorine

One major additive is chlorine, which is used in most water treatment plants in South Africa (Hendry, 2009; Friedrich *et al*., 2009). Chlorination of public water supply effectively destroys or inactivates most pathogenic organisms and helps control microbial growth in the distribution system (Walsh *et al.*, 2008). Chlorine levels in municipal tap water is not toxic as SANS 241:2006 has established a maximum residual disinfectant level (MRDL) for chlorine (≤ 5 mg/L) and DBPs within municipally supplied tap water, to ensure safe drinking water that does not pose a chronic health risk is supplied to the South African public (SANS 241:2006). However, many consumers question their water quality in that chlorine gives water an unpleasant taste and odour and so turn to the use of HWTDs (McEncroe, 2007).

2.4.4.2 Fluoride

Fluoride occurs in trace quantities naturally in soil, water, plants, animals and humans. Human exposure to fluoride is mainly through drinking water and to a lesser extent from foods. Exposure to other sources of fluoride can come from industrial production of phosphatic fertilizers, which may contaminate drinking water (Mandinic *et al*., 2010). Fluoride is known to have both, beneficial and harmful effects on dental health. Fluoride is an essential element in small quantities for normal mineralization of bones and helps prevent dental caries by the formation of enamel (Maheshwari, 2006). Excess exposure to fluoride, on the other hand, can result in pathological changes (mottling of teeth and dental fluorosis) in bones and teeth (Singh *et al*., 2007). The level of fluoride in drinking water that is regarded as safe is 1.0 mg/L.

2.4.5 Disinfection By-products

Disinfection by-products form when disinfectants react with NOM and/or pollution originating from human activity (Hebert *et al*., 2010). Chlorine for instance can form the by-product chlorite which if ingested at high concentrations may cause harmful effects on the nervous system, especially in infants and young children, as well as in foetuses. There is also a high association of exposure to chlorinated drinking water and cancer. This is generally due to trihalomethane production (a chlorinated DBP) (Villaneuva *et al*., 2007).

2.5 PHYSICAL CONSTITUENTS / CHARACTERISTICS

2.5.1 Taste, Odour and Appearance

The flavour and odour of drinking water can be attributed to its chemical and microbial content, chemicals added or removed during treatment, and inputs and reactions that occur during distribution and storage (Dietrich, 2006). Taste and Odour compounds may be found in raw water and wastewater effluents of industrial, municipal or individual activities. These compounds can also be produced when molecules in raw water react with ozone or chlorine used as disinfectants during treatment processes (Proulx *et al*., 2012).

They may also enter drinking water through distribution networks via leaching of compounds from pipe and reservoir materials (Rella *et al*., 2002). Even though taste and odour compounds do not always represent health risks public perception of water quality is greatly influenced. In addition to this, if water is not aesthetically pleasing it can influence the behaviour and use of drinking water alternatives (Proulx *et al*., 2012).

2.5.2 Turbidity

Turbidity can be defined as the reduction in transparency of a liquid due to the presence of suspended matter. It usually consists of a mixture of organic matter (microorganisms) and inorganic matter (clay and soil) (Mwabi *et al*., 2011 and DWAF, 1996). Turbidity is an indicator of the degree of physical pollution of water, to be treated, or the quality of water delivered for human consumption. Turbidity is an effective parameter for the assessment of source water variations as well as filtration efficiency during conventional treatment of drinking water (Allen *et al*., 2008). Turbidity has no health effects; however, turbidity can interfere with disinfection and provide a medium for microbial growth (Laurent, 2007). This leads to the assumption that turbidity may indicate the presence of disease causing organisms. Studies conducted by Clark et al. (1992); LeChevallier and Norton, 1993 have shown a correlation between microbial contamination and turbidity of treated water. In South Africa municipally supplied tap water concentrations has an established maximum contaminant level (MCL) for turbidity of ≤ 1 NTU for aesthetic and ≤ 5 NTU for operational purposes (SANS 241: 2006).

2.5.3 pH

One of the most common analyses of soil and water testing is pH, and is the standard measure of how acidic or alkaline a solution is with values ranging from zero (most acidic) to 14.0 (most alkaline), with 7.0 being neutral (Addy *et al*., 2004). The pH value of water is the principal factor in determining its corrosiveness (Benham *et al*., 2011). The normal range for pH in drinking water is 6 to 8.5 and is mostly a result of natural geological conditions and types of minerals found in local rock (Bonte *et al.*, 2008). One of the most important factors affecting variations in the pH of water is the bedrock and soil composition through which it moves. Certain types of rock, for example limestone can, neutralize acids while others, for example granite, have virtually no effect on pH (Oram, 2013). Human activities such as dumping of chemicals into the water by individuals, industries, and communities can also have an effect on the pH of a body of water. Another contributing factor is acid rain which can lower the pH in environmental water sources making them more acidic (Addy *et al*., 2004). Changes in pH can affect water quality both directly and indirectly. Leaching of some metals and organic chemicals from pipes may be due to a low pH in soft water (USEPA, 2004). A high pH can also cause leaching from cement-lined pipes or tanks over a long exposure period (Kirmeyer *et al*., 2002). The nature of drinking water in terms of its acidity and alkalinity is measured by pH and therefore can be used as an indicator test for potential health effects on humans (Lucentini *et al.*, 2007). The South African National Standard 241 has established a maximum operational range for pH (5-9.7) within municipally supplied tap water in South Africa (SANS 241: 2006).

2.5.4 Total Dissolved Solids

Water flowing over soil or through river banks dissolves the minerals present in the strata of the soil (Ranganathan *et al.*, 2008). Total dissolved solids (TDS) are an indicator of the amount of these dissolved ions in water. Total dissolved solids in drinking water can also originate from natural sources such as sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process. The piping or hardware used to distribute drinking water can also contribute to TDS levels (Benham, 2011). The ions that contribute to TDS predominantly comprise of inorganic salts such as calcium, magnesium, potassium, sodium, carbonates, and chlorides and sulphates (Benham, 2011). Total dissolved solid is a measure of all compounds dissolved in water but is not a specific measurement of any one contaminant (Benham, 2011). Toxicity can be caused by total dissolved solids through increased in salinity, changes in the ionic composition of the water and toxicity of individual ions (Phyllis and Duffy, 2007). High levels of TDS in drinking water can cause aesthetic problems such as a bitter, salty or metallic taste as well as unpleasant odours. Individual minerals that make up TDS, such as nitrates, sodium, sulfates, cadmium, copper, and fluoride cam cause a variety of health risks. These include stiffness in the joints, hardening of the arteries, kidney stones, gall stones and blockages of arteries (Ebrahim *et al*., 2011). South African municipally supplied tap water concentrations have an established maximum contaminant level of ≤ 1200 mg/L for TDS (SANS 241: 2006).

2.5.5 Conductivity

Measuring conductivity of water can be of paramount importance in determining water quality as it can be used to detect environmental changes and pollution events (Ramos, 2006). It is monitored in order to detect ion-related abnormalities in terms of inorganic and organic waste contamination. This is in relation to anion and cation variations indicating the presence or absence of bases, acids, salts and main ionic contributors such as calcium, sodium, potassium, magnesium, ammonium, orthophosphate, chloride and sulphate (Bonte *et al.*, 2008). If the conductivity measured is in water is greater than two times sits hardness, this may indicate the presence of contaminants such as sodium, chloride, nitrate, or sulphate (Mechenich and Andrews, 2004). Increased conductivity in drinking water can cause aesthetic effects including a salty taste to the water. Adverse health effect include disturbance of salt and water balance in infants, heart patients, persons with high blood pressure, and renal disease (Memon *et al*., 2008). The maximum contaminant level of conductivity established for South Africa municipal water is ≤ 170 mS/m (SANS 241:2006).

2.5.6 Total Hardness

Hardness of water is due to the presence of cations such as calcium, magnesium; and in lower traces; aluminium, iron and other bivalent and trivalent cations .The main factors contributing to water hardness are calcium and magnesium (Malakootian et al., 2010). Water is described as either hard or soft, in accordance with NSF 44 the quality of water for it to be soft: 0-75 mg/L; moderate: 75-150 mg/L; hard: 150-300 mg/L; very hard: > 300 mg/L. Hard water contains high levels of calcium (Ca) or magnesium (Mg) and soft water contains less Ca and mg (Chiu et al., 2010). Water that moves through soil and rock dissolves small amounts of minerals. Calcium and magnesium ions found in groundwater originate from the dissolution of carbonate rocks (Anne, 2011). Water supplied afro drinking that has been abstracted from chalk aquifers results in hard drinking water which may increase the environmental impact of the households using the water (Godseeken et al., 201). Hard water may cause scale formation in hot water pipes, kitchen devices, water supply facilities, boilers, cooling towers (Malakootian et al., 2010). Although some literature suggests that there is no link between water hardness health effects (Sarin, 2004), several studies have indicated that there may be a link between water hardness and coronary heart disease (Anne, 2011). The maximum contaminant level established by SANS 241 for total hardness of municipally supplied drinking water is ≤ 150 mg/L (SANS 241: 2006).

3. STUDY METHODOLOGY

3.1 INTRODUCTION

The efficient testing of home water treatment technologies is becoming increasingly important with the increased sale of HWTD in South Africa. Ensuring that the consumers get devices that do not decrease the quality of the water is important, especially since people that use these technologies believe the tap water quality to be of a lower quality.

Testing and certification of HWTDs in the USA and Europe is mostly done by the NSF which is seen as the golden standard. In South Africa HWTDs are tested by the South African Bureau of Standards (SABS), these standards refer to and include the NSF standards. The decision was made to follow the NSF standards for the testing of the HWTDs selected in this study and great lengths were taken to implement and standardise these methods.

This section describes the study design and testing regimes implemented for use during this study.

3.2 STUDY DESIGN

3.2.1 Study Type

This was an exploratory, quantitative study that relied on a combination of descriptive surveys, analysis of documentary evidence, and analytical quantitative laboratory experiments (Appendix A).

3.2.2 Study Area

The overview of selected HWTDs currently available on the South African market, as well as the purchase of the selected HWTDs included in this study, were sourced from informal market retailers, direct marketers, and retail stores within the Pretoria and Johannesburg areas (Gauteng Province, South Africa).

3.2.3 Overview of Available Home Water Treatment Devices

Information about the types of HWTDs sold specifically in the Gauteng Province of South Africa was obtained using a combination of:

a) Visits to conventional retail stores in and around Pretoria and Johannesburg area that sell small-scale water purification devices.
b) Contacting sales representatives and market retailers directly selling small-scale purification devices to the general public within the Gauteng region.
c) Internet searches for small-scale purification devices that can be bought online.

Although the study area was defined as the Gauteng province of South Africa, information gathered from other provinces was also included within the results discussed in detail in the results section.

3.2.4 Home Water Treatment Device Selection Criteria

Within this study the testing of HWTDs was limited to those that claimed to improve or enhance treated water supplied by the local municipal water authorities. The HWTDs tested were divided into two groups, namely gravity fed (jug and counter top devices) and faucet mounted (plumbed in devices).

3.2.5 Overview of Selected Home Water Treatment Devices

The list of selected devices included in this study, along with their specific devices characteristics, is shown in the results section of this report. To ensure the anonymity of the HWTDs tested they are listed in alphabetical code as commercial names were not used. This was also done to protect the National Health Laboratory Services (NHLS), the Water and Health Research Centre (WHRC) at the University of Johannesburg, and the Water Research Commission (WRC) from any legal ramifications, responsibilities, endorsements or claims resulting from the outcome of the study.

3.2.6 Ethical Considerations

Ethical clearance for the project was obtained from the University of Johannesburg (UJ) Faculty of Health Science Academic Ethics Committee. Anonymity of the participants, products and manufacturers was ensured by keeping all details confidential. Each product was assigned a laboratory alphabetical code that was only accessible to the project team and the WRC project manager. All necessary measures were taken to ensure the trustworthiness and reliability of the results throughout the study. The Department of Water Affairs will be informed of the outcome and results obtained from this project via a WRC report. All manufacturers and suppliers will be invited to participate in individual results discussions to assist them with correcting any possible shortfalls with their products.

3.3 RESEARCH METHODOLOGY

3.3.1 Equipment and Materials

All chemicals and test kits used during this study were used without further purification or modification. A complete list of the chemicals, test kits, equipment, and consumables is shown in Appendix B.

3.3.2 Testing Methodology Overview

All experiments were performed using the laboratory and experimental set-up described in this section. The washing and challenging buffers were changed to correspond to the requirements for each test as described in the NSF standards (NSF P231, 42, 44 and 53).

3.3.2.1 Experimental Set-up

Laboratory physical apparatus set up, for the gravity fed and faucet mounted HWTDs, was conducted using the set up recommended by the NSF as outlined in Figure 3.1 and 3.2.

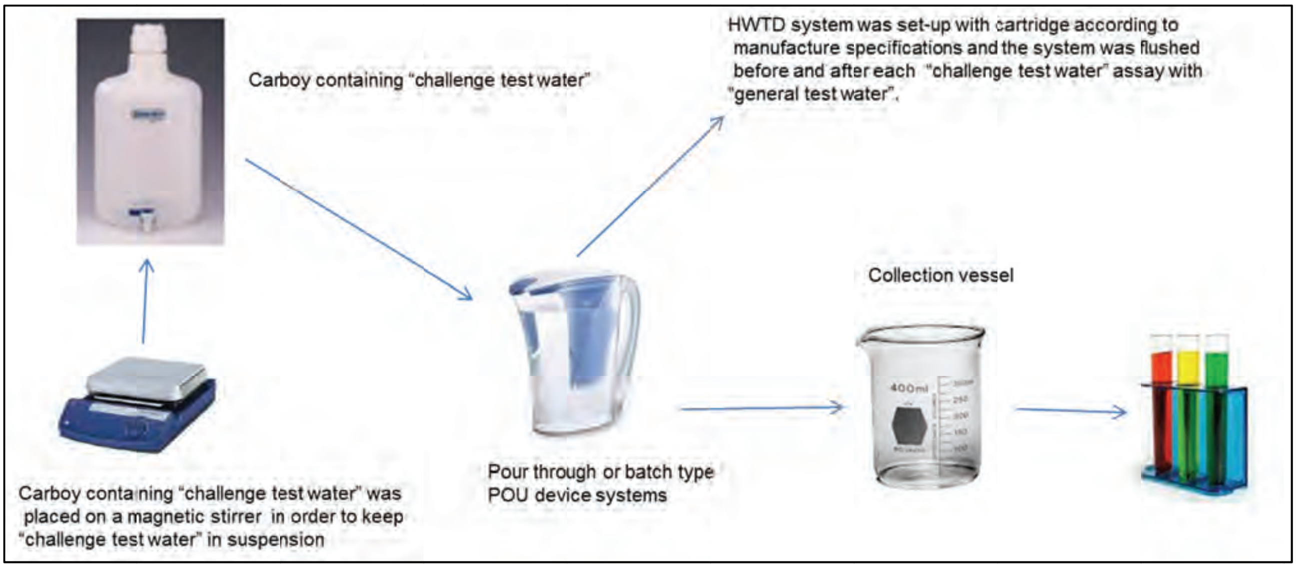

Figure 3.1 Typical experimental set up used for all the experiments performed with gravity fed HWTDs tested as part of this study.

Gravity fed devices (Figure 3.1) and faucet mounted devices (Figure 3.2) were tested differently using the recommendations by the NSF. Each HWTD was viewed as a biochemical column used for the separation of molecules, proteins, etc. Three replicates of HWTD were tested simultaneously for their exclusion capabilities in terms of their chemical, microbiological and physicochemical parameters (one HWTD replicate for each of the testing regimes). This means that for each HWTD the bed volume was determined to establish the volume of NSF recommended challenge test water to be added to the device, as well as the volume of recommended NSF general test water needed to wash (flush) the cartridge before and after a challenge.

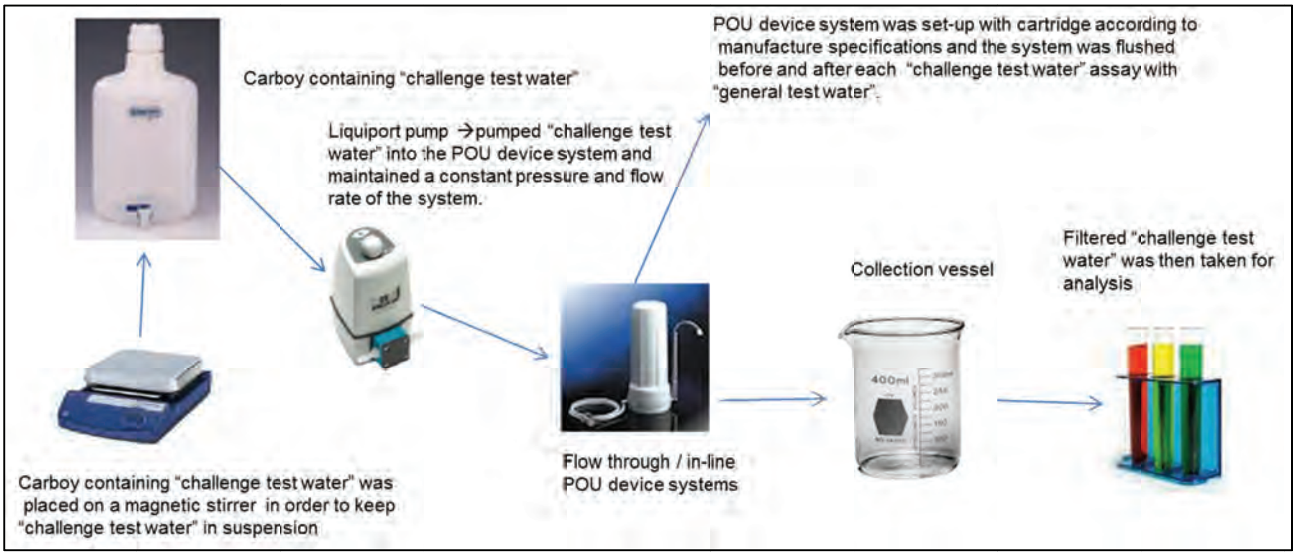

Figure 3.2 Typical experimental set up used for all the experiments performed with the faucet mounted HWTDs tested as part of this study.

Three holding units of each type or brand of HWTDs to be tested were purchased with three replacement filter cartridges. This was done in order to accommodate the anticipated testing regime following the protocol standards outlined in NSF 42, 44, 53 and NSF P231, which requires three of the same type / brand of unit to be tested simultaneously, for microbiological, chemical and physicochemical contaminants over a three day period.

3.3.2.2 Guidelines and Standards

The experiments to evaluate HWTDs were based on the established concepts as practiced by SANS and the NSF. The purchased HWTDs were tested using a combination of the SANS 1865:2006 (Point of use drinking water treatment units), SANS 241:2006 (Drinking Water Part 1: Microbiological, physical aesthetic and chemical determinants), NSF Protocol P231 (Microbiological Water Purifiers), NSF 42-2009 (Drinking Water Treatment Units – Aesthetic Effects), NSF 44-2009 (Residential Cation Exchange Water Softeners) and NSF 53-2009e (Drinking Water Treatment Units – Health Effects). A summary of the requirements and testing limits is given in Table 3.1.

The SANS 1865: 2006 and 241:2006 standards were purchased online from www.sabs.co.za/webstore/standards/product and the NSF Protocol P231 and NSF 42, 44 and 53-2009 standards were purchased online from www.techstreet.com. The South African National Standard 1865:2006 makes reference to SANS 241:2006 as well as NSF 42, 44 and 53. All gravity fed and faucet mounted devices were tested to deliver water quality comparable to the standards specified in SANS 241:2006 class I type water. None of these documents have been included in the report due to possible copyright infringements but can be purchased online.

In addition to testing the systems for deliverable water quality which should meet the required standards in SANS 241:2006, the individual systems were also tested in accordance with the removal claims made by their manufacturers. Attention was also given to ensure that all tests and experiments conformed to SANS 5667-2:1991 (Guidance on sampling techniques), SANS 5667-3:1991 (Guidance on the preservation and handling of water samples), SANS 5667-5:1991 (Guidance on sampling of drinking water from treatment works and piped distribution systems) guidelines and included the techniques as described in "Standard methods for water and waste water samples" (Eaton et al., 2005), also all controls were included to ensure the validity and reliability of the reported results.

3.3.2.3 Testing Methodology

Each HWTD device was assembled as per manufacturer's instructions and maintenance in terms of cleaning and cartridge preparation/activation was also done accordingly. The flow rate bed volume and pressure requirements were also determined in order for the system to operate optimally.

Contaminant removal challenge tests was performed with NSF recommended challenge test water spiked with either NSF / SANS 241:2006 recommended concentration of challenge contaminant in accordance with the manufacturers claims in terms of their HWTD removal capabilities. The starting concentration of spiked contaminant NSF/ SANS 241:2006 challenge test water was determined using the appropriate test before being run through the unit. After the spiked test water is run through the device, the sample was collected and the final contaminant concentration was determined using the appropriate tests, as described in the section below.

Table 3.1 Summary of the tests used in this study as well as SANS 241 and NSF standards and requirements

	SANS 241:2006 class 1 water		**NSF Standards in Regulation with FDA / EPA Standards**			
Determinant	**Units**	**Standard**	**Units**	**Spike (Influent Challenge) MCL (max contamination level)**	**Minimum Required Removal Efficiency**	**Standard Number and Page Reference**
Microbiological Determinants						
Bacterial: *Escherichia coli* (ATCC: 25922) or faecal coliforms	CFU count /100ml	Not detected (Acute Health)	CFU /100ml	1×10^6 CFU/100ml	99.99% reduction or Log 6 Mechanical Reduction: ≤0.5 µM	NSFP231 pg. 18-22 NSF 42 pg. 26
Cytopathogenic viruses: *Poliovirus 1 and Rotavirus*	count/ 10 L	Not detected (Acute Health)	count/L	1×10^7 /L	99.99% reduction or Log 4 Mechanical Reduction: ≤0.2 µM	NSFP231 pg. 22-31
Protozoan parasites: *Giardia muris / lamblia*	count/ 10 L	Not detected (Acute Health)	count/L	1×10^6 /L	99.99% reduction or Log 3 Mechanical Reduction: ≤ 4 -6 µM	NSFP231 pg. 22-31
Physical and Aesthetic Determinants						
Chlorine as Cl^- (free/residual)	mg/L	≤5 mg/L (Chronic Health)	mg/L	2.0 mg/L	≥1.0mg/L or ≥50% reduction	NSF42 pg. 34
Conductivity at 25°C	mS/m	≤170 mS/m (Aesthetic)	N/A	N/A	N/A	N/A
pH value at 25°C	pH units	≥5-≤9.7 (Operational)	pH units	High pH 11 Low pH 4	6.5-8.5	NSF 42 pg. 41
Turbidity Reduction	NTU	≤1 (Operation) ≤5 (Aesthetic)	NTU	11 NTU	≥0.5 NTU or 95% reduction	NSF 53 pg. 51
Mechanical Reduction	NTU	≤1 (Operational Turbidity)	particles/ ml or µM	10000 particles/ml (ISO Course and Fine Test Dust Particle Size Range: 0-80 µM)	85% reduction or 12 µM	NSF53 pg. 25 NSF42 pg. 23-45
Total Dissolved Solids as TDS	mg/L	≤1200 mg/L (Aesthetic)	mg/L	1500 mg/L	500 mg/L or 67% reduction	NSF 42 pg. 29
Chemical Determinants (Macro-determinants)						
Inorganic Removal: Fluoride as F^-	mg/L	≤1.5 (Chronic Health)	mg/L	8.0 mg/L	1.5 mg/L or 81% reduction	NSF53 pg. 32
Zinc as Zn	mg/L	≤5 (Aesthetic)	mg/L	10 mg/L	5.0 mg/L or 50% reduction	NSF42 pg. 43

Table 3.1 Summary of the tests used in this study as well as SANS 241 and NSF standards and requirements

	SANS 241:2006 class 1 water		**NSF Standards in Regulation with FDA / EPA Standards**			
Determinant	**Units**	**Standard**	**Units**	**Spike (Influent Challenge) MCL (max contamination level)**	**Minimum Required Removal Efficiency**	**Standard Number and Page Reference**
Copper as Cu	µg/L	≤2000 or 2 mg/L (Chronic Health)	mg/L	3 mg/L	1.3 mg/L or 57% reduction	NSF53 pg. 63
Iron as Fe	µg/L	≤300 or 0.3 mg/L (Aesthetic) and ≤2 mg/L (Chronic Health)	mg/L	3 mg/L	0.3 mg/L or 90% reduction	NSF42 pg. 39
Heavy Metal Removal: Lead as Pb	µg/L	≤10 or 0.01 mg/L (Chronic Health)	mg/L	0.15 mg/L	0.01 mg/L or 93% reduction	NSF53 pg. 66
Aluminium as Al	µg/L	≤300 or 0.3 mg/L (Operational)	mg/L	0.5 mg/L	0.2 mg/L or 60% reduction	NSF42 pg. 9 or NSF 53 pg. 10
Total Chromium as Chromate	µg/L	≤50 or 0.05 mg/L (Chronic Health)	mg/L	0.3 mg/L	0.1 mg/L or 67% reduction	NSF 53 pg. 63
Manganese as Mn	µg/L	≤100 or 0.1 mg/L (Aesthetic) or ≤0.5 mg/L (Chronic Health)	mg/L	1 mg /L	0.05 mg/L or 95% reduction	NSF42 pg. 38
Organic Chemical Determinants						
Total Organic Carbon as carbon (TOC)	mg/L	≤10 mg/L (Chronic Health)	mg/L	15 mg/L (not NSF approved, but SANS approved)	≤10 mg/L (Chronic Health)	N/A
Taste and Odour: Phenol	µg/L	≤10 or 0.01 mg/L (Aesthetic)	mg/L	mg/L	0.25 mg/L or 95% reduction	NSF42 pg. 37
Additional Tests in Accordance with NSF (not SANS 241 Related)						
Scale Removal: Phosphates and Silicates	N/A	N/A	mg/L	10 mg/ml (Phosphate) 16 mg/ml (Silicate)	0.5 mg/L to 10 mg/ ml (Phosphate) 0.5 mg/L to 16 mg/ ml (Silicate) (range according to manufacture specifications)	NSF42 pg. 47
Total Hardness: Alkalinity and Calcium as $CaCO_3$	mg/L	≤150 (Aesthetic)	mg/L	342 mg/L	Soft: 0 to75 mg/L Moderate: 75 to 150 mg/L Hard: 150 to 300 mg/L Very Hard: Above 300 mg/L (range according to manufacture instructions)	NSF44 pg. 21

The data were used to determine the percentage reductions per contaminant and so determine the HWTDs removal capabilities. After each challenge the HWTDs was flushed three times with the pre-determined bed volume (general test water) as recommended by the NSF. This was done to ensure that contaminants not captured by the device were removed from the device. After flushing the HWTDs the next contaminant reduction challenge test was performed. Experiments were repeated over a three day period for each HWTD, and for each individual test to obtain three separate data sets (24hrs, 48hrs and 72hrs after device calibration; Figure 3.3). Detailed explanations of these individual tests are given below. All relevant controls were included in all the assays to ensure the validity and reliability of the results.

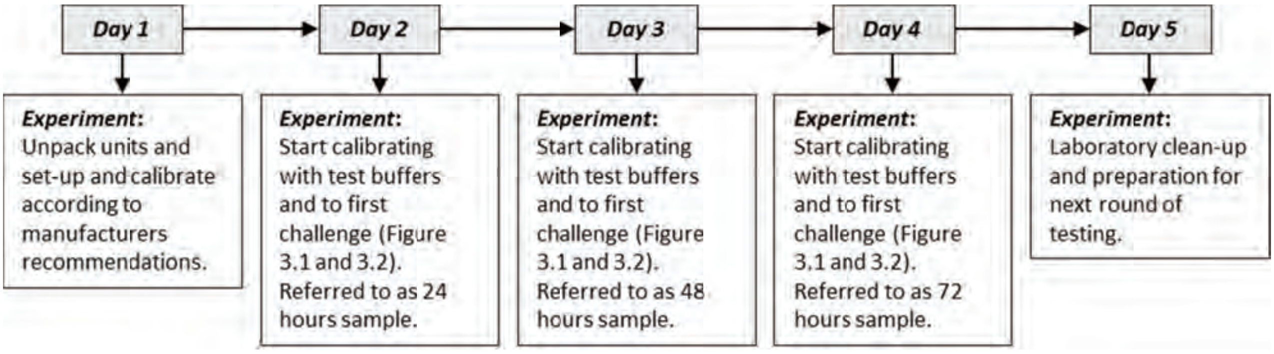

Figure 3.3 Outline of the typical weekly procedure used to test the home water treatment devices for each test.

3.3.3 Microbiological Testing

The microbiological determinant tests were performed in accordance with NSF P231 Microbiological Protocol, NSF 53 (Health Effects) and SANS 241:2006 in terms of POU small-scale purification device minimum performance requirement criteria.

3.3.3.1 Bacterial Culture Removal Efficiency Analysis

An overnight culture of (*E. coli*) ATTC: 25922 grown at 37°C in nutrient broth to obtain the organism in the stationery growth phase. The optical density of the broth culture was determined using the Merck UV Vis Spectrophotometer Pharo 300 Spectroquant spectrophotometer in order to determine the number of colony forming units (CFU) per 100ml of solution / most probable number (MPN). This was then compared to a previously determined standard growth curve of analysis performed on the organism following the techniques described in Standards Methods for the Examination of Water and Wastewater (APHA et al., 1985). The bacterial cells were collected by centrifugation and washed three times in Phosphate Buffered Saline pH 7.4 (Sigma: P5368-10PAK) before use. The suspensions were filtered through sterile Whatman Number 2 filter paper (Sigma: Z240222-1PAK) to remove any bacterial clumps. New batches of organisms were prepared daily for use in challenge testing. The numbers of organisms suspended in phosphate buffered saline were approximately 1×106 CFU/100ml (NSF P231 and 42 recommendations) and were inoculated into NSF recommended challenge test water. The HWTDs were challenged using the methodology described above. After the challenge the sample water was collected from the HWTD and the final contaminant concentration was determined. This was determined using the membrane filtration technique on Brilliance *E. coli*/Coliform Agar (Quantum Biotechnologies: CM0956B), following the techniques described in Standards Methods for the Examination of Water and Wastewater (APHA *et al*., 1985). Each sample dilution was assayed in triplicate. This data was used to determine percentage reductions per contaminant and so determine the HWTD removal capabilities of bacteria, which in accordance with NSF P231 and 42; the minimum reduction requirement is 99.99%.

3.3.3.2 Bacterial, Viral and Protozoan Parasites / Cyst Mechanical Reduction Particulate Size Exclusion Assays

These tests were performed in terms of mechanical reduction claims which indicate the possible additional tests adapted from the NSF standards 42 and NSF P231 for the testing of HWTDs if the manufacturer proclaims the device removes microbial pathogens such as bacteria, cytopathogenic viruses or protozoan parasites, by size exclusion. If the manufacturer claimed their device disinfected or destroyed microbial pathogens these tests were not performed and so the HWTD could not be validated in terms of its disinfection capabilities, however the HWTD could be validated in terms of its size exclusion capabilities. In brief relation to this particular assay the NSF recommended challenge test water was spiked with a 10000 particles/ml of ISO 121103-1 Fine and Coarse Test Dust. These were purchased from Powder Technologies Incorporated (PTI), and have a particle size range from 0-80 µM. Home water treatment devices were challenged using the test water in the methodology described above. After the challenge the sample test water was collected from the HWTD and the final contaminant concentration of particles/ml was determined with reference to a technical data sheet obtained from Powder Technologies Incorporated (PTI). National sanitation standards: standard 42 and 53, allowed for the size exclusion capabilities of the HWTD to be determined in terms of a particulate removal size reported in µM. The particulate removal size of the HWTD was then related to the approximated particle size of microbial pathogens and so the ability of the HWTD to remove these pathogens in terms of size was then determined. In accordance with NSF standards bacterial mechanical reduction range is ≤ 0.5 µM, cytopathogenic viruses: Poliovirus 1 and Rotavirus mechanical reduction range is ≤ 0.2 µM and protozoan parasites: *Giardia muris* / *lamblia* mechanical reduction range is ≤ 4 -6 µM.

3.3.4 Physicochemical Determinant (physical and aesthetic) Tests

The physicochemical determinant (physical and aesthetic) tests were done in accordance with NSF 42 (Aesthetic Effects), NSF 53 (Health Effects) and SANS 241:2006 in terms of the HWTD requirement criteria set out in the standards.

3.3.4.1 Free Chlorine as Cl^-

The NSF recommended challenge test water to be spiked with 2 mg/L Dichloroisocyanuric Acid Sodium Salt Dihydrate GR for Analysis (Merck: 1.10888.0100) (measured with Chlorine Test 0.01-6 mg/L Cl2 Spectroquant 1200 Tests Merck: 1.00598.0001 on the Merck Pharo 300 Spectroquant) was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration in mg/L was determined. In accordance with NSF 42 the minimum reduction requirement of Chlorine by HWTDs should be 1 mg/L or 50% reduction.

3.3.4.2 Conductivity at 25°C

Municipal tap water of a known conductivity measured with a Hanna Comb pH/EC/TDS/Temp Tester Model HI198129 probe was challenged through the HWTDs devices using the methodology described above. After the challenge the sample challenge water was collected from the HWTDs and the final concentration was determined in mS/m. In accordance with SANS 241:2006 the minimum reduction requirement of conductivity in municipal tap water is ≤ 170 mS/m.

3.3.4.3 pH Value at 25°C

The NSF recommended challenge test water to be spiked with either a high pH of 11 or a low pH of 4 (measured with a Hanna Comb pH/EC/TDS/Temp Tester Model HI198129 probe) and challenged through the HWTDs. Using the methodology described above, pH adjustments were made using either Sodium Hydroxide Pellets (Sigma: S8045-500 g) or 37% Hydrochloric Acid (Sigma: 320331-500 ml). After the challenge the sample test water was collected from the HWTDs and the final pH value was determined. In accordance with NSF 42 the minimum reduction requirement of pH by HWTDs should range from a pH value of 6.5-8.5.

3.3.4.4 Turbidity Removal

The NSF recommended challenge test water spiked with 11NTU ISO 121103-1 Fine Test Dust purchased from Powder Technologies Incorporated (PTI) (measured with Oakton Instruments T-100 Turbidity Meter) to be challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final concentration in NTU was determined. In accordance with NSF 53 the minimum reduction requirement of turbidity by HWTDs should be ≤ 0.5 NTU or 95% reduction.

3.3.4.5 Mechanical Reduction Particulate Size Exclusion Assays

The NSF recommended challenge test water to be spiked with 10000 particles/ml of ISO 121103-1 Fine and Course Test Dust purchased from Powder Technologies Incorporated (PTI), which has a particle size range from 0-80 µM. Home water treatment devices were challenged with test water using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration was determined in particles/ml and referred to technical data sheets obtained from Powder Technologies Incorporated (PTI) and NSF standard 42 and 53. This allowed for the size exclusion capabilities of the HWTDs to be determined in terms of a particulate reduction size reported in µM. In accordance with NSF 42 and 53 the minimum reduction requirement of particulate reduction / mechanical reduction of HWTDs should be ≤ 12 µM or 85% reduction.

3.3.4.6 Total Dissolved Solids (TDS)

The NSF recommended challenge test water spiked with 1500 mg/L Sea Salts (Sigma: S9883-1Kg) (measured with a Hanna Comb pH/EC/TDS/Temp Tester Model HI198129 probe) to be challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final concentration of TDS in mg/L was determined. In accordance with NSF 42 the minimum reduction requirement of TDS by HWTD should be 500 mg/L or 67% reduction.

3.3.5 Chemical Determinant Tests

The chemical determinant (macro-, micro-, organic and NSF additional) tests were done in accordance with NSF 42 (Aesthetic Effects), NSF 53 (Health Effects) and SANS 241:2006. All chemical determinant assays were performed on the Merck UV Vis Spectrophotometer Pharo 300 Spectroquant spectrophotometer, with the use of the Merck Thermoreacter TR620 Spectroquant. The Merck UV Vis Spectrophotometer Pharo 300 Spectroquant spectrophotometer combines the advantage of a system photometer with those of a spectrophotometer, which allows chemical water test kits to be optimally adapted to the instrument with EPA analytical quality assurance standards of result reporting. All quality assurance checks and calibrations were performed on this machine on a weekly basis. The specific methodical approach relating to each assay protocol has been fully described within Merck Pharo 300 Spectroquant Methods (2012).

3.3.5.1 Fluoride as F^-

The NSF recommended challenge test water to be spiked with 8 mg/L Fluoride Standard Solution (Merck: 1.19814.0500) (measured with Fluoride Test 0.10-20.0 mg/L Spectroquant 250 Tests Merck: 1.14598.0002) was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration in mg/L was measured. In accordance with NSF 53 the minimum reduction requirement of Fluoride by HWTDs should be 1.5 mg/L or 81% reduction.

3.3.5.2 Zinc as Zn

The NSF recommended a Zinc spike of 10 mg/L added to the challenge test water. Zinc Standard Solution (Merck: 1.19806.0100) (measured with Zinc Cell Test 0.2-5 mg/L Zn Spectroquant 25 Tests Merck: 1.14566.0001) was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration was determined in mg/L. In accordance with NSF 42 the minimum reduction requirement of Zinc by HWTD should be 5 mg/L or 50% reduction.

3.3.5.3 Copper as Cu

The NSF recommended challenge test water to be spiked with 3 mg/L Copper Standard Solution (Merck: 1.19786.0100) (measured with Copper Test 0.2-6 mg/L Cu Spectroquant 250 Tests Merck: 1.14767.0001) and challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration in mg/L was measured. In accordance with NSF 53 the minimum reduction requirement of Copper by HWTD should be 1.3 mg/L or 57% reduction.

3.3.5.4 Iron as Fe

The NSF recommended an iron spike of 3 mg/L for the challenge teat water Iron Standard Solution (Merck: 1.19781.0100) (measured with Iron Test 0.005-5 mg/L Fe Spectroquant 1000 Tests Merck: 1.14761.0001) which was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration in mg/L was determined. In accordance with NSF 42 the minimum reduction requirement of Iron by HWTDs should be 0.3 mg/L or 90% reduction.

3.3.5.5 Lead as Pb

The NSF recommended challenge test water to be spiked with 0.15 mg/L Lead Standard Solution (Merck: 1.19776.0100) (measured with Lead Test 0.010-5 mg/L Pb Spectroquant 50 Tests Merck: 1.09717.0001) and challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration was measured in mg/L. In accordance with NSF 53 the minimum reduction requirement of Lead by HWTD should be 0.01 mg/L or 93% reduction.

3.3.5.6 Aluminium as Al

The NSF recommended challenge test water to be spiked with 0.5 mg/L Aluminium Standard Solution (Merck: 1.19770.0100) (measured with Aluminium Test 0.02-1.2 mg/L Spectroquant 350 Tests Merck: 1.14825.0001) and challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration in mg/L was determined. In accordance with NSF42 and 53 the minimum reduction requirement of Aluminium by HWTDs should be 0.2 mg/L or 60% reduction.

3.3.5.7 Total Chromium as Chromate

The NSF recommended a chromium spike of 0.3mg/L to be added to the challenge test water. Chromate Standard Solution (Merck: 1.19780.0500) (measured with Chromate Test 0.02-6.69 mg/L CrO_4 Spectroquant 250 Tests Merck: 1.14758.0001) was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contamination concentration was measured in mg/L. In accordance with NSF 53 the minimum reduction requirement of Chromate by HWTDs should be 0.1 mg/L or 67% reduction.

3.3.5.8 Manganese as Mn

The NSF recommended challenge test water to be spiked with 1 mg/L Manganese Standard Solution (Merck: 1.19789.0100) (measured with Manganese Test 0.05-2 mg/L Spectroquant 250 Tests Merck: 1.01739.0001) was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration in mg/L was determined. In accordance with NSF 42 the minimum reduction requirement of Manganese by HWTDs should be 0.05 mg/L or 95% reduction.

3.3.5.9 Total Organic Carbon (TOC) as C

Distilled water spiked with 15mg/L TOC Standard Solution ACC (Merck: 109017.01) (measured with TOC Cell Test 5-80 mg/L Spectroquant 25 Tests Merck: 1.14878.0001) was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration was measured in mg/L. In accordance with SANS 241:2006 the minimum reduction requirement of TOC from municipal tap water is ≤ 10 mg/L (Chronic Health).

3.3.5.10 Phenol

The NSF recommended challenge test water to be spiked with 5 mg/L Phenol GR for Analysis (Merck: 1.00206.0250) (measured with Phenol Test 0.002-5 mg/L Spectroquant 50 Tests Merck: 1.00856.0001) and challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration in mg/L was determined. In accordance with NSF 42 the minimum reduction requirement of Phenol by HWTDs should be 0.25 mg/L or 42% reduction.

3.3.6 Additional Tests in Accordance with NSF (not SANS241:2006 related)

3.3.6.1 Removal of Phosphates

The NSF recommended a spike of 10mg/L to be added to the challenge test water. Phosphate Standard Solution (Merck: 1.19898.0500) (measured with Phosphate Test 0.01-5 mg/L PO_4 Spectroquant 420 Tests Merck: 1.14848.0001) was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration was measured in mg/L. In accordance with NSF 42 the minimum reduction requirement of Phosphate by HWTDs should be 0.5-10 mg/L or in accordance with manufacturers specifications.

3.3.6.2 Removal of Silicates

The NSF recommended challenge test water to be spiked with 16 mg/L Silicon Standard Solution (Merck: 1.70236.0100) (measured with Silicate (Silic Acid) Test 0.005-5 mg/L Si/SiO_2 Spectroquant 300 Tests Merck: 1.14794.0001) and challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration in mg/L was determined. In accordance with NSF 42 the minimum reduction requirement of Silicate by HWTDs should be 0.5-16 mg/L or in accordance with manufacturers specifications.

3.3.6.3 Alkalinity and Calcium as $CaCO_3$ (Total Hardness)

The NSF recommended a spike of 342mg/L to be added to the challenge test water. Calcium Carbonate (Sigma: 481807-25 g) (measured with Total Hardness Cell Test 5-215 mg/L $CaCO_3$ Spectroquant 25 Tests Merck: 1.00961.0001) was challenged through the HWTDs using the methodology described above. After the challenge the sample test water was collected from the HWTDs and the final contaminant concentration was measured in mg/L. In accordance with NSF 44 the minimum reduction requirement of Calcium Carbonate by HWTDs should to be classified as soft (0 to 75 mg/L), moderate (75 to 150 mg/L), hard (150 to 300 mg/L) and very hard (above 300 mg/L; ranges according to manufacture instructions) and with SANS 241:2006 should be ≤ 150 mg/L.

3.3.7 Data Comparison and Statistical Analysis

All the information obtained the laboratory testing was compiled into a Microsoft Excel spread sheet and the data was used to determine the removal efficiency of each contaminant. Laboratory data was then compared to the documentary data acquired from manufacturer claims in relation to their HWTDs, which was tested and the results reported. Statistical analyses were performed using Sigma Plot Version 12.01 software. The data were converted and reported as percentage reductions per contaminant. The data was also compared to SANS 241:2006 and NSF P231, 42, 44 and 53 standards to evaluate the tested HWTDs removal efficiency in terms of the specified minimal concentrations allowed per contaminant.

4. RESULTS AND DISCUSSION

4.1 OVERVIEW OF AVAILABLE HOME WATER TREATMENT DEVICES

A survey was of available HWTD products currently available in South Africa in stores or via the internet or brochures was done and it demonstrated that consumers have a wide range of products that they can choose from for their home water treatment (Table 4.1). The decision of what type of device to use can be a daunting task and to assist the consumers with this a pamphlet was launched and distributed by the research team. The pamphlet focused on what each type of treatment technology can be used for, what to consider with each type of treatment technology in terms of example maintenance as well as what to consider when manufacturer claims regarding quality control and certification of the product. This is discussed in more detail in Volume 2 published as part of this project.

Table 4.1 Summary of HWTDs currently available in South Africa. Treatment technology used, approximate price of the units (in 2012) and certifications claimed by the manufacturer.

	Product Name	Treatment Technology	Cost	Certification
Pure SA	3 stage under counter water purifier	•AC block filter •MF bacteriostatic 0.3 µM polyethylene filter •IER	R 1795.00	FDA, NSF and Microban approved.
	3 stage water filter system, dual purpose single purifier	•GAC filter •IER •MF 0.5 µM filter	R600.00	FDA, NSF and Microban approved.
	Dual purpose double counter top water purifier	• AC block filter •MF bacteriostatic 0.3 µM polyethylene filter	R900.00	FDA, NSF and Microban approved.
	3 stage UV Light Water Purifier	•AC block filter •MF bacteriostatic 0.3 µM polyethylene filter •UV Light	R1850.00	FDA, NSF and Microban approved.
EMWC	System 40	•SI GAC filter •3 µM MF bacteriostatic •5 µM filtration screens	R3450.00	Conforms to British Standards 6920 and is WRAS approved
	5 stage reverse osmosis system	•MF 0.5 µM filter • Carbon filter •MF 0.5 µM filter •RO Membrane • In-Line AC water filter	R4290.00	Conforms to British Standards 6920 and is WRAS approved
	4L per min UV water filter system	•UV light	R1050.00	Conforms to British Standards 6920 and is WRAS approved
	Freshpoint UF system	•UF hollow fibre filter system	R2277.00	Conforms to British Standards 6920 and is WRAS approved
Pure Aqua	RO-100 series	•MF 0.5 µM polyethylene sediment filter •Carbon block filters •RO membrane •GAC filter	N.A.	Member of water quality association, ANAB accredited and ISO 9001:2008 certified
	UVR series	•MF 0.5 and 0.35 µM polyethylene sediment filter •Carbon block filters •UV light	N.A.	Member of water quality association, ANAB accredited and ISO 9001:2008 certified
Glacier	12 litre glass home unit	•CF 0.2 µM filter •Mineral stones •GAC filter •BSF silica sand •IER zeolite and magnetic water tap	R1495.00	CE accredited and ISO 9001:2008 certified

Table 4.1 Summary of HWTDs currently available in South Africa. Treatment technology used, approximate price of the units (in 2012) and certifications claimed by the manufacturer.

	Product Name	Treatment Technology	Cost	Certification
	12 litre PVC home unit	•CF 0.2 µM filter •Mineral stones •GAC filter •BSF silica sand •IER zeolite and magnetic water tap	R1295.00	CE accredited and ISO 9001:2008 certified
	12 litre UV glass home unit	•CF 0.2 µM filter •Mineral stones •GAC filter •BSF silica sand •IER zeolite and magnetic water tap UV light	R1995.00	CE accredited and ISO 9001:2008 certified
	Stainless steel home unit and candle ceramic filter	•SI CF 0.2 µM filter •GAC filter	R1295.00	CE accredited and ISO 9001:2008 certified
	Smaller RO system	•Filmtec RO membrane 0.001 µM •MF 5 µM compressed fibre filter •Carbon block filter •Coconut shell carbon filter •AC filter	R2999.00	CE accredited and ISO 9001:2008 certified
	18 000L Double Under Counter Unit	•MF 5 µM pre-sediment fibre filter •GAC filter •IER KDF bacteriostatic cartridge	R2230.00	CE accredited and ISO 9001:2008 certified
	18 000L Single Counter Top Unit	•IER KDF bacteriostatic cartridge •GAC filter	R1315.00	CE accredited and ISO 9001:2008 certified
H_2O International	Ode V WD717 Water Distiller	•Water distiller •AC filter	N.A.	CE accredited
	RCT CP Deluxe Replaceable Countertop Deluxe	•IER KDF riolyte media bacteriostatic cartridge •GAC filter •UF pre-sediment filter •CF candle filter	N.A.	CE accredited
	PCT Portable Countertop	•IER KDF riolyte media bacteriostatic cartridge •GAC filter •UF pre-sediment filter	N.A.	CE accredited
First Water	CT1: GAC/KDF	•KDF bacteriostatic cartridge •GAC filter	R2450.00	WQA and NSF
	US1: GAC/KDF	•KDF bacteriostatic cartridge •GAC filter	R3300.00	WQA and NSF
	PUR009	•Water distiller	R5500.00	WQA and NSF
	US5RO-50-BP	•Pre and post sediment carbon filter •RO membrane water purifier	R4200.00	WQA and NSF
Aqua Connections	Waterpik Instapure	•GAC filter	R320.00	N/A
Pure	Pure Single 3 in 1 Counter Top	•IER •GAC filter •MF 5 µM	R500.00	FDA, Microban, WQA and NSF (Components)
	Pure Double Counter Top Purifiers	•GAC filter •MF 0.3 µM	R800.00	FDA, Microban, WQA and NSF (Components)

Table 4.1 Summary of HWTDs currently available in South Africa. Treatment technology used, approximate price of the units (in 2012) and certifications claimed by the manufacturer.

	Product Name	Treatment Technology	Cost	Certification
	Pure UV Light 2 Stage Counter Top Twister	•GAC filter •MF 0.3 µM •UV light	R1650.00	FDA, Microban, WQA and NSF (Components)
	Pure UV Light 3 Stage Counter Top Twister	•IER •GAC filter •MF 0.3 µM •UV light	R1950.00	FDA, Microban, WQA and NSF (Components)
	Pure Portable Siphon System	•GAC filter •1 µM cloth filter	R150.00	FDA, Microban, WQA and NSF (Components)
Eish H_2O	Tap Filter-NHI-DAX1010T	•Contains Polypropylene and AC filter.	N.A.	N/A
	Mini Tap Filter TAPM	•5 stage filtration system	N.A.	N/A
	Tap Filter NHITC-008	•Tap filter with dual ceramic filter	N.A.	N/A
	RO without pump	•Sediment Filter •GAC filter •Block AC •RO Membrane	R2600.00	N/A
	UV Water Purification System	•UV light	R660.00	N/A
Filter Shop	Double Counter Top Filter	•5 µM sediment Filter •GAC filter	R290.00	N/A
	Triple Counter Top Filter	•KDF bacteriostatic cartridge •5 and 0.2 µM filter	R599.99	N/A
	Reverse Osmosis (RO) Water Filter	•RO membrane •Carbon Block •GAC filter •MF 5 µM •Taste and odour filter	R3000.00	N/A
	Under the Counter UV Light System	•GAC filter •MF 5 and 0.2 µM •UV light	R2800.00	N/A
SEAL Water Tech	Mini Tap Filter	•5 stage filtration system	R170.00	N/A
	Single Counter Top Filter	• 2 stage filtration with a GAC and polypropylene filter system	R490.00	N/A
	Mineral Water Filter Pot 12L	•CF 0.2 µM filter •Mineral stones •GAC filter •BSF silica sand •IER zeolite	R400.00	N/A
	Under Counter Two Stage Filtration Unit	•KDF filtration technology	R2000.00	N/A
	6 Stage RO Unit 150LPD without pump	•Polypropylene filter •GAC filter •Carbon block •RO membrane •Post carbon filtration •Re-mineralization process	R3420.00	N/A
Philips	WP3811	•Microclean filter technology	R499.00	N/A
	WP3911	•Microclean filter technology	R249.00	N/A
BRITA	Elemaris XL Jug	•4 step maxtra filtration process •Intensive prefiltration •Ion exchange filtration •AC filtration •Intensive final filtration	R395	TUV/SUD

Table 4.1 Summary of HWTDs currently available in South Africa. Treatment technology used, approximate price of the units (in 2012) and certifications claimed by the manufacturer.

	Product Name	Treatment Technology	Cost	Certification
	Marella Large Water Filter Jug	•4 step maxtra filtration process •Intensive prefiltration •IER filtration •AC filtration •Intensive final filtration	R309.99	TUV/SUD
Aquathin	Aqualite RO/DI Water Purification System	•RO deionization process	N.A.	ISO 9001:2000 / 2008
	Space Saver Model	•Kitchen top RO deionization model	N.A.	ISO 9001:2000 / 2008
	DM-KTF	•Kitchen tap KDF carbon filter	R250.00	N/A
	DM-CT	•Counter top KDF and carbon technology	R609.00	N/A
Blue Spot	7 Stage RO Purifier	•5 and 1 µM filter •GAC filter •0.0001 µM RO membrane •Carbon filter •Mineral ball and stone	R2000.00	N/A
	5 Stage RO Purifier	•5 and 1 µM filter •GAC filter •0.0001 µM RO membrane •Carbon filter	R1799.00	N/A
	Tankless RO Purifier 300 GPD	•5 and 1 µM filter •GAC filter •0.0001 µM RO membrane •Carbon filter	R4999.00	N/A
	eSpring Filter	•Multistage activated pressed carbon block filter	R1799.00	N/A
	eSpring Water Purifier with UV Light	•UV technology	R6999.00	N/A
	5 Stage UV Light Purifier	•5 and 1 µM filter •GAC filter •Carbon filter •UV technology	R1999.00	N/A
	Double Counter Top Water Purifier	•Polypropylene filter •GAC filter	R549.00	N/A
Perfect Water	Two Stage Purifier (WP)	•Sediment filter •GAC based filter	R690.00	WQA
Little Luxury	3 Stage Tap Filter Unit	•Organic carbon filter	R149.00	N/A
	Lux Pure Filter Unit Crystal Springs 3S	•KDF activated carbon filter	R748.50	N/A
	Ceramic Tap Water Purifier Unit	•Ceramic •Nano-KDF •Activated carbon based filter	R219.95	N/A
Instapure	Essentials Tap Filter System (F2)	•Carbon based filter	R269.00	N/A
Kent Gold	UF Membrane Purifier	•Sediment filter •Silver carbon filter •UF membrane	R499.99	WQA S200 NSF 53 TUV/SUD ISO 9001:2008 CE
Water Well	Mineral Filter Pot 12L (MP01)	•Ceramic filter •Sediment based filter	R259.99	N/A

Table 4.1 Summary of HWTDs currently available in South Africa. Treatment technology used, approximate price of the units (in 2012) and certifications claimed by the manufacturer.

	Product Name	Treatment Technology	Cost	Certification
Aqua Optima	Aqua Optima Jug (AMF001A)	•Activated carbon based filter	R139.99	NSF43,48 AS 3497
Sunbeam	Sunbeam Water Filtration Jug (SFJ1000)	•IER •Activated carbon filter	R99.99	Food and safety standard
Russell Hobbs	Water Filtration Cooler 3L With Brita Maxtra Filter Technology	•IER •Activated carbon filter	R1099.99	TUV/SUD
Aqua Plus	Select Economy Shark Series 2.5L Jug	•Activated carbon filter	R194.99	N/A
Bobble Bottle	Bobble Bottle	•Activated carbon filter	R199.99	FDA/NSF 42: Plastic

The research team decided only to test gravity fed and faucet mounted (see previous section for detailed descriptions) HWTDs as part of this study since these are devices that consumers have easy access to in shops. These devices were selected from shops in and around Pretoria and Johannesburg. It was noted that several stores sold the same make of devices supporting the hypothesis that consumers would be more tempted to purchase them as part of their monthly shopping. The devices tested in this study, along with some of their typical characteristics, are shown in Table 4.2. No brand names are given to protect the manufacturer / supplier and only the laboratory identification letter is shown in the table. This identification letter will also be used for the discussion of the laboratory results obtained in the sections to follow.

4.2 MICROBIOLOGICAL TESTING

Microbiological determinant tests were performed in accordance with NSF P231 Microbiological Protocol, NSF 42 (Aesthetic) and 53 (Health Effects) and SANS 241:2006 in terms of HWTD minimum performance requirement criteria set out within these standards.

All the HWTDs purchased for this study were tested in terms of their microbiological removal capabilities in terms of cyst, bacteria, viruses and particulate mechanical size exclusion capabilities. This was done in order to assess if the final treated water quality met the standards of SANS 241:2006 and NSF P231, 42 and 53, in spite of manufacturer removal claims. The manufacturer’s claims, however, were also taken into consideration.

4.2.1 Bacterial Culture Removal Efficiency Analysis

Home water treatment devices A to M were analysed in terms of bacteriological performance. Each device was challenged with 1×10^6 CFU / 100 ml of *Escherichia coli* (ATCC: 25922) (NSF P231, 42 and 53 recommendations) spiked into challenge test water. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration / bacterial removal number of CFU / 100 ml was determined using the membrane filtration technique. Each sample dilution was assayed in triplicate. The data obtained were used to determine the removal efficiency of each contaminant (Figure 4.1) and so the HWTDs exclusion capabilities (Table 4.3). In accordance with NSF P231, 42 and 53 the minimum removal requirement of bacteria in HWTDs is 99.99% CFU / 100 ml and SANS 241:2006 requires a count per 100 ml not detected in tap water to prevent any acute health effects.

Table 4.2 Home water treatment devices included in this study.

Device	Treatment Technology	Treatment Mode	Claims according to Manufacturers Specifications	Certification
Device A	Carbon based filter	Gravity fed	Use with Municipally Treated Water. Removes organic contaminants and chlorine. Improves taste and odour.	FDA/NSF 42: Plastic
Device B	Activated carbon based filter	Gravity fed	Use with Municipally Treated Water. Removes lime scale, chlorine and heavy metals. Improves taste and odour.	N/A
Device C	Ion exchange resin and activated carbon based filter	Gravity fed	Use with Municipally Treated Water. Removes chlorine, lime scale, lead, copper, aluminium, pesticides and organic impurities. Improves taste.	TUV/SUD
Device D	Ion exchange and activated carbon based Filter	Gravity fed	Use with Municipally Treated Water. Removes chlorine, lime scale, lead and copper. Improves taste.	TUV/SUD
Device E	Ion exchange resin and activated carbon based filter	Gravity fed	Use with Municipally Treated Water. Removes large particles (sediment rust), lime scale, herbicides, pesticides, chlorine, aluminium, lead and copper. Improves taste.	Food and safety Standard
Device F	Activated carbon based filter	Gravity fed	Use with Municipally Treated Water. Removes herbicides, pesticides, sediments, chlorine, lime scale, aluminium, copper, lead, calcium carbonate. Retains fluoride, potassium and magnesium.	NSF43,48 AS 3497
Device G	Ceramic and sediment based filter	Gravity fed	Use with Municipally Treated Water. Removes heavy metals and chemicals. Improves taste.	N/A
Device H	Sediment, silver carbon based filter, with UF membrane	Faucet mounted	Use with Municipally Treated Water. Removes chlorine, bacteria and cysts. Improves taste and odour.	WQA S200 and NSF 53, TUV/SUD, ISO 9001:2008, CE
Device I	Ceramic, nano-KDF and activated carbon based filter	Faucet mounted	Use with Municipally Treated Water. Removes rust, worms, algae, parasites, asbestos, lindenmin, trihamin, insolvents, chlorine, organic pathogens, pesticides, sediment, cysts, heavy metals (lead and chromium) and asbestos. Improves taste.	N/A
Device J	KDF activated carbon based filter	Faucet mounted	Use with Municipally Treated Water. Removes 99.9% *E. coli* and cholera, organic, inorganic and micro particles, selected spectrum bacteria, heavy metals, rust, tin, mercury, lead and 99% chlorine.	N/A
Device K	Carbon based filter	Faucet mounted	Use with Municipally Treated Water. Reduces chlorine, pesticides, trihalomethanes, industrial solvents, bad taste and odour, scale, sediment, sand and rust.	N/A
Device L	Organic carbon based filter	Faucet mounted	Use with Municipally Treated Water, Removes asbestos fibres, pesticides, 80% sand, rust and sediment, floating debris, 99% chlorine, toxins, chemicals, 99.7% bacteria, cholera and *E. coli*, 70% industrial solvents and Lindane, lead, mercury, 70% trihalomethanes and Inorganics. Improves taste and smell	N/A
Device M	Sediment and GAC based filter	Faucet mounted	Use with Municipally Treated Water. Removes sand, silt, dirt and rust, 95% TDS, 99% VOC, asbestos, cysts, turbidity and pesticides. Improves taste and odour	WQA

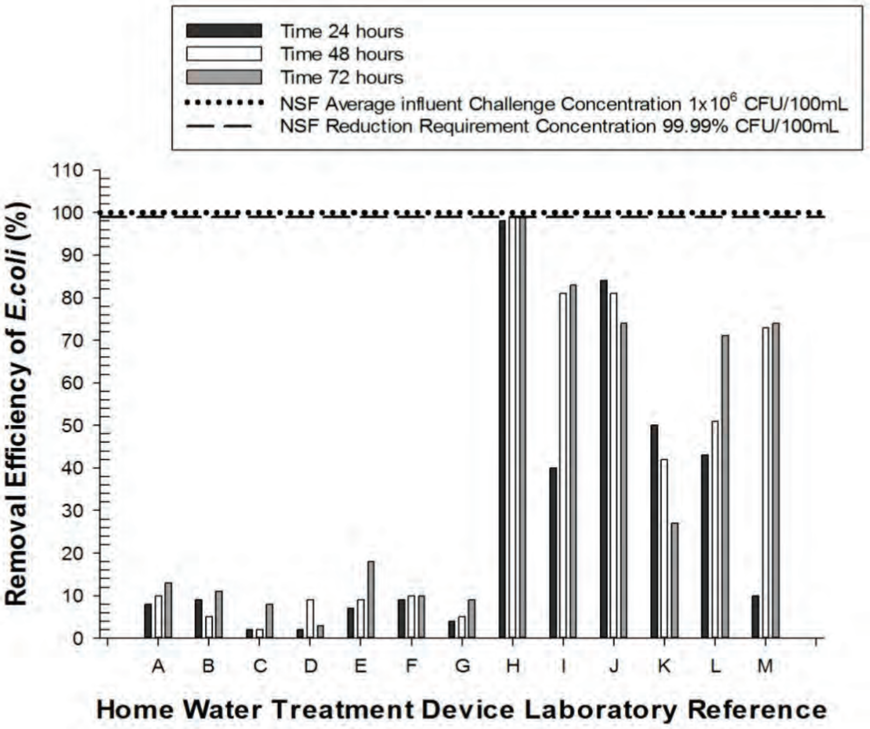

Figure 4.1 Results obtained for the bacteriological testing of the HWTD tested with Escherichia coli showing the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water treatment step.

In accordance with Figure 4.1 and Table 4.3, HWTDs H, I, J and L had manufacturing claims of above 99.7% bacteriological removal. None of these claims could be justified from the results as not one of the devices tested successfully reduced *E. coli* levels after treatment in comparison to the claims made by their manufacturers. However device H did reduce the *E. coli* very close to its manufacturers claims; and devices I and J, did perform quite well. Device L, however, performed rather poorly. None of the devices tested (A-M) met the NSF P231 standard of 99.99% CFU/ml removal or the SANS 241:2006 bacteriological removal count per 100 ml.

A general pattern was observed in devices A-F, which had OC, IER and AC water treatment technologies as in all of them bacteriological removal performance was low. The poor performance of these devices could be attributed to the type of water treatment technology used by manufacturers. Reports by Chaidez *et al.* (2004) have indicated that carbon based filters show no exclusion capabilities of bacterial contaminants from water. However a concerning factor reported by Chaidez *et al.* (2004) and Kohen *et al.* (2005) was that activated carbon POU devices tend to amplify the number of bacteria present in tap water by promoting biofilm formation due to their freely available carbon source and so the microbiological health risk is greater, since the water quality after AC POU treatment can become compromised. Similar findings were reported by Snezana *et al.* (2008) in relation to IER water treatment technologies which showed no removal capabilities in terms of faecal bacteria.

Devices K, L and M seemed to fare far better results in terms of bacteriological removal performance in comparison to devices A-G, utilizing GAC, OC, sediment, KDF and AC water treatment technologies. These findings can be corroborated by De Vet *et al.* (2009) and Nemade *et al.* (2009) where sediment sand filters were found to reduce microbial population by half and studies performed by Devi *et al.* (2008) reported that water treatment technologies utilizing KDF filtration media showed 50% bacterial residual values after treatment. Studies performed by Fengyi *et al* (2009) and Lin *et al.* (2010) utilizing GAC water treatment technologies reported 75% removal of bacteria.

Table 4.3 Results obtained for the bacteriological testing of the the HWTD tested with *Escherichia coli* showing the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	NC	8	10	13
B	AC	GF	NC	9	5	11
C	IER and AC	GF	NC	2	2	8
D	IER and AC	GF	NC	2	9	3
E	IER and AC	GF	NC	7	9	18
F	AC	GF	NC	9	10	10
G	Ceramic and Sediment	GF	NC	4	5	9
H	Sediment, Silver AC and UF	GF	100	98	99	99
I	Ceramic	FM	100	40	81	83
J	KDF AC	FM	99.9	84	81	74
K	GAC	FM	NC	50	42	27
L	Organic Carbon	FM	99.7	43	51	71
M	Sediment and KDF AC	FM	NC	10	73	74

Footnote:

– indicates 100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

AC – activated carbon
IER – ion exchange resin
UF – ultra filtration
GAC – granular activated carbon
KDF – kinetic degradation fluxion
GF – gravity fed
FM – faucet mounted

Devices I and J preformed fairly well in terms of bacteriological removal, utilizing ceramic and KDF water treatment technologies. These findings are supported within reports made by Kaufman *et al.* (2011), which have indicated that dense ceramic clay filters with low porosity are successful at excluding bacterial contaminants in water. Another study performed by Brown *et al.* (2008) could probably also substantiate these results as they reported that a point of use water treatment technology utilizing ceramic filters, with silver NF and KDF coating showed 60% bacterial removal rates.

Device H performed the best overall in terms of bacteriological removal, utilizing sediment, UF and AC water treatment technologies. This finding could be substantiated by reports made by Li *et al.* (2008); Pryor *et al.* (1998) and Walsh *et al.* (2008) which have reported that UF technologies are very successful at reducing microbes in contaminated water sources. Also studies performed by De Vet *et al.* (2009); Murphy *et al.* (2009) and Scouter *et al.* (2003) have reported that closely packed sediment filers were successful at reducing microbes in water sources.

Device G performed rather poorly with regards to bacteriological removal in comparison to devices H and I which utilized the same water treatment technologies of ceramic and sediment. This finding could perhaps be attributed to the porosity and type of ceramic clay utilized by the manufacturers to treat water, as studies performed by Bielefeldt *et al.* (2009) and Mohan *et al.* (2006) have reported that denser clays are more successful at bacterial adsorption than more porous clays. Studies performed by De Vet *et al.* (2009) also suggested that sediment sand filters which were loosely packed (due to the use of larger particles) indicated lower microbial population removal ranges.

Overall the findings from this study suggest that only device H, should be considered for bacterial removal in tap water since UF has been shown to successfully reduce contaminating microbes in water, however, should there be an outbreak of cholera this device would not successfully remove a 100% of pathogenic contaminants.

4.2.2 Bacterial, Viral and Protozoan Parasites / Cysts Mechanical Reduction Particulate Size Exclusion Assays

Home water treatment devices A to M were analysed in terms of their particulate size exclusion capabilities in relation to bacterial, viral and protozoan removal. These tests were performed in terms of mechanical reduction claims, which indicate the possible additional tests adapted from the NSF standards 42, 53 and P231 for the testing of HWTDs. These tests were conducted on devices if the manufacturer claimed the device removed microbial pathogens such as bacteria, viruses or protozoan parasites by size exclusion. Similar studies utilizing mechanical reduction particulate size removal assays in relation to microbial pathogen size have been reported by Bielefeldt *et al.* (2010); Lin *et al.* (2010); Lundquist *et al.* (2011); Nieuwenhuijzen and Graaf (2010) and Polaczyk *et al.* (2008).

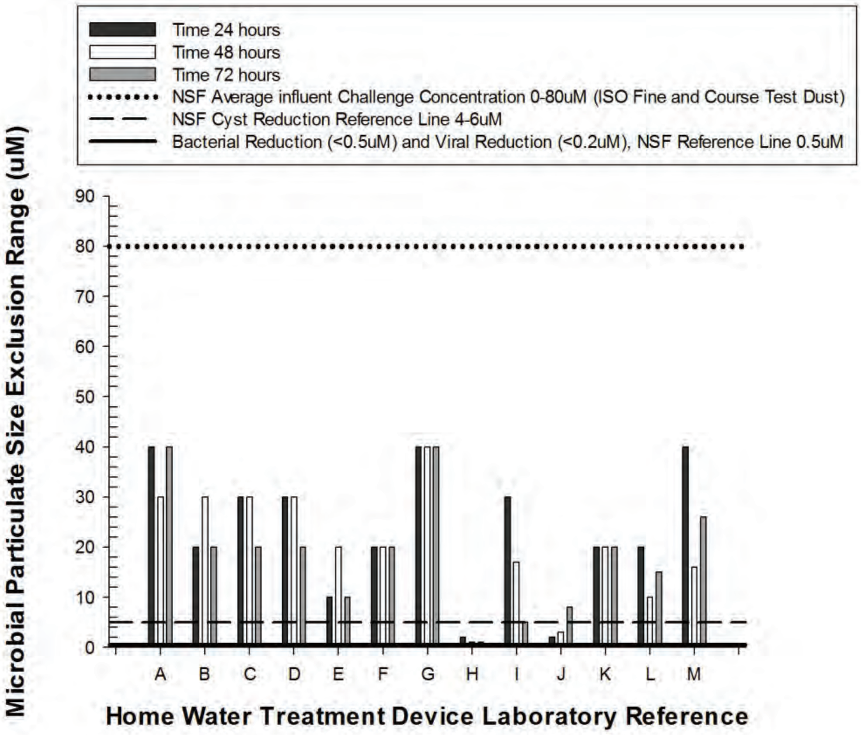

Figure 4.2 Results obtained for the mechanical removal (Particulate Size Exclusion) experiments of the HWTDs that simulates bacterial, viral and protozoan parasites / cysts showing the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the the required levels according to SANS 241 for potable water.

Home water treatment devices were challenged with NSF recommended challenge test water spiked with 10000 particles/ml of ISO 121103-1 Fine and Coarse Test Dust, which has a particle size range from 0-80 µM. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration of particles/ml in terms of removal efficiency was compared to technical data sheets obtained from Powder Technologies Incorporated (PTI) and NSF standards 42 and 53. This allowed for the size exclusion capabilities of the HWTDs to be determined in terms of a particulate removal size and reported in µM (Figure 4.2). The particulate removal size of HWTDs was then related to the approximated particle size of microbial pathogens and so the ability of the HWTDs to exclude these pathogens in terms of size was determined in relation to manufacturer removal efficiency claims (Table 4.4).

In accordance with NSF standards P231, 42 and 53 and studies performed by Bielefeldt *et al.* (2010); Lin *et al.* (2010); Lundquist *et al.* (2011); Nieuwenhuijzen and Graaf (2010) and Polaczyk *et al.* (2008) the minimum bacterial particulate removal range is ≤ 0.5 µM (99.4% removal), cytopathogenic viruses: *Poliovirus 1 and Rotavirus* particulate removal range is ≤ 0.2 µM (99.8% removal) and protozoan parasites / cysts: *Giardia muris / lamblia* particulate removal range is ≤ 4-6 µM (94% removal). SANS 241:2006 requires a count per 10 L not detected for protozoan parasites and cytopathogenic viruses and a count per 100 ml not detected for *E. coli* in tap water in order to prevent any acute health effects.

Table 4.4 Results obtained for the mechanical removal (Particulate Size Exculsion) experiments of the HWTDs that simulates bacterial, viral and protozoan parasites / cysts showing the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)						Particulate Exclusion Range (µM)		
			#Manufacturer Claim			24 hrs	48 hrs	72 hrs	24 hrs	48 hrs	72 hrs
			Cyst	Bacterial	Viral						
A	Organic Carbon	GF	NC	NC	NC	12	17	15	40	30	40
B	AC	GF	NC	NC	NC	33	28	35	20	30	20
C	IER and AC	GF	NC	NC	NC	34	27	35	30	30	20
D	IER and AC	GF	NC	NC	NC	30	26	36	30	30	20
E	IER and AC	GF	NC	NC	NC	47	23	46	10	20	10
F	AC	GF	NC	NC	NC	21	32	42	20	20	20
G	Ceramic and Sediment	GF	NC	NC	NC	6	15	18	40	40	40
H	Sediment, Silver AC and UF	GF	100	100	NC	98	97	99	2	1	1
I	Ceramic	FM	100	100	100	50	82	87	30	17	5
J	KDF AC	FM	NC	99.9	NC	92	89	76	2	3	8
K	GAC	FM	NC	NC	NC	40	30	24	20	20	20
L	Organic Carbon	FM	NC	99.7	NC	36	50	69	20	10	15
M	Sediment and KDF AC	FM	100	NC	NC	4	70	70	40	16	26

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

AC – activated carbon
KDF – kinetic degradation fluxion
GF – gravity fed
IER – ion exchange resin
GAC – granular activated carbon
FM – faucet mounted
UF– ultra filtration

4.2.2.1 Protozoan Parasites / Cysts Mechanical Reduction Particulate Size Exclusion Assays

In accordance with Figure 4.2 and Table 4.4, HWTDs H, I and M tested within this study had manufacturing claims of 100% cyst removal. None of these claims could be justified from the results reported; not one of the devices tested successfully reduced particulate levels consistently with the claims made by their manufacturers. Device H, however did manage to reduce particulate levels very close to its manufacturers claims, whereas devices I and M performed rather poorly. Device J had no manufacturer claims with regards to removal of cysts, but performed fairly well in these particle size exclusion tests. Device H met the NSF P231, 42 and 53 standard of minimum protozoan parasites / cysts: *Giardia muris / lamblia* particulate removal range of ≤ 4-6 µM (94% removal) over the three days of testing. Device J also met this standard on the first two days of testing and device I met this standard on the last day of testing. Device M did not meet the NSF standard at all. None of the devices tested (A-M) met the SANS 241:2006 protozoan count per 10 L of not being detected over the three days of testing.

A general observation of the results showed devices H, I and J, which utilized sediment, AC, UF and KDF water treatment technologies showed good cyst particle removal. These findings are supported within reports by Brown *et al.* (2008), which have indicated that a point of use water treatment technologies utilizing ceramic filters, with silver NF and KDF coating showed 80% removal rates of cysts. Additionally reports made by Li *et al.* (2008); Pryor *et al.* (1998) and Walsh *et al.* (2008) have indicated that UF water treatment technologies are very successful at reducing cysts in contaminated water sources. Also studies performed by De Vet *et al.* (2009); Murphy *et al.* (2009) and Scouter *et al.* (2003) have reported that closely packed sediment filers were successful at reducing contaminating cysts from a water source.

Device M performed rather poorly in particulate removal tests in comparison to devices H which also utilized the same water treatment technology. This finding could perhaps be attributed to the density of the sediment, as studies performed by De Vet *et al.* (2009) also suggested that sediment sand filters which were loosely packed with larger rock particles indicated lower cyst / particulate size removal ranges.

Overall HWTDs which utilized sediment, AC, UF and KDF water treatment technologies could be considered for cyst removal in drinking water. However should there be an outbreak of *Giardia muris / lamblia* device H (which utilized sediment, AC and UF water treatment technologies) would be recommended to successfully remove a 100% of pathogenic contaminates.

4.2.2.2 Bacterial Mechanical Reduction Particulate Size Exclusion Assays

In accordance with Figure 4.2 and Table 4.4, HWTDs H, I, J and L tested in this study had manufacturing claims of between 99.7 to 100% bacteriological removal. None of these claims proved true to form, as not one of the devices successfully reduced particulate levels in comparison to the claims made by their manufacturers. Device H, however, did manage to reduce particulate very close to it manufacturing claims and devices I and J, in general performed quite well. Device L, however, performed rather poorly.

None of the devices tested (A-M) met the P231, 42 and 53 standard of minimum bacterial particulate removal range of ≤ 0.5 µM (99.4% removal) or the SANS 241:2006 bacteriological removal count per 100ml of not being detected, over the three days of testing. Device H, however, did manage to perform closely to these particulate size exclusion ranges utilizing sediment, AC and UF water treatment technologies. Studies performed by Nieuwenhuijzen and Graff (2012); Polaczyk *et al.* (2008) and Varbanets *et al.* (2009) have shown that UF membrane technology is very successful at bacterial exclusion. Device J managed to reduce particulate fairly well utilizing KDF and AC water treatment technologies. Studies performed by Devi *et al.* (2008) reported that water treatment technologies utilizing KDF filtration media showed 50% bacterial residual values after treatment. Device I utilized ceramic water treatment technology and also performed fairly well with regards to particulate exclusion capabilities. This result could be substantiated by studies performed by Brown *et al.* (2008) as they reported that a point of use water treatment technology utilizing ceramic filters, with silver nano and KDF coating showed 60% bacterial removal rates. Device L performed rather poorly within the bacterial size exclusion assays and this could probably be attributed to its OC water treatment technology as reports by Chaidez *et al.* (2004) have indicated that carbon based filters show no exclusion capabilities of bacterial contaminants from water.

Overall HWTDs which utilized sediment, AC and UF water treatment technologies could be considered for bacterial removal in drinking water. However should there be an outbreak of example cholera (caused by *Vibrio cholera*), or any other bacterial outbreak, none of the devices tested in this study would be successful at removing 100% of bacterial contaminates. In cases of bacteria with low infectious doses this would be problematic since low numbers of example *V. cholera* can cause diarrhoea in susceptible people.

4.2.2.3 Viral Mechanical Reduction Particulate Size Exclusion Assays

The only HWTD tested in this study that had manufacturing claims of 100% viral removal was device H (Figure 4.2 and Table 4.4). Device H did not succeed at removing viral particulate size contamination in accordance with its manufacturer's claims; however it did manage to come very close to this range.

None of the devices tested (A-M) met the P231, 42 and 53 standard of minimum viral particulate removal range of ≤ 0.2 µM (99.8% removal) or the SANS 241:2006 bacteriological removal count per 100 ml of not being detected over the three days of testing. Device H, however did manage to come very close to these particulate size exclusion ranges utilizing sediment, AC and UF water treatment technology. The probable reason that device H, did not manage to reach this particulate size removal range was because its UF membrane pore size was slightly too big to completely eliminate particles of this small sized nature. This finding can be substantiated by studies performed by Lundquist *et al.* (2011) and Stephenson *et al.* (2006) where UF membranes utilized within water treatment technologies were unsuccessful at excluding particulate contaminates ≤ 0.3 µM; however studies performed by Li *et al.* (2010) suggest that NF, MF such as nanoalumina membrane fibres filters can completely reduce virus concentrations in water. Since none of the HWTDs tested in this study utilized NF membrane water filtration technologies, these reports could not be substantiated, but these findings could prove as to why device H was successful at reducing the particulate contamination to very low particle size removal ranges.

Overall none of HWTDs tested within this study would be successful at removing 100% of viruses in water.

4.3 PHYSICOCHEMICAL DETERMINANT TESTS

The physicochemical determinant (physical and aesthetic) tests were done in accordance with NSF 42 (Aesthetic Effects), NSF 53 (Health Effects) and SANS 241:2006 in terms of HWTD requirement standards of criteria. All the HWTDs purchased for this study were tested in terms of their physicochemical removal capabilities in order to assess if the final treated water quality met the standards NSF 42 and 53 and SANS 241:2006 class I type tap water, in spite of whether the manufacturer made removal claims or not; however their claims were taken into consideration. Only the devices which had manufacturing claims for physicochemical removal were discussed within this section, however results with significant value were mentioned for devices which had no removal claims.

4.3.1 Free Chlorine as Cl^-

Home water treatment devices A to M were analysed in terms of their free chlorine removal capabilities. The HWTDs were challenged with NSF recommended challenge test water spiked with 2 mg/L Dichloroisocyanuric Acid Sodium Salt Dihydrate. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.3) in relation to manufacturer removal efficiency claims (Table 4.5). In accordance with NSF 42 the minimum removal requirement of free chlorine in HWTDs should be 1 mg/L or 50% removal. SANS 241:2006 requires ≤ 5 mg/L concentration of free chlorine in tap water to prevent any chronic health effects.

In accordance with Figure 4.3 and Table 4.5, the HWTDs tested in this study had manufacturing claim removals of free chlorine within a 99 to a 100% range. The results in general had a varied range of removal efficiencies of free chlorine; all the devices tested (other than device I), proved to have removal efficiencies greater than 50% which met the NSF 42 standard of 1 mg/L. Nevertheless, only four of the thirteen devices tested (device G, H, J and M) came close to meeting the claims their manufacturers made in terms of free chlorine removal. All of the devices, however, did meet SANS 241:2006 MRDL for chlorine of ≤ 5 mg/L in tap water. In general, studies have shown that the unpleasant taste of chlorine and residual levels of chloramines, TTHMs and HAA5s may be lowered at point of use by using powdered or granular activated carbon media filtration technologies (Coulliette *et al.*, 2010; McAllister, 2005 and Wright *et al.*, 2006). These reported findings can support the results of this study since device I was the only device in this study to perform poorly in terms of free chlorine removal; and device I was the only device which did not utilize some form of sediment or AC within its treatment technology. Device I used ceramic filtration and studies performed by McAllister (2005) have shown that ceramic filtration does not exclude chlorine.

Overall, most of the HWTDs successfully reduced free chlorine to levels of an acceptable NSF 42 standard, however, the question is still posed as to whether these levels of free chlorine removal is acceptable and whether chlorine removal from tap water lower than 0.5 mg/L can be deemed safe for human consumption? In studies performed by McLennan et al. (2009) and Liguori et al. (2010), it was shown that POU devices which produced low residuals of chlorine (≤ 0.5 mg/L) after POU treatment, the water could not be deemed safe for storage as it harboured naturally occurring faecal indicator and heterotrophic bacteria, the water had to be consumed within 30 minutes after treatment for it still to be considered potable and not contaminated. If the findings within this study are well-founded then all the HWTDs tested within this study (other than devices A, B, F and I), for free chlorine need to be very carefully utilized (i.e. once chlorinated tap water has been filtered through them it needs to be consumed within 30 minutes and not stored), in order for the filtered water's quality to be considered uncompromised.

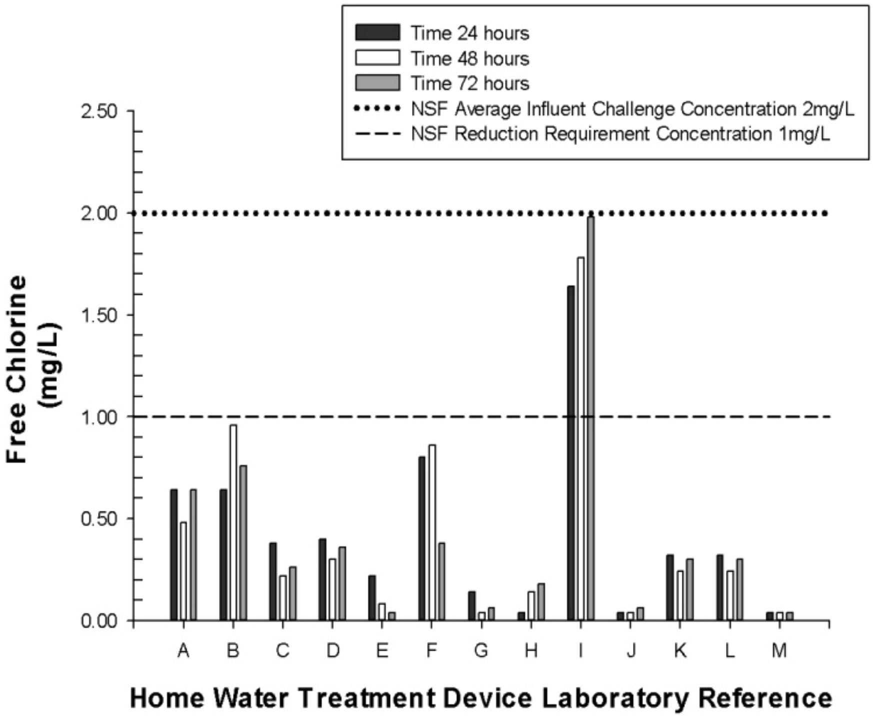

Figure 4.3 Results obtained for the removal efficiency of HWTDs for the removal of free chlorine in water showing the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the allowable levels after treatment of the water.

Table 4.5 Results obtained for the removal efficiency of HWTDs for the removal of free chlorine in water showing the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	100	68	76	68
B	AC	GF	100	68	52	62
C	IER and AC	GF	100	81	89	87
D	IER and AC	GF	100	80	85	82
E	IER and AC	GF	100	89	96	98
F	AC	GF	100	60	57	81
G	Ceramic and Sediment	GF	100	93	98	97
H	Sediment, Silver AC and UF	GF	100	98	93	91
I	Ceramic	FM	100	18	11	1
J	KDF AC	FM	99	98	98	97
K	GAC	FM	100	84	88	85
L	Organic Carbon	FM	99	1	69	59
M	Sediment and KDF AC	FM	100	98	98	98

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

AC – activated carbon
KDF – kinetic degradation fluxion
GF – gravity fed
IER – ion exchange resin
GAC – granular activated carbon
FM – faucet mounted
UF– ultra filtration

4.3.2 Conductivity at 25°C

Home water treatment devices A to M were analysed in terms of their electrical conductivity. HWTDs were challenged with municipal tap water of a known conductivity (78.9 mS/m). After the challenge the eluted municipal tap water was collected from the HWTDs and the final elution concentration / removal efficiency in mS/m was reported (Figure 4.4). These results were compared to the standards stipulated in SANS 241:2006 (the minimum removal requirement of electrical conductivity in municipal tap water is ≤170 mS/m in order to prevent any aesthetic changes to the water), to investigate if the overall water quality produced by the HWTDs was comparable to the standards specified in SANS 241:2006 class I type tap water (Table 4.6).

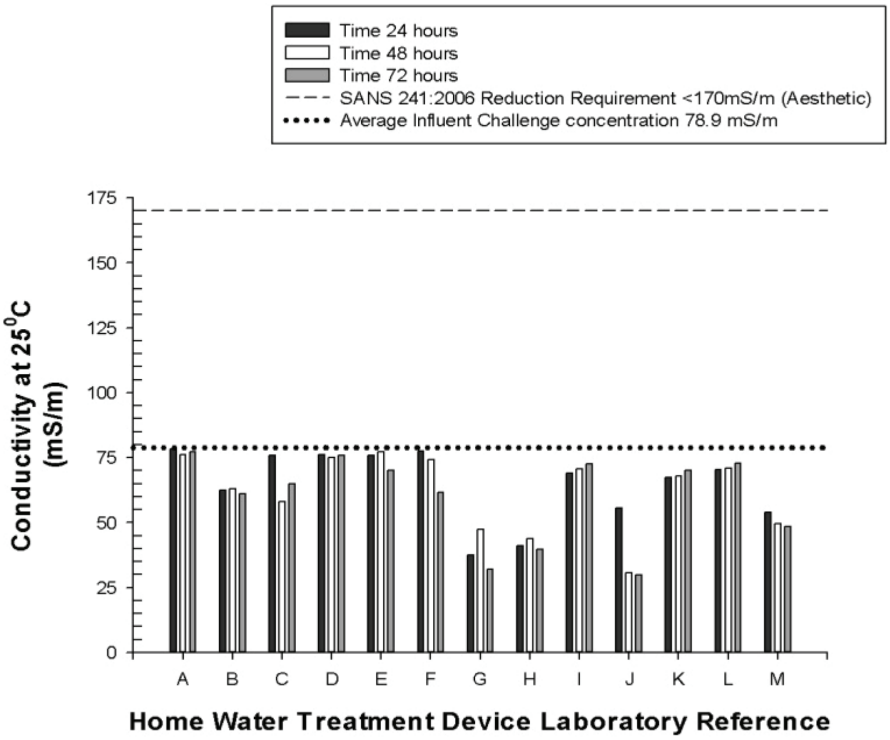

Figure 4.4 Results obtained for the removal efficiency of HWTDs for the redusing the conductivity (25°C) of the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the the allowable levels according to SANS 241 for potable water.

All the HWTDs purchased for this study were tested in terms of their capabilities to reduce electrical conductivity in order to assess if the final treated water quality met the standards of SANS 241:2006, even though their manufacturers made no claims in terms of overall conductivity. In accordance with Figure 4.4 and Table 4.6, all of the devices (A-M) managed to meet SANS 241:2006 MCL of ≤ 170 mS/m expectancy standard of electrical conductivity over the 3 days of testing.

Devices G, H and J performed exceptionally well showing reduced electrical conductivity levels. Devices G, H and J utilized ceramic, sediment, AC, UF and KDF water treatment technologies and studies performed by Gulson *et al.* (1997); Fengyi *et al.* (2009); Pryor *et al.* (1998) and Varkey *et al.* (2012) have indicated strong electrical conductivity results within these water treatment technologies. One concern was the results produced by devices C, D and E which utilized IER technologies. Studies performed by Geldenhys *et al.* (2002) reported noticeable decreases in electrical conductivity within water treatment devices that utilized IER as the removal in electrical conductivity was attributed to the removal of ions. This poor performance of electrical conductivity reduction of the IER water treatment technologies in devices C, D and E, could be attributed to the fact that the water treatment technologies (i.e. filters) were exposed to rather stringent chemical testing regime in terms of pH change and chemical ions (such as iron, manganese, chromium, calcium, etc.) and this could have caused their IER to become coated or clogged, lessening their efficacy in removing ions affecting their conductivity removal. These findings can be supported by Gulson *et al.* (1997) and Herman (1996) where it was reported that the IER sites of bench top water filter systems were overloaded with other elements such as magnesium, copper and zinc lessening their efficacy in removing other elements such as calcium.

Overall the findings from this study suggest that all the HWTDs tested in this study were effective at reducing electrical conductivity to the accepted standards of SANS 241:2006. However, since electrical conductivity is only an indicator test for ion-abnormalities, further testing is required in terms of ionic contributors / contaminants to determine the potential benefits or removal capabilities of these HWTDs.

Table 4.6 Results obtained for the removal efficiency of HWTDs for the redusing the conductivity (25°C) of the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	NC	1	4	2
B	AC	GF	NC	21	20	23
C	IER and AC	GF	NC	4	26	18
D	IER and AC	GF	NC	4	5	4
E	IER and AC	GF	NC	4	2	11
F	AC	GF	NC	2	6	22
G	Ceramic and Sediment	GF	NC	52	40	59
H	Sediment, Silver AC and UF	GF	NC	48	45	50
I	Ceramic	FM	NC	13	10	8
J	KDF AC	FM	NC	30	61	62
K	GAC	FM	NC	15	14	11
L	Organic Carbon	FM	NC	11	10	8
M	Sediment and KDF AC	FM	NC	32	37	39

Footnote:

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

AC – activated carbon
KDF – kinetic degradation fluxion
GF – gravity fed
IER – ion exchange resin
GAC – granular activated carbon
FM – faucet mounted
UF– ultra filtration

4.3.3 pH Value at 25°C

Home water treatment devices A to M were analysed in terms of their pH value. HWTDs were challenged with NSF recommended challenge test water spiked with either a high pH value of 11.0 or a low pH value of 4.0. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration / removal efficiency in pH units was reported (pH High – Figure 4.5 and pH Low – Figure 4.6) in relation to manufacturer removal efficiency claims and the standards specified in SANS 241:2006 class I type tap water (pH High – Table 4.7 and pH Low – Table 4.8). In accordance with NSF 42 the minimum removal requirement of pH in HWTDs should range from a pH value of 6.5-8.5. SANS 241:2006 requires a pH range from a pH value of 5.0 to 9.7 in tap water to prevent any operational effects.

All the HWTDs purchased for this study were tested in terms of their neutralising capabilities in order to assess if the final treated water quality met the standards of SANS 241:2006 and NSF 42. Even though their manufacturers made no claims with regards to the capabilities of their devices to alter pH, this test was performed as an overall indicator test of final treated water quality produced by these devices.

High pH challenge testing was performed in order to observe the HWTDs abilities to neutralise alkaline water. In terms of high pH challenge testing in accordance with Figure 4.5 and Table 4.7, all the devices (other than device G) failed to meet the NSF 42 standard of pH removal range 6.5 -8.5 over the 3 days of testing, however devices I, J, L and M managed to meet the NSF 42 pH range testing after 2 to 3 days of testing. Devices B, D, G, H, J, K and M managed to meet SANS 241:2006 maximum operational range for pH (5-9.7) standard over the 3 days of testing, device C met this standard on day 1 of testing and devices I and M met this standard on the second and third day of testing, however devices A, E and F failed to meet this standard after 3 days of testing.

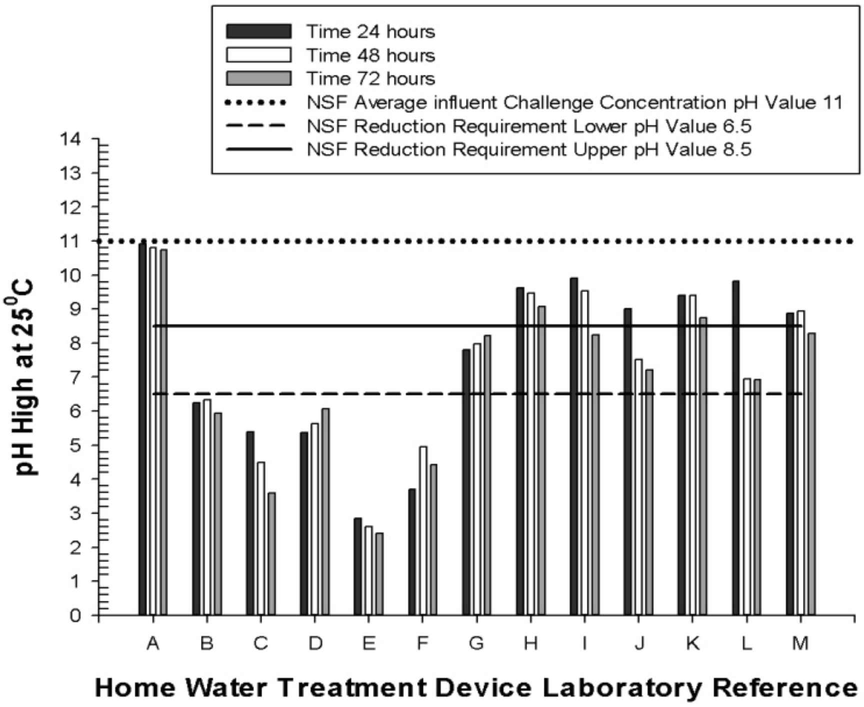

Figure 4.5 Results obtained for the reduction of water pH (when tested using buffer with high pH 25°C) by the selected HWTDs. The graphs shows the pH reduction of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the the allowable levels according to SANS 241 for potable water. Results for the testing of HWTD with high pH values at 25°C.

Table 4.7 Results obtained for the reduction of water pH (when tested using buffer with high pH 25°C) by the selected HWTDs.The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual pH values obtained.

HWTD	Treatment Technology	Treatment Mode	pH Value / pH Units			
			Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	NC	10.90	10.80	10.73
B	AC	GF	NC	6.25	6.33	5.93
C	IER and AC	GF	NC	5.38	4.48	3.58
D	IER and AC	GF	NC	5.37	5.62	6.06
E	IER and AC	GF	NC	2.85	2.61	2.41
F	AC	GF	NC	3.70	4.95	4.41
G	Ceramic and Sediment	GF	NC	7.81	7.98	8.21
H	Sediment, Silver AC and UF	GF	NC	9.61	9.46	9.06
I	Ceramic	FM	NC	9.91	9.53	8.23
J	KDF AC	FM	NC	9.00	7.51	7.21
K	GAC	FM	NC	9.40	9.40	8.75
L	Organic Carbon	FM	NC	9.81	6.95	6.92
M	Sediment and KDF AC	FM	NC	8.87	8.93	8.28

Footnote:

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

AC – activated carbon
IER – ion exchange resin
UF– ultra filtration
KDF – kinetic degradation fluxion
GAC – granular activated carbon
GF – gravity fed
FM – faucet mounted

Low pH challenge testing was performed in order to observe the HWTDs abilities to neutralise acidic water. In terms of low pH challenge testing in accordance with Figure 4.6 and Table 4.8, all the devices (other than devices G, H, J and M) failed to meet the NSF 42 standard of pH removal range 6.5 -8.5 over the 3 days of testing, however device K managed to meet the NSF 42 pH range testing after 2 days of testing. Devices G, H, I, J, K and M managed to meet SANS 241:2006 maximum operational range for pH (5-9.7) standard over the 3 days of testing, device L met this standard on day 1 of testing, however devices A, B, C, D, E and F failed to meet this standard after 3 days of testing.

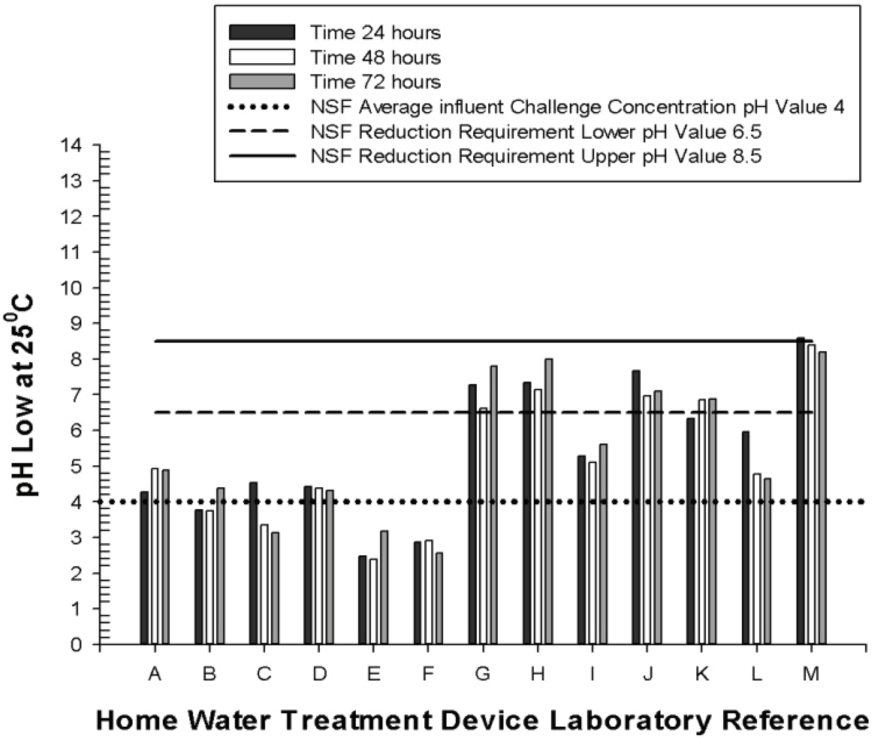

Figure 4.6 Results obtained for the increase of water pH (when challenged using buffer with low pH 25°C) by the selected HWTDs. The graphs shows the pH increase of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines. Results for the testing of HWTD with high pH values at 25°C.

Device G performed the best at neutralising both acidic and alkaline challenge test water to both NSF and SANS 241:2006 standard and it utilized ceramic water treatment technology. Devices H and M managed to meet neutralising only acidic challenge test water to NSF standard, using sediment, AC, UF and KDF water treatment technologies. Devices H, J, K and M managed to meet SANS 241:2006 removal range limits in terms of neutralising both acidic and alkaline challenge water, utilizing ceramic, sediment, AC, UF, KDF and GAC water treatment technologies in combination. Devices A, E, C and F performed very poorly at neutralising both acidic and alkaline challenge test water to both NSF and SANS 241:2006 standards, utilizing OC, IER and AC water treatment technologies.

The above findings can be sustained by studies performed by Plappally *et al.* (2010) and Varkey *et al.* (2012) where ceramic water treatment technologies indicated excellent pH neutralising results. Studies performed by Herman *et al.* (1996); McAllister (2005) and Pryor *et al.* (1998) have also suggested that the use of sediment, UF, KDF and GAC water treatment technologies at being successful at neutralising both acidic and alkaline waters. However studies performed by Ahmedna *et al.* (2004) and Fengyi *et al.* (2009) suggest that OC and AC water treatment technologies showed no buffering effects in terms of water pH neutralisation. The only concerning factor was that studies reported by Snezana *et al.* (2008) which indicated that IER water treatment technologies were very effective at neutralising pH ions, however this was not the case for devices C, D and E which utilized these water treatment technologies. Although these findings could be substantiated by reports made by Gulson *et al.* (1997) and Herman (1996) where it was reported that the IER sites of bench top water filter systems were overloaded with other elements such as magnesium, copper and zinc lessening their efficacy in removing other elements such as calcium, rendering there ion exchange and buffering systems ineffective.

Table 4.8 Results obtained for the increase of water pH (when tested using buffer with high pH 25°C) by the selected HWTDs.The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual pH values obtained.

HWTD	Treatment Technology	Treatment Mode	pH Value / pH Units			
			Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	NC	4.28	4.92	4.88
B	AC	GF	NC	3.76	3.74	4.37
C	IER and AC	GF	NC	4.53	3.34	3.12
D	IER and AC	GF	NC	4.41	4.38	4.31
E	IER and AC	GF	NC	2.48	2.38	3.18
F	AC	GF	NC	2.86	2.90	2.55
G	Ceramic and Sediment	GF	NC	7.28	6.62	7.81
H	Sediment, Silver AC and UF	GF	NC	7.35	7.14	7.99
I	Ceramic	FM	NC	5.28	5.10	5.61
J	KDF AC	FM	NC	7.67	6.97	7.10
K	GAC	FM	NC	6.32	6.86	6.89
L	Organic Carbon	FM	NC	5.95	4.77	4.65
M	Sediment and KDF AC	FM	NC	8.60	8.40	8.19

Footnote:

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

AC – activated carbon
KDF – kinetic degradation fluxion
GF – gravity fed
IER – ion exchange resin
GAC – granular activated carbon
FM – faucet mounted
UF– ultra filtration

Overall, the findings from this study suggest that HWTDs G, H, J, K and M tested within this study that the use of ceramic, sediment, UF, KDF and GAC water treatment technologies are successful at neutralising both acidic and alkaline waters. However, since pH water testing is only an indicator test for ion-abnormalities further testing was required in terms of ionic contributors / contaminants to determine the potential benefits or removal capabilities of these HWTDs.

4.3.4 Turbidity Removal

Home water treatment devices A to M were analysed in terms of their turbidity removal capabilities. HWTDs were challenged with NSF recommended challenge test water spiked with 11NTU ISO 121103-1 Fine Test Dust. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration / removal efficiency in NTU was reported (Figure 4.7) in relation to manufacturer removal efficiency claims and the standards specified in SANS 241:2006 class I type tap water (Table 4.9). In accordance with NSF 42 the minimum removal requirement of turbidity in HWTDs should be ≤ 0.5 NTU or 95% removal. SANS 241:2006 requires a turbidity value of ≤ 1 NTU (operational) and ≤ 5 NTU (aesthetic) in tap water.

All the HWTDs purchased for this study were tested in terms of their turbidity / sediment removal capabilities in order to assess if the final treated water quality met the standards of SANS 241:2006, in spite of whether the manufacturer made removal claim or not, however their claims were taken into consideration.

In accordance with Figure 4.7 and Table 4.9, HWTDs E, F, H-M tested within this study had manufacturer claims for removal in a range from 80 to a 100% turbidity removal in terms of reducing particulate and sediment in treated water. None of these claims could be justified from the reported results as not one of the devices tested successfully reduced turbidity levels after treatment in comparison to the claims made, actually most of these devices performed rather poorly other than device H.

Additionally all the devices tested (other than H) failed to meet the NSF 53 standard of ≤ 5 NTU or 95% turbidity removal over the 3 days of testing. Some of the devices H, I and J managed to meet SANS

241:2006 MCL of ≤ 0.5 NTU expectancy standard of turbidity for aesthetic use over the 3 days of testing, devices L and M met this standard on the last two days of testing. Device H was the only unit that met SANS 241:2006 MCL of ≤ 0.1 NTU expectancy standard of turbidity for operational use over the 3 days of testing.

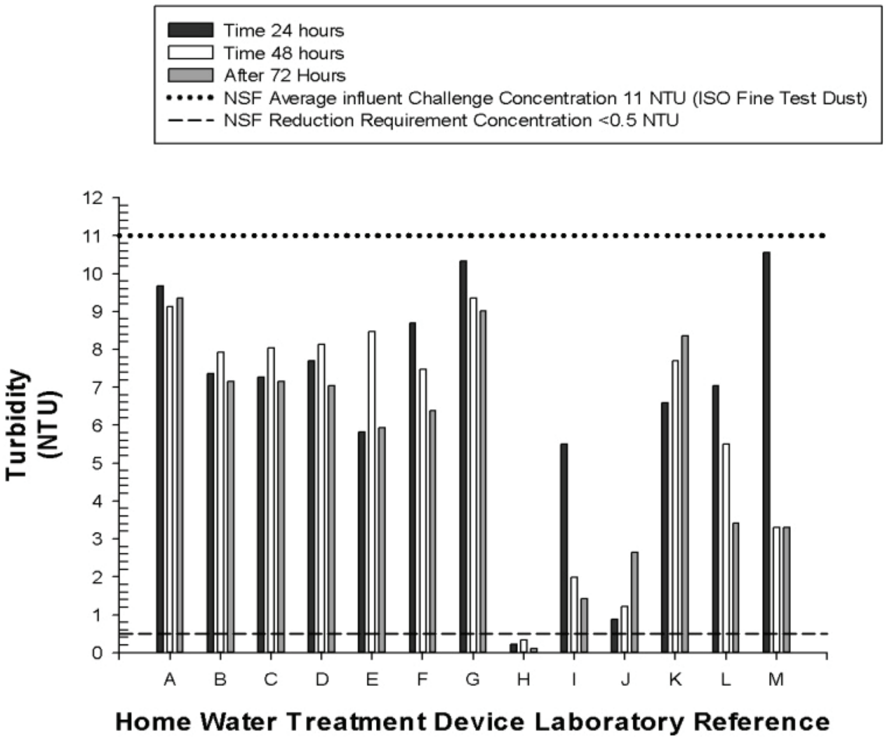

Figure 4.7 Results obtained for the removal efficiency of HWTDs for the redusing of turbidity in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines as well as the minimum turnbidity allowed by the NSF after the water has been treated.

Devices A-F which contained OC, IER and AC water treatment technologies similar results of low turbidity removal were found. The low turbidity removal of these devices could perhaps be attributed to the type of water treatment technologies utilized by manufacturers, as reports by Chaidez *et al.* (2004) have indicated that carbon based filters reported no exclusion capabilities of particle contaminants from water. Similar findings were reported by Snezana *et al.* (2008) in relation to IER water treatment technologies which showed no particulate exclusion capabilities.

Devices K, L and M reported better results in terms of turbidity removal performances in comparison to devices A-F; utilizing GAC, OC, sediment, KDF and AC water treatment technologies. These findings can be supported by Lundquist *et al.* (2011) where sediment sand filters were reported to show 50% removal rates of turbidity and similar studies by Devi *et al.* (2008) reported that water treatment technologies utilizing KDF filtration media indicated 70% removal values of turbidity after treatment. Studies performed by Fengyi *et al.* (2009) and Lin *et al.* (2010) utilizing GAC water treatment technologies reported 75% removal of bacterial contaminates.

Devices I and J preformed fairly well in terms of turbidity removal, utilizing ceramic and KDF water treatment technologies. These findings are supported within reports made by Bielefeldt *et al.* (2010) and Kaufman *et al.* (2011), which have indicated that dense ceramic clay filters with low porosity are successful at excluding bacterial and particulate contaminants in water. Another study performed by Brown *et al.* (2008) could probably also substantiate these results as they reported that a point of use water treatment technology utilizing ceramic filters, with silver nano and KDF coating showed 60% bacterial and particulate removal rates.

Table 4.9 Results obtained for the removal efficiency of HWTDs for the redusing of turbidity in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	NC	12	17	15
B	AC	GF	NC	33	28	35
C	IER and AC	GF	NC	34	27	35
D	IER and AC	GF	NC	30	26	36
E	IER and AC	GF	100	47	23	46
F	AC	GF	100	21	32	42
G	Ceramic and Sediment	GF	NC	6	15	18
H	Sediment, Silver AC and UF	GF	100	98	97	99
I	Ceramic	FM	100	50	82	87
J	KDF AC	FM	99	92	89	76
K	GAC	FM	100	40	30	24
L	Organic Carbon	FM	80	36	50	69
M	Sediment and KDF AC	FM	100	4	70	70

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

AC – activated carbon
KDF – kinetic degradation fluxion
GF – gravity fed
IER – ion exchange resin
GAC–- granular activated carbon
FM – faucet mounted
UF– ultra filtration

Overall, device H performed the best in terms of turbidity removal, utilizing sediment, UF and AC water treatment technologies. This finding could probably be substantiated by reports made by Nieuwenhuijzen and Graff (2012); Polaczyk *et al.* (2008) and Varbanets *et al.* (2009) which have reported that UF water treatment technologies are very successful at reducing microbes and turbidity in contaminated water sources. Also studies performed by De Vet *et al.* (2009); Murphy *et al.* (2009) and Scouter *et al.* (2003) have reported that closely packed sediment filers were successful at reducing particulate from water sources.

Device G performed rather poorly in turbidity removal in comparison to devices H and I which utilized the same water treatment technologies of ceramic and sediment. This finding could perhaps be attributed to the porosity and type of ceramic clay utilized by the manufacturers to treat water, as studies performed by Bielefeldt *et al.* (2010) and Mohan *et al.* (2006) have reported that denser type clays are more successful at particulate exclusion than more porous type clays. Studies performed by Tellen *et al.* (2010) also suggested that sediment bio-sand filters which were not compacted well indicated lower turbidity removal ranges.

Overall the findings from this study suggest that only device H, should be considered for turbidity removal in tap water since ultrafiltration has been shown to successfully exclude particulate in water.

4.3.5 Mechanical Reduction Particulate Size Exclusion Assays

Home water treatment devices A to M were analysed in terms of their mechanical removal / particulate size exclusion capabilities. HWTDs were challenged with NSF recommended challenge test water spiked with10000 particles/ml of ISO 121103-1 Fine and Coarse Test Dust, which has a particle size range from 0-80 µM. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration of particles/ml in terms of removal efficiency referrals to technical data sheets obtained from Powder Technologies Incorporated (PTI) and NSF standards 42 and 53, allowed for the size exclusion capabilities of the HWTD devices to be determined in terms of a particulate removal size reported in µM (Figure 4.8) in relation to manufacturer removal efficiency claims (Table 4.10). In accordance with NSF 42 the minimum removal requirement of mechanical particulate size removal in HWTDs should be ≤ 12 µM or 85% removal. Similar studies utilizing mechanical removal particulate size removal assays in relation to particulate size exclusion have been reported by Bielefeldt *et al.* (2010); Lin *et al.* (2010); Lundquist *et al.* (2011); Nieuwenhuijzen and Graaf (2010) and Polaczyk *et al.* (2008).

All the HWTDs purchased for this study were tested in terms of their particle size removal capabilities in order to assess if the final treated water quality met the standards of NSF 42, in spite of whether the manufacturer made removal claim or not, however their claims were taken into consideration.

In accordance with Figure 4.8 and Table 4.10, HWTDs E, F, H-M tested within this study had manufacturing claim removals in a range from 80 to a 100% particulate and sediment removal in treated water. None of these claims could be justified from the reported results, not one of the devices tested successfully reduced particulate after treatment in comparison to the claims made. However devices H and J met the NSF 42 the minimum removal requirement of mechanical particulate size removal of ≤ 12 µM or 85% removal over the 3 days of testing, device E met this standard on days 1 and 3 of testing, device L met the standard on the second day of testing and device I met this standard on the last day of testing.

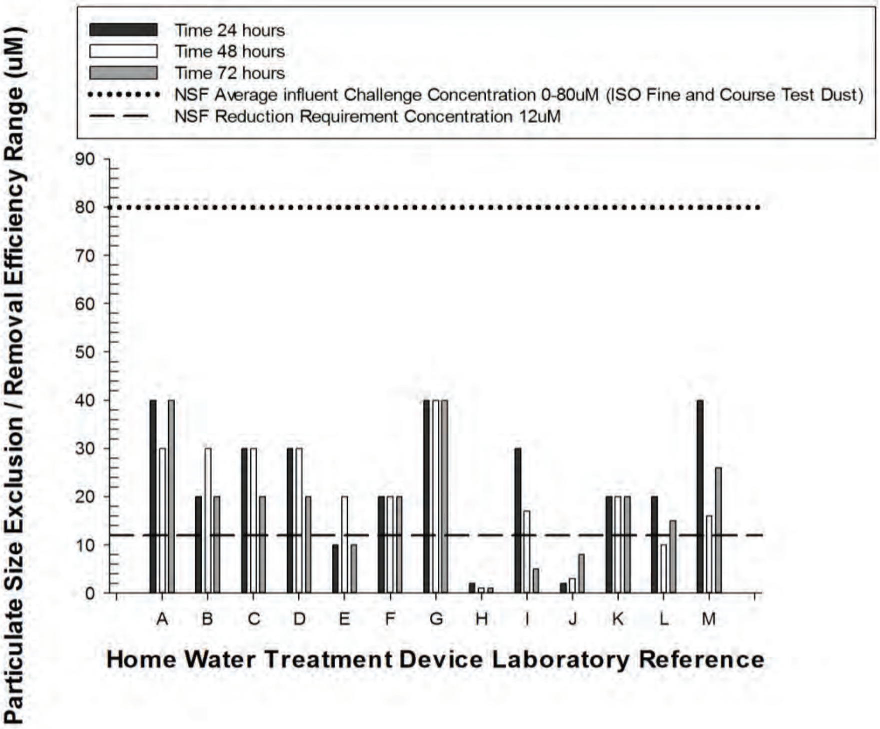

Figure 4.8 Results obtained for the removal efficiency of HWTDs for mecahnical reduction or particle removal form test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels following the water treatment.

Devices A-F which contained OC, IER and AC water treatment technologies an overall finding was that particulate removal was low. The low particulate exclusion performance of these devices could perhaps be attributed to the type of water treatment technologies utilized by manufacturers. These findings can be substantiated in reports by Chaidez *et al.* (2004) where carbon based filters showed no exclusion capabilities of particle contaminants from water. Similar findings were reported by Snezana *et al.* (2008) in relation to IER water treatment technologies which showed 10 µM particulate size exclusion capabilities, as observed in device E.

Devices K, L and M performed in terms of particulate removal in comparison to devices A-F, utilizing GAC, OC, sediment, KDF and AC water treatment technologies. These findings can be supported by Lundquist *et al.* (2011) where sediment sand filters were reported to show 50% removal rates of particulate size exclusion and similar studies by Devi *et al.* (2008) reported that water treatment technologies utilizing KDF filtration media indicated 70% removal values of particulate after treatment. Studies performed by Fengyi *et al.* (2009) and Lin *et al.* (2010) utilizing GAC water treatment technologies reported 75% removal of particulate contaminates.

Devices I and J performed better than devices K, L and M in terms of particulate removal, utilizing ceramic and KDF water treatment technologies. These findings are supported within reports made by Bielefeldt *et al.* (2010) and Kaufman *et al.* (2011), which have indicated that dense ceramic clay filters with low porosity are successful at excluding particulate contaminants in water. Another study performed by Brown *et al.* (2008) could probably also substantiate these results as they reported that a point of use water treatment technology utilizing ceramic filters, with silver NF and KDF coating showed 60% particulate removal rates.

Overall device H performed the best in terms of particulate removal, utilizing sediment, UF and AC water treatment technologies. This finding could probably be substantiated by reports made by Nieuwenhuijzen and Graff 2012; Polaczyk *et al.* (2008) and Varbanets *et al.* (2009) which have reported that UF water treatment technologies are very successful at reducing particulate and sediment in contaminated water sources. Also studies performed by De Vet *et al.* (2009); Murphy *et al.* (2009) and Scouter *et al.* (2003) have reported that densely packed sediment filers were successful at reducing particulate from water sources.

Device G performed rather poorly in particulate removal in comparison to devices H and I which utilized the same water treatment technologies of ceramic and sediment. This finding could perhaps be attributed to the porosity and type of ceramic clay utilized by the manufacturers to treat water, as studies performed by Bielefeldt *et al.* (2010) and Mohan *et al.* (2006) have reported that denser type clays are more successful at particulate exclusion than more porous type clays. Studies performed by Tellen *et al.* (2010) also suggested that sediment bio-sand filters which were not compacted well indicated lower turbidity and particulate removal ranges.

Table 4.10 Results obtained for the removal efficiency of HWTDs for mecahnical reduction or particle removal form test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)				Particulate Exclusion Range (µM)		
			#Manufacturer Claim Particle Removal	24 Hrs	48 hrs	72 hrs	24 hrs	48 hrs	72 hrs
A	Organic Carbon	GF	NC	12	17	15	40	30	40
B	AC	GF	NC	33	28	35	20	30	20
C	IER and AC	GF	NC	34	27	35	30	30	20
D	IER and AC	GF	NC	30	26	36	30	30	20
E	IER and AC	GF	100	47	23	46	10	20	10
F	AC	GF	100	21	32	42	20	20	20
G	Ceramic and Sediment	GF	NC	6	15	18	40	40	40
H	Sediment, Silver AC and UF	GF	100	98	97	99	2	1	1
I	Ceramic	FM	100	50	82	87	30	17	5
J	KDF AC	FM	99	92	89	76	2	3	8
K	GAC	FM	100	40	30	24	20	20	20
L	Organic Carbon	FM	80	36	50	69	20	10	15
M	Sediment and KDF AC	FM	100	4	70	70	40	16	26

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

AC – activated carbon
IER – ion exchange resin
UF– ultra filtration

KDF – kinetic degradation fluxion
GAC – granular activated carbon

GF – gravity fed
FM – faucet mounted

Overall the findings from this study suggest that only device H, should be considered for particulate removal in tap water since ultrafiltration has been shown to successfully exclude particulate in water.

4.3.6 Total Dissolved Solids (TDS)

Home water treatment devices A to M were analysed in terms of their total dissolved solids (TDS) exclusion capabilities. The HWTDs were challenged with NSF recommended challenge test water spiked with 1500 mg/L Sea Salts. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration / removal efficiency in mg/L was reported (Figure 4.9) in relation to manufacturer removal efficiency claims and the standards specified in SANS 241:2006 class I type tap water (Table 4.11). In accordance with NSF 42 the minimum removal requirement of TDS in HWTDs should be 500 mg/L or 67% removal. SANS 241:2006 requires a TDS value of ≤ 1200 mg/L in tap water to prevent any aesthetic effects.

All the HWTDs purchased for this study were tested in terms of their TDS removal capabilities in order to assess if the final treated water quality met the standards of SANS 241:2006, in spite of whether the manufacturer made removal claim or not, however their claims were taken into consideration. In accordance with Figure 4.9 and Table 4.11, HWTDs E, F, H-M tested within this study had manufacturing claim removals in a range from 80 to a 100% TDS removal in terms of reducing particulate, sediment, scale formation and hardness in treated water. None of these claims could be justified from the TDS tests performed on these units. None of the devices tested effectively reduced TDS levels after treatment in comparison to the statements made by their manufactures. Overall all the devices tested reported rather low TDS removal rates. Additionally all the devices tested (other than J) failed to meet the NSF 42 standard of 500 mg/L or 67% TDS removal over the 3 days of testing. Some of the devices C, D, F, G and J managed to meet SANS 241:2006 MCL of ≤ 1200 mg/L expectancy standard of TDS over the 3 days of testing, however devices A, B, E, I, K and L did not and devices H and M met the SANS 241:2006 TDS removal standard on testing days 2 and 3, however did not on day 1.

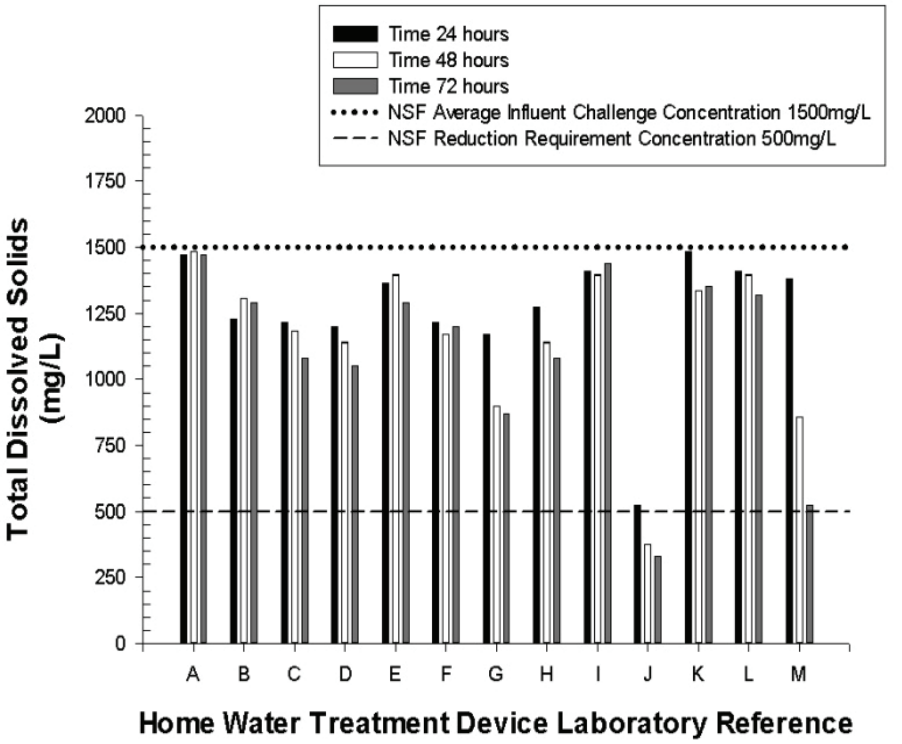

Figure 4.9 Results obtained for the removal efficiency of HWTDs for the removal of dissolved solids in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the the minimum required levels for the total dissolved solids after water treatment.

Table 4.11 Results obtained for the removal efficiency of HWTDs for the removal of dissolved solids in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	NC	2	1	2
B	AC	GF	NC	18	13	14
C	IER and AC	GF	NC	19	21	28
D	IER and AC	GF	NC	20	24	30
E	IER and AC	GF	100	9	7	14
F	AC	GF	100	19	22	20
G	Ceramic and Sediment	GF	NC	22	40	42
H	Sediment, Silver AC and UF	GF	100	15	24	28
I	Ceramic	FM	100	6	7	4
J	KDF AC	FM	99	65	75	78
K	GAC	FM	100	1	11	10
L	Organic Carbon	FM	80	6	7	12
M	Sediment and KDF AC	FM	95	8	43	65

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

AC – activated carbon
IER – ion exchange resin
UF– ultra filtration
KDF – kinetic degradation fluxion
GAC– granular activated carbon
GF – gravity fed
FM – faucet mounted

A general pattern could be observed whereby devices J and M which contained KDF (most predominant), AC and sediment water treatment technologies indicated a good TDS removal result (for device J over the three days of testing and for device M on the last day of testing), whereas devices A, I, K and L which contained organic carbon (most prominent), ceramic and GAC a poor TDS removal potential was found. These findings can be substantiated by studies performed by Gulson *et al.* (1997) where results reported good results in terms of TDS removal in devices which utilized KDF and AC in combination, whereas findings reported by Ahmedna *et al.* (2004); Nemade *et al.* (2009) and Varkey *et al.* (2012) suggest that GAC, OC and ceramic methods of water purification yielded low removal rates of TDS. Additionally studies by Geldenhys *et al.* (2002); Herman *et al.* (1996) and Snezana *et al.* (2008) reported high removal rates of TDS utilizing IER water treatment technologies.

Devices C, D and E utilized these treatment technologies and devices C and D managed to meet the SANS 241:2006 removal standards of TDS, however device E did not, this result could be attributed to the type of IER technology being utilized (i.e. anionic or cationic).In terms of TDS the removal results reported by Herman *et al.* (1996) and Snezana *et al.* (2008) suggest that IER anionic or cationic water treatment technologies either exclude or include different types dissolved ions and so this could potentially influence the overall result of TDS removal, however cationic IER (device C and D) were more successful at reducing TDS than anionic IER (device E). In general the best option for dealing with TDS in drinking water is to determine after analysis the specific ions contributing to the TDS measurement and then choose the best water treatment technology which can rectify the problem, especially in the case of IER and water softening (Deshommes *et al.*, 2010). Other studies by Kommeni *et al.* (2004) and Snezana *et al.* (2008) have shown that reverse osmosis and distillation water treatment technologies are often the best water treatment option in terms of TDS removal, however none of the devices tested within this study utilized these technologies and so these findings could not be substantiated.

Overall the findings from this study suggest that only device J, should be considered for TDS removal in terms of reducing particulate, sediment, scale formation and hardness in treated water since it complied with NSF and SANS 241:2006 standards, however devices C, D, F, G and M could be considered since they met the regulatory requirements of SANS 241:2006.

4.4 CHEMICAL ANALYSIS

The chemical determinant (macro-, micro-, organic and NSF additional) tests were done in accordance with NSF 42 (Aesthetic Effects), NSF 44 (Water Softeners) and NSF 53 (Health Effects) and SANS 241:2006 in terms of HWTD requirement standards of criteria. Note not all the HWTDs purchased for this study were tested in terms of their chemical removal capabilities; only the devices which actually had manufacturing claims for the specific chemicals assays performed within this section were tested for in terms of a claim made by the manufacturer for that particular chemical removal capability claim that they made reference to reducing when utilizing their HWTDs.

4.4.1 Chemical Determinant Tests

4.4.1.1 Fluoride as F^-

Home water treatment devices F, G, J and L were analysed in terms of their inorganic removal capabilities of fluoride. HWTD were challenged with NSF recommended challenge test water spiked with 8 mg/L Fluoride Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.10) in relation to manufacturer removal efficiency claims (Table 4.12). In accordance with NSF 53 the minimum removal requirement of fluoride in HWTDs should be 1.5 mg/L or 81% removal. SANS 241:2006 requires ≤ 1.5 mg/L concentration of fluoride in tap water to prevent any chronic health effects.

In accordance with Figure 4.10 and Table 4.12, three of the HWTDs G, J and L tested within this particular study had their manufacturers proclaiming a 100% removal efficacy of fluoride; none of them achieved this value nor did they efficiently reduce fluoride to the NSF 53 recommended standard of 1.5 mg/L or 81% removal. Manufacturers of device F proclaimed that it added fluoride to water after treatment, however the results proved otherwise, this device actually reduced fluoride content of treated water. Another concerning factor is that none of these devices proved to have the capabilities to reduce or keep the fluoride content of the treated water to the recommended SANS 241:2006 MCL of ≤1.5mg/L. Thus, if within the worst case scenario the South African municipality had to fail at regulating the water quality content of fluoride the HWTDs tested within this study would be unsuccessful at regulating the fluoride content of the treated water to ensure safe drinking water that does not pose a chronic health risk is consumed. In terms of treatment technology studies by Devi *et al.* (2008) and Kommineni *et al.* (2004) it was shown that only four treatment methods are suitable for reducing the levels of fluoride from drinking water, namely activated alumina filters, distillation, reverse osmosis an anion exchange; none of these treatment technologies were utilized within the HWTDs tested within this study. Overall the results of this study in terms of inorganic fluoride removal or addition to treated water by HWTDs tested within this study are unjustified.

Table 4.12 Results obtained for the removal efficiency of HWTDs for the removal of inorganic fluoride in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
F	AC	GF	Add	40	48	50
G	Ceramic and Sediment	GF	100	31	21	11
J	KDF AC	FM	100	45	60	63
L	Organic Carbon	FM	100	8	22	21

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

Add – indicates that the manufacturer claimed that the home water treatment device added this chemical / physical compound to the final water quality eluted from the device.

AC – activated carbon
GF – gravity fed
KDF – kinetic degradation fluxion
FM – faucet mounted

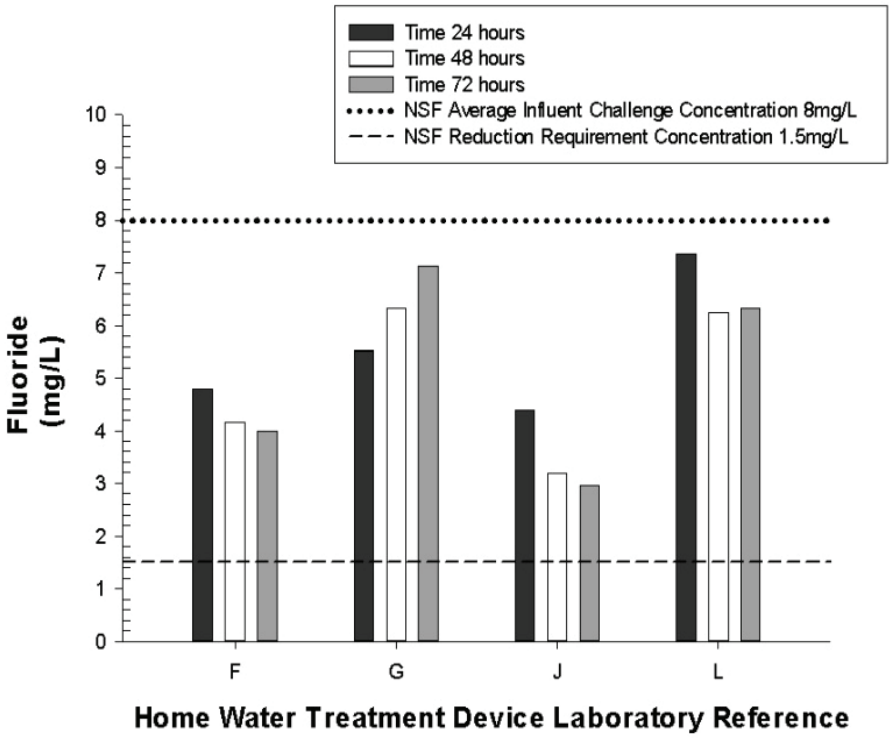

Figure 4.10 Results obtained for the removal efficiency of HWTDs for the removal of inorganic fluoride in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

4.4.1.2 Zinc as Zn

Home water treatment devices G and L were analysed in terms of their removal capabilities of zinc. The HWTDs were challenged with NSF recommended challenge test water spiked with 10 mg/L Zinc Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.11) in relation to manufacturer removal efficiency claims (Table 4.13). In accordance with NSF 42 the minimum removal requirement of zinc in HWTDs should be 5 mg/L or 50% removal. SANS 241:2006 requires ≤ 5 mg/L concentration of zinc in tap water to prevent any aesthetic effects.

Table 4.13 Results obtained for the removal efficiency of HWTDs for the removal of zinc in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
G	Ceramic and Sediment	GF	100	81	84	85
L	Organic Carbon	FM	100	83	92	92

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

GF – gravity fed

FM – faucet mounted

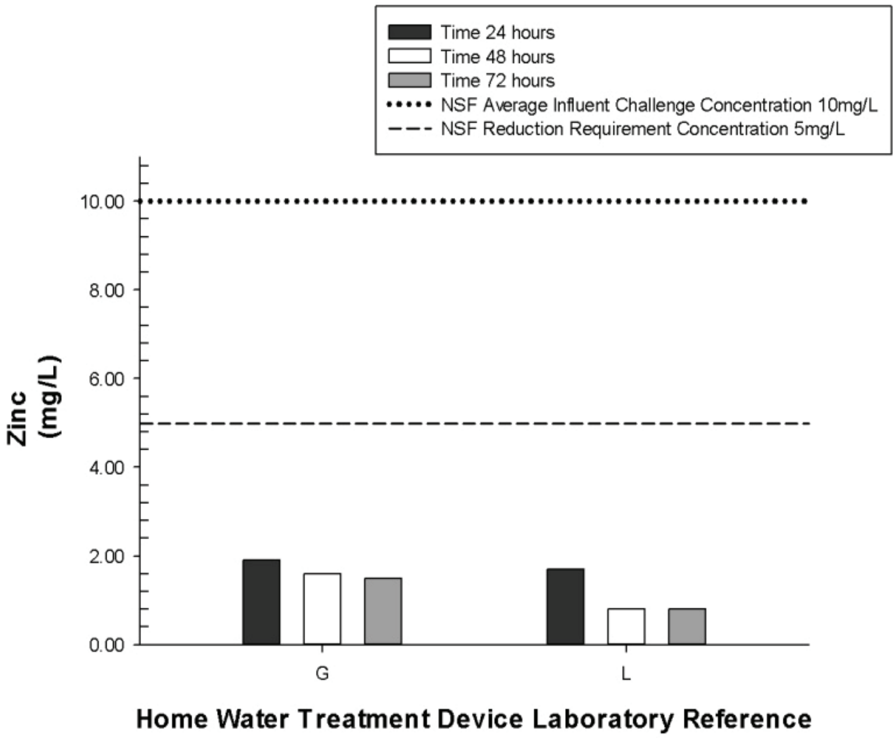

Figure 4.11 Results obtained for the removal efficiency of HWTDs for the removal of zinc in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

In accordance with Figure 4.11 and Table 4.13, HWTDs G and L tested within this study had manufacturing claims of a 100% zinc removal. While neither of the devices (G and L) removed a 100% of zinc, they both came very close and performed very well. Both of the devices tested meet the NSF 42 standard of 5 mg/L or 50% removal and SANS 241:2006 MCL of ≤ 5 mg/L expectancy standard of zinc removal over the 3 days of testing. Devices G and L utilized ceramic, sediment and organic carbon water treatment technologies and studies performed by Gulson *et al.* (1997); McAllister *et al.* (2005) and Varkey *et al.* (2012) have reported similar findings.

Overall the findings from this study suggest that both HWTDs G and L tested within this study are effective at removing zinc contamination from tap water, to acceptable levels that would produce potable water without any ill health effects and in general would improve the aesthetic nature (taste and clarity) of tap water.

4.4.1.3 Copper as Cu

Home water treatment devices C, D, E, F, G, L and M were analysed in terms of their removal capabilities of copper. The HWTDs were challenged with NSF recommended challenge test water spiked with 3 mg/L Copper Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.12) in relation to manufacturer removal efficiency claims (Table 4.14). In accordance with NSF 53 the minimum removal requirement of copper in HWTDs should be 1.3 mg/L or 57% removal. SANS 241:2006 requires ≤ 2 mg/L concentration of copper in tap water to prevent any chronic health effects.

The findings from this study suggest that HWTDs C, D, E, F, and G which utilize AC, IER, sediment, KDF and ceramic filtration technologies in combination could be effectively considered for the treatment of tap water, should there be a concern of copper contamination.

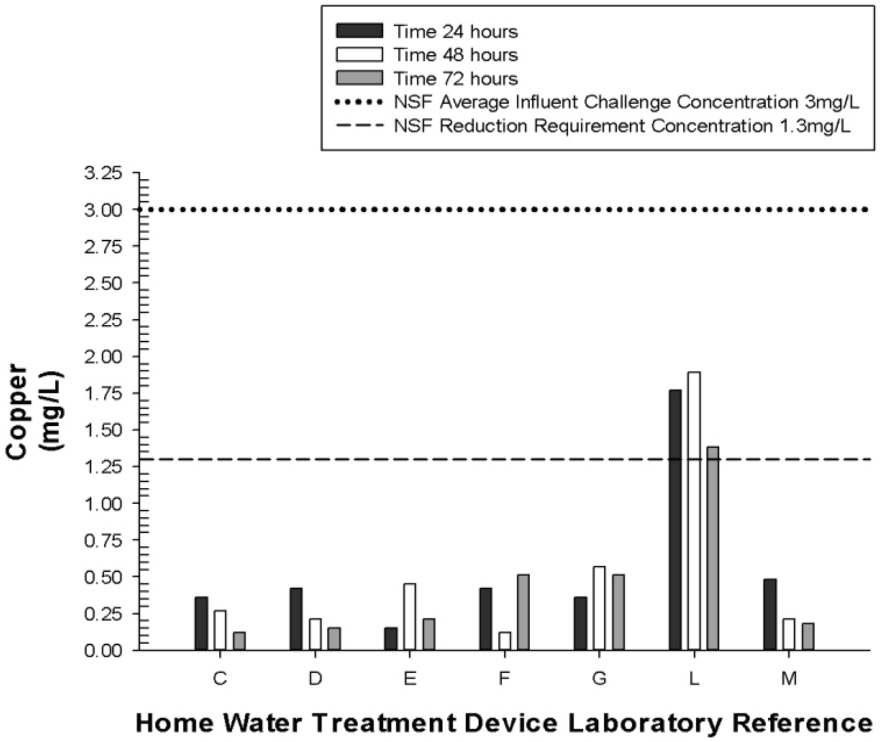

Figure 4.12 Results obtained for the removal efficiency of HWTDs for the removal of copper in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Table 4.14 Results obtained for the removal efficiency of HWTDs for the removal of copper in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
C	IER and AC	GF	100	88	91	96
D	IER and AC	GF	100	86	93	95
E	IER and AC	GF	100	95	85	93
F	AC	GF	100	86	96	83
G	Ceramic and Sediment	GF	100	88	81	83
L	Organic Carbon	FM	100	41	37	54
M	Sediment and KDF AC	FM	100	84	93	94

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

AC – activated carbon
KDF – kinetic degradation fluxion
FM – faucet mounted
IER – ion exchange resin
GF – gravity fed

In accordance with Figure 4.12 and Table 4.14, the HWTDs tested within this study had manufacturing claims of a 100% copper removal. All of the devices tested (other than L) were within reason close to their removal claims; however none of the devices effectively removed a 100% of the copper contaminant. Furthermore all of the devices tested (other than L), proved to have a removal efficiency of copper greater than 57% which met the NSF 53 standard of 1.3 mg/L and also reduced copper concentration within the treated water well below the SANS 241:2006 MCL of ≤ 2 mg/L, which would successfully prevent chronic health risks. On the other hand device L performed rather poorly and did not succeed in reducing copper after treatment to an acceptable NSF 53 standard; however did succeed in reducing copper satisfactorily to an acceptable SANS 241:2006 standard. Studies performed by Gulson *et al.* (1997) have reported concentrations of copper are most effectively reduced for drinking and cooking use with POU reverse osmosis and distillation water treatment units. Even though none of these water treatment technologies were utilized within this study AC, IER, sediment, KDF and ceramic filtration utilized in combination proved effective, these findings can be supported within studies performed by McAllister (2005) and Varkey *et al.* (2012). However organic carbon which was the treatment technology utilized in device L without any other treatment technology combination or supplementation proved to be ineffective at reducing copper contamination, suggesting that organic carbon filtration technology alone is infective at reducing copper contamination to an acceptable potable level, similar findings were reported by Ahmedna *et al.* (2004) and Bates (2000).

4.4.1.4 Iron as Fe

Home water treatment devices G and L were analysed in terms of their removal capabilities of iron. The HWTDs were challenged with NSF recommended challenge test water spiked with 3 mg/L Iron Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.13) in relation to manufacturer removal efficiency claims (Table 4.15). In accordance with NSF 42 the minimum removal requirement of iron in HWTDs should be 0.3 mg/L or 90% removal. SANS 241:2006 requires ≤ 0.3 mg/L (aesthetic) and ≤ 2 mg/L (chronic) concentration of iron in tap water to prevent any side effects.

In accordance with Figure 4.13 and Table 4.15, the HWTDs G and L tested within this study had manufacturing claims of a 100% iron removal. In general both devices did not manage to effectively remove a 100% of iron, however device G did come close to this amount after 24 hours of testing, but then drastically deteriorated in performance as time progressed. Furthermore both devices failed to meet the NSF 42 standard of 0.3 mg/L or 90% removal and SANS 241:2006 MCL of ≤ 0.3 mg/L expectancy of iron over the 3 days of testing. Studies performed by Nemande *et al.* (2009) have indicated that ceramic, sediment and organic carbon treatment technologies (as found within device G and L) are ineffective at removing iron contamination. However studies performed by Geldenhuys *et al.* (2002) and Gulson *et al.* (1997) and have shown that reverse osmosis, ion exchange, oxidizing filters, aeration and distillation can remove dissolved iron from contaminated water supplies.

A concerning finding was raised in studies performed by Nemande *et al.* (2009) and Pryor *et al.* (1998), they reported that HWTDs which utilized membrane system and sediment based water treatment technologies successfully excluded natural organic matter and iron from treated water, however this organic matter and iron remained confined within membranes and filters allowing non-pathogenic bacteria to harbour which caused membrane fouling, affecting the taste, smell and appearance of treated water.

The findings from this study suggest that HWTDs G and L which utilize sediment, ceramic and organic carbon filtration technologies are ineffective at removing iron contamination from tap water.

Table 4.15 Results obtained for the removal efficiency of HWTDs for the removal of iron in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
G	Ceramic and Sediment	GF	100	90	49	24
L	Organic Carbon	FM	100	52	44	42

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

GF – gravity fed

FM – faucet mounted

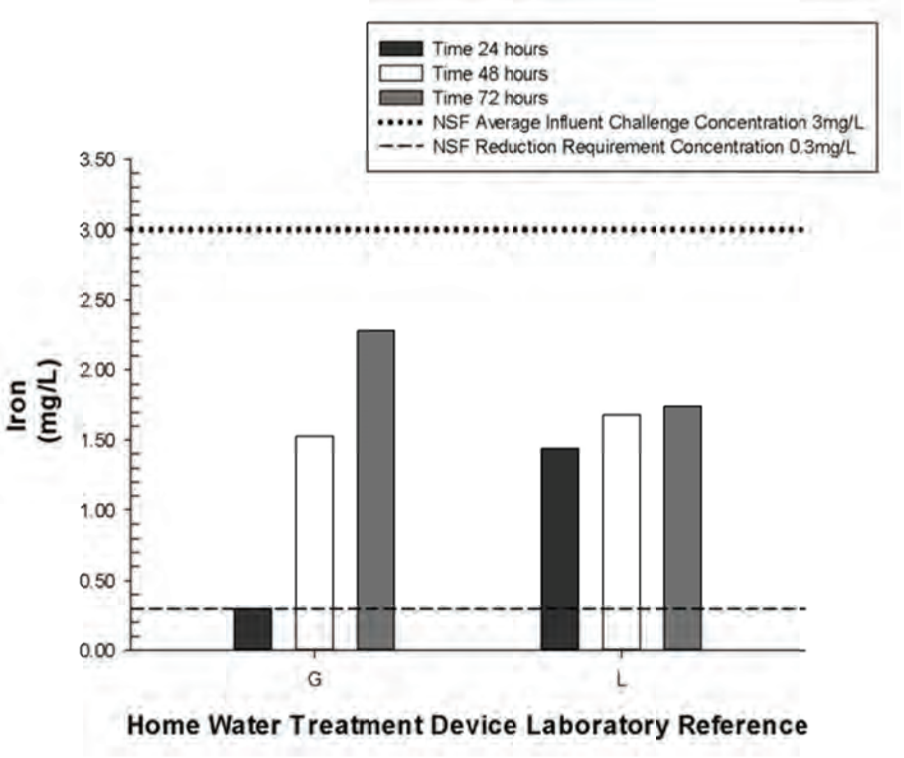

Figure 4.13 Results obtained for the removal efficiency of HWTDs for the removal of iron in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

4.4.1.5 Lead as Pb

Home water treatment devices B-G and I, J, L and M were analysed in terms of their removal capabilities of lead. The HWTDs were challenged with NSF recommended challenge test water spiked with 0.15 mg/L Lead Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.14) in relation to manufacturer removal efficiency claims (Table 4.16). In accordance with NSF 53 the minimum removal requirement of lead in HWTDs should be 0.01 mg/L or 93% removal. SANS 241:2006 requires ≤ 0.01 mg/L concentration of lead in tap water to prevent any chronic health effects.

In accordance with Figure 4.14 and Table 4.16, HWTDs B, C, D, E, F, G, I, J, L and M tested within this study had manufacturing claims of a 100% lead removal. None of these claims could be justified from the results reported, while all of the devices did manage to reduce lead after treatment they did not fare well in terms of removing a 100% of lead contaminants and devices E, G, J, L and M performed very poorly. All the devices failed to meet the NSF 53 standard of 0.01 mg/L or 93% removal and SANS 241:2006 MCL of ≤ 0.01 mg/L expectancy standard of lead over the 3 days of testing, although device B was very close to these removal ranges. A general observation could be made whereby the devices B, C, D, F and I which contained AC, IER and ceramic somehow seemed to fare better in terms of their lead removal potentials than the devices L and M that contained sediment, KDF and organic carbon. Studies performed by Ahmedna *et al.* (2004); Herman and Jennings (1996) and Snezana *et al.* (2008) support these findings as they reported reverse osmosis, distillation and activated carbon filters coupled with IER and ceramic water treatment technologies to be the most successful in reducing lead contamination in water, while other studies performed by Gulson *et al.* (1997) suggest sediment, KDF and organic carbon water treatment technologies to be inferior in terms of lead removal.

Overall the findings from this study suggest that all the HWTDs tested within this study are ineffective at removing lead contamination from tap water, to acceptable levels that would produce potable water without any ill health effects and that the lead removal claims made by their manufacturers are unjustified and they should not be recommended for lead removal from tap water.

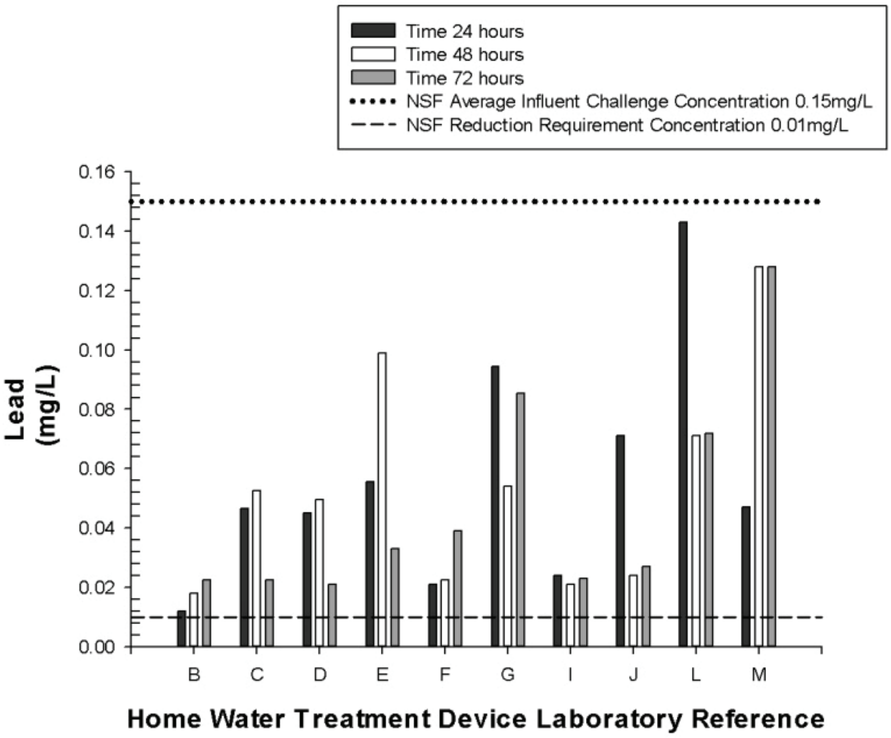

Figure 4.14 Results obtained for the removal efficiency of HWTDs for the removal of lead in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Table 4.16 Results obtained for the removal efficiency of HWTDs for the removal of lead in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
B	AC	GF	100	92	88	85
C	IER and AC	GF	100	69	65	85
D	IER and AC	GF	100	70	67	86
E	IER and AC	GF	100	63	34	78
F	AC	GF	100	86	85	74
G	Ceramic and Sediment	GF	100	37	64	43
I	Ceramic	FM	100	84	86	85
J	KDF AC	FM	100	53	84	82
L	Organic Carbon	FM	100	5	53	52
M	Sediment and KDF AC	FM	100	69	15	15

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

AC – activated carbon
IER – ion exchange resin
KDF – kinetic degradation fluxion
GF – gravity fed
FM – faucet mounted

4.4.1.6 Aluminium as Al

Home water treatment devices C, E, F, G and L were analysed in terms of their removal capabilities of aluminium. The HWTDs were challenged with NSF recommended challenge test water spiked with 0.5 mg/L Aluminium Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.15) in relation to manufacturer removal efficiency claims (Table 4.17). In accordance with NSF 42 and 53 the minimum removal requirement of aluminium in HWTDs should be 0.2 mg/L or 60% removal. SANS 241:2006 requires ≤ 0.3 mg/L concentration of aluminium in tap water to prevent any operational effects.

In accordance with Figure 4.15 and Table 4.17, HWTDs C, E, F, G and L tested within this study had manufacturing claims of a 100% aluminium removal. None of these claims could be justified from the results reported, while all of the devices did manage to reduce aluminium after treatment they did not fare well in terms of removing a 100% of aluminium contaminants. Device C failed to meet the NSF 42 standard of 0.2 mg/L or 60% aluminium removal, devices E and L met this standard on the second day of testing, device G on the last day and device F on the first day and then showed poor aluminium removal potential. Device C also failed to meet SANS 241:2006 MCL of ≤ 0.3 mg/L expectancy standard of aluminium over the 3 days of testing and devices G and L met this standard on the 2 day of testing, however devices E and F met this standard on all three days of testing.

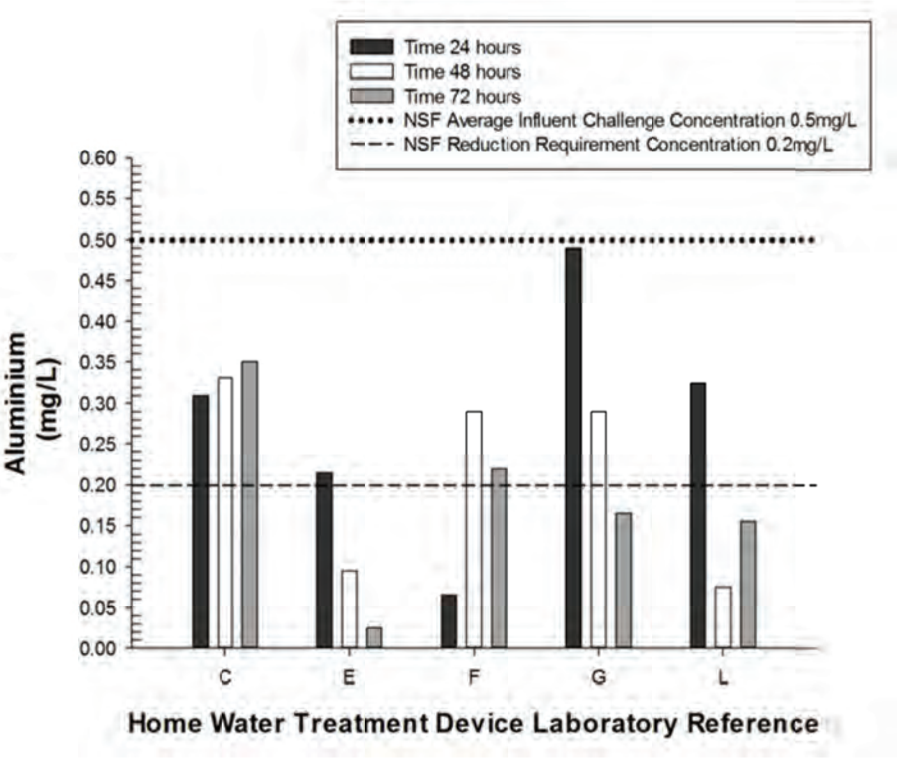

Figure 4.15 Results obtained for the removal efficiency of HWTDs for the removal of aluminium in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Devices C and E both used IER and AC water treatment technologies, however device E overall showed excellent aluminium removal potentials whereas device C performed poorly. This result could perhaps be attributed to the type of IER water technology each device utilized (i.e. either being cationic or anionic), aluminium is a positively charged ion and so cationic exchange resins (perhaps utilized by device E) would be more successful in reducing its concentration than an anionic exchange resin (perhaps utilized by device C), which would fail at reducing a positivity charged ion such as aluminium. These findings can be supported by Marta *et al.* (2008) and Wang *et al.* (2010) whereby the ion removal potentials of IER where reported. Devices F and L overall performed rather poorly in reducing aluminium concentrations after treatment, both these devices utilized carbon based water treatment technologies and reports by Gulson *et al.* (1997) and Mohan *et al.* (2006) have indicated that carbon based filters show poor absorption of aluminium. Device G which utilized ceramic water treatment technology showed a gradual decrease in aluminium concentration over the 3 days in testing, with its meeting the standards stipulated by NSF 42 on day three. Studies performed by McAllister (2005) and Plappally *et al.* (2010) have shown that ceramic water treatment technologies can gradually absorb aluminium ions, decreasing the concentration of aluminium in treated water over time.

Table 4.17 Results obtained for the removal efficiency of HWTDs for the removal of aluminium in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
C	IER and AC	GF	100	38	34	30
E	IER and AC	GF	100	57	81	95
F	AC	GF	100	87	42	56
G	Ceramic and Sediment	GF	100	2	42	67
L	Organic Carbon	FM	100	35	85	69

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

AC – activated carbon

IER – ion exchange resin

GF – gravity fed

FM – faucet mounted

Overall the findings from this study suggest that HWTDs technologies that utilize cationic exchange resins (as in the case of device E) are successful at reducing aluminium contaminates in treated water. Ceramic water filtration technologies (as in device G) could be considered, however further evaluation in terms of a longevity study would be recommended. As for carbon based water treatment technologies (as in device F and L) they would not be recommended in terms of efficient removal of aluminium from tap water, however, farther longevity studies would be suggested to substantiate their manufacturers claims.

4.4.1.7 Total Chromium as Chromate

Home water treatment devices G, I and L were analysed in terms of their removal capabilities of chromium. The HWTDs were challenged with NSF recommended challenge test water spiked with 0.3 mg/L Chromate Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.16) in relation to manufacturer removal efficiency claims (Table 4.18). In accordance with NSF 53 the minimum removal requirement of chromium in HWTDs should be 0.1 mg/L or 67% removal. SANS 241:2006 requires ≤ 0.05 mg/L concentration of chromate in tap water to prevent any chronic health effects.

Thus SANS 241:2006 has established a maximum contaminant level (MCL) for chromium (≤ 0.05 mg/L) within municipally supplied tap water, to ensure safe drinking water that does not pose a chronic health risk is supplied to the South African public (SANS 241:2006). However even with this taken into consideration consumers tend to be concerned with the chromium concentrations in their drinking water due to the excessive mining of chromium ore which occurs in this country and so they often tend to turn to use of HWTDs to rectify the problem (Mohan *et al.*, 2006).

In accordance with Figure 4.16 and Table 4.18, HWTDs G, I and L tested within this study had manufacturing claims of a 100% chromium removal. None of these claims proved true to form, however devices I and L, did perform well in terms of chromium removal, but not in completely removing it as claimed by their manufacturers. Devices I and L did managed to meet the NSF 53 standard of 0.1 mg/L or 67% chromium removal, over the 3 days of testing, however device G did not. In terms of SANS 241:2006 (which is stricter than NSF 53), device G failed to meet to the MCL of ≤ 0.05mg/L expectancy standard of chromium over the 3 days of testing and device L met this standard over the last two days of testing, however device I met this standard only on the first day of testing. In general device G performed very poorly and it utilized ceramic and sediment water treatment technology, however device I performed fairly well in comparison to device G and it also utilized ceramic water treatment technology. This finding could perhaps be attributed to the porosity and type of ceramic clay utilized by the manufacturers to treat water, as studies performed by Mohan *et al.* (2006) have reported that denser type clays are more successful at chromium adsorption than more porous type clays. On the other hand device L was very successful at reducing chromium after treatment and it utilized organic carbon water treatment technology. This finding can be substantiated by findings reported by Mohan *et al.* (2006) where by high chromium levels were successfully reduced utilizing carbon based filter technologies.

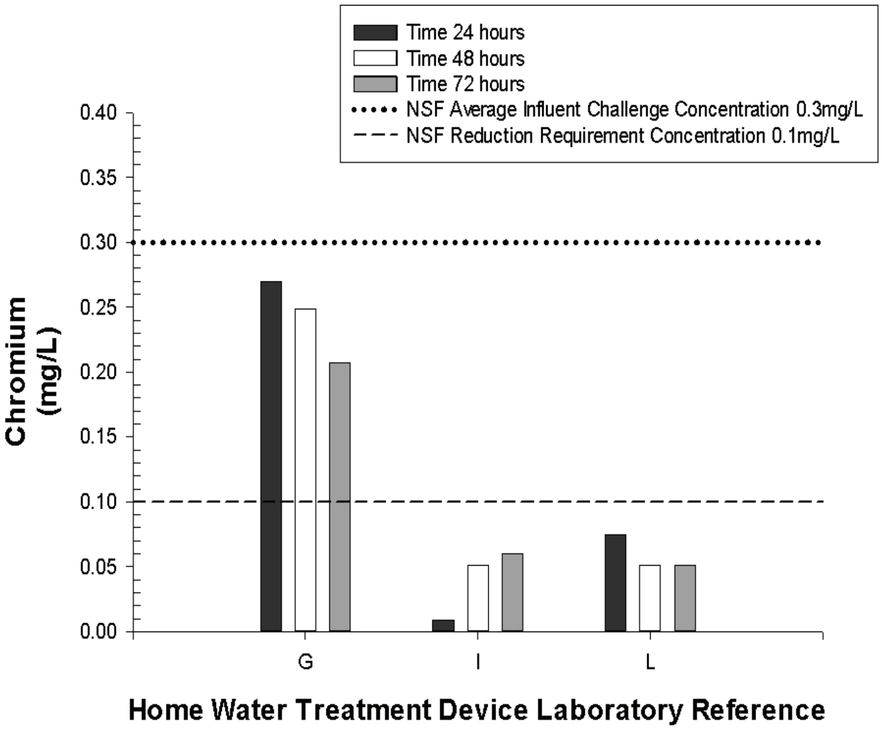

Figure 4.16 Results obtained for the removal efficiency of HWTDs for the removal of chromium in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Table 4.18 Results obtained for the removal efficiency of HWTDs for the removal of chromium in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
G	Ceramic and Sediment	GF	100	10	17	31
I	Ceramic	FM	100	97	83	80
L	Organic Carbon	FM	100	75	83	83

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

GF – gravity fed

FM – faucet mounted

Overall the findings from this study suggest that HWTDs technologies that utilize carbon (device L) and dense ceramic (device I) based water treatment technologies are successful at reducing chromium contaminates from tap water.

4.4.1.8 Manganese as Mn

Home water treatment devices F, G, L and M were analysed in terms of their removal capabilities of manganese. The HWTDs were challenged with NSF recommended challenge test water spiked with 1 mg/L Manganese Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.17) in relation to manufacturer removal efficiency claims (Table 4.19). In accordance with NSF 42 the minimum removal requirement of manganese in HWTDs should be 0.05 mg/L or 95% removal. SANS 241:2006 requires ≤ 0.5 mg/L (chronic health) and ≤ 0.1 mg/L (aesthetic) concentration of manganese in tap water.

In accordance with Figure 4.17 and Table 4.19, HWTDs G, L and M tested within this study had manufacturing claims of a 100% manganese removal, while device F manufacturers proclaimed it added manganese to treated water. None of these claims could be justified with the results reported, while devices G, L and M did manage to reduce manganese after treatment they did not fare well in terms of removing a 100% of manganese contaminants and device F did not add manganese to the water after treatment but instead lowered its concentrations. All the devices failed to meet the NSF 42 standard of 0.05 mg/L or 95% removal and SANS 241:2006 MCL of ≤ 0.1 mg/L expectancy standard of manganese over the 3 days of testing. Device M came the closest to both of the above mentioned standards in terms of manganese removal, however was very inconsistent over the 3 days of testing. Studies by Geldenhuys *et al.* (2002); Gulson *et al.* (1997) and Kommineni *et al.* (2004) have reported concentrations of manganese are most effectively reduced with POU reverse osmosis, ion exchange, oxidizing filters, and aeration and distillation water treatment units. This could perhaps assist in supporting the results of this study since none of the HWTDs tested within this study utilized any of the above mentioned treatment technologies and so their overall performance was poor. In addition findings reported by Pryor *et al.* (1998) suggest that HWTDs that remove manganese by size exclusion or membrane technology are more prone to fouling, affecting the taste, smell and appearance of treated water.

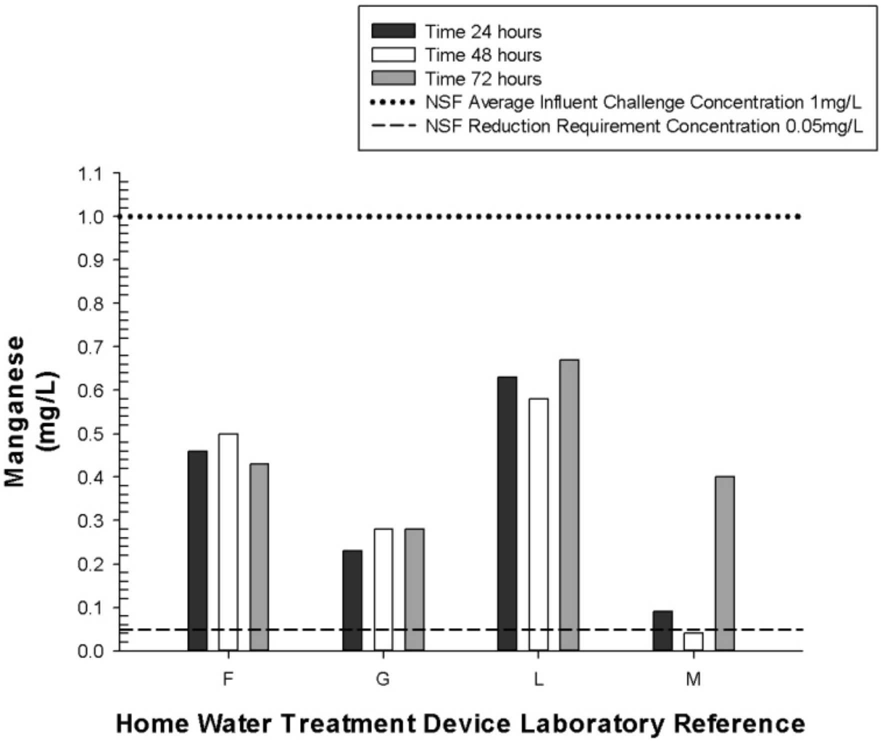

Figure 4.17 Results obtained for the removal efficiency of HWTDs for the removal of manganese in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Overall the findings from this study suggest that the HWTDs (utilizing AC, ceramic, sediment, organic carbon and KDF water treatment technologies) tested within this study are ineffective at removing manganese contamination from water and so would be ineffective in improving the aesthetic water quality of treated water.

Table 4.19 Results obtained for the removal efficiency of HWTDs for the removal of manganese in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
F	AC	GF	Add	54	50	57
G	Ceramic and Sediment	GF	100	77	72	72
L	Organic Carbon	FM	100	37	42	33
M	Sediment and KDF AC	FM	100	91	96	60

Footnote:

– indicates 100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

Add – indicates that the manufacturer claimed that the home water treatment device added this chemical / physical compound to the final water quality eluted from the device.

AC – activated carbon

GF – gravity fed

KDF – kinetic degradation fluxion

FM – faucet mounted

4.4.1.9 Total Organic Carbon (TOC) as C

Home water treatment devices A, C, I, J, K, L and M were analysed in terms of their removal capabilities of total organic carbon (TOC). The HWTDs were challenged with distilled water spiked with 15 mg/L TOC Standard Solution. After the challenge the eluted municipal tap water was collected from the HWTDs and the final elution concentration / removal efficiency in mg/L was reported (Figure 4.18) in relation to manufacturer removal efficiency claims (Table 4.20). In accordance with SANS 241:2006 requires ≤ 10 mg/L concentration of TOC in tap water to prevent any chronic health effects.

In accordance with Figure 4.18 and Table 4.20, HWTDs A, C, I, J, K, L and M tested within this study had manufacturing claims between 99-100% total carbon organic contaminants removal in treated water. None of these claims proved true to form, while devices C and K did manage to reduce TOC after 3 days of water treatment and device A after 2 days of testing they did not fare well in terms of removing a 100% of TOC contaminants. Devices I, J, L and M performed even worse over the 3 days of testing as they did not meet their manufacturing claims of reducing TOC, they actually managed to add more organic carbon (results reported are above the initial TOC challenge water spike) to the final treated water product. All the devices failed to meet SANS 241:2006 MCL of ≤ 10 mg/L expectancy standard of TOC over the 3 days of testing, other than device C. The accomplishments of device C could be attributed to the fact that it utilized IER water treatment technology (whereas the other devices tested did not) and studies performed by Wang *et al.* (2010) have reported successful TOC removal results utilizing IER in water purification. The poor performance and addition of further organic carbon to the final treated water product by devices A, I, J, L and M, could perhaps be attributed to the fact that they all utilized some form of organic carbon treatment methods of water purification. Studies by Yoro *et al.* (1999) and Yue *et al.* (2005) can support these findings as they reported increases in TOC levels of treated water when utilizing carbon based water treatment technologies, attributing it the fact that the carbon based filters allowed carbon to leach into the treated water. Other reports by Matilainen *et al.* (2010) and Yue *et al.* (2005) indicated that TOC significantly affects many aspects of POU water treatment; if it is not removed or harbours on filters this can have an overall influence on the performance of the unit as it processes water, affecting the application of water treatment chemicals and so compromises the biological stability of treated water. In addition studies by Matilainen *et al.* (2010) and Yoro *et al.* (1999) reported TOC as being responsible for coagulation during the water treatment process and in terms of HWTDs this has a tendency to interfere with the removal of other contaminants, causing membrane fouling since TOC acted as a substrate for bacterial growth.

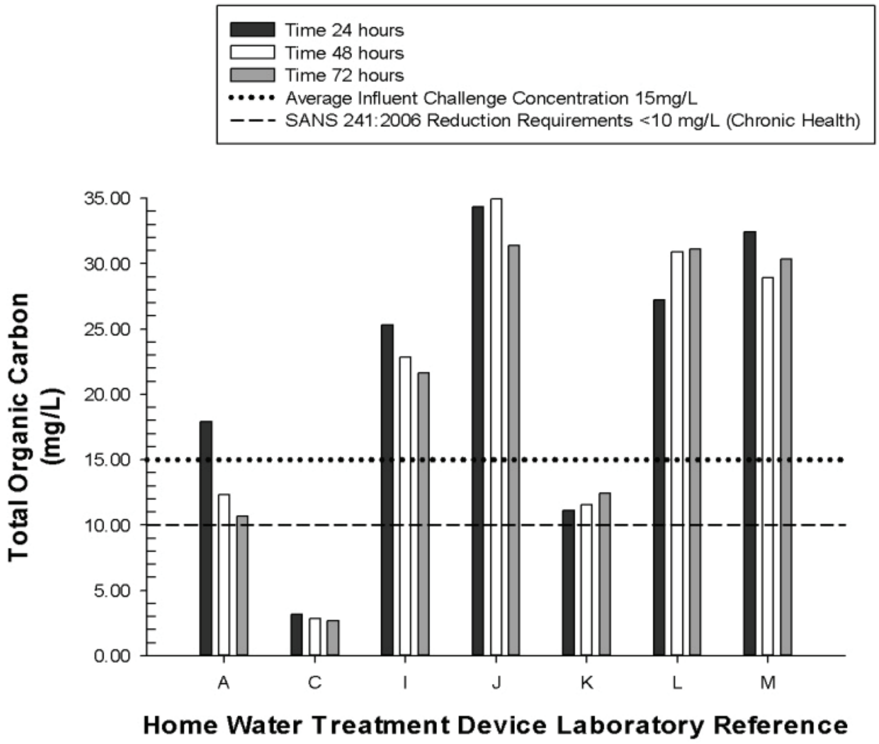

Figure 4.18 Results obtained for the removal efficiency of HWTDs for the removal of total organic carbon in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Table 4.20 Results obtained for the removal efficiency of HWTDs for the removal of total organic carbon in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	100	*19	18	29
C	IER and AC	GF	100	79	81	82
I	Ceramic	FM	100	*69	*52	*44
J	KDF AC	FM	100	*129	*136	*109
K	GAC	FM	100	26	23	17
L	Organic Carbon	FM	100	*81	*106	*107
M	Sediment and KDF AC	FM	99	*116	*93	*102

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

***** – indicates final result percentage was not a removal, it was an increase (i.e. the result indicated an increase within the particular assay above the spike reference of 100% and so more of the chemical / physical compound was found within the final water quality of the home water treatment device than what was originally added to the spiked challenge test water).

AC – activated carbon	**KDF** – kinetic degradation fluxion	**GF** – gravity fed
IER – ion exchange resin	**GAC** – granular activated carbon	**FM** – faucet mounted

Thus overall the findings from this study suggest that all the HWTDs (other than C) tested within this study are ineffective at removing TOC contamination from tap water, to acceptable levels that would improve tap water quality and that there is a good chance of membrane fouling of these devices due to their carbon based technologies which allow bacteria to harbour. However, device C utilizing IER water treatment technology could be considered for TOC removal, since it met the standards required by SANS 241:2006.

4.4.1.10 Phenol

Home water treatment devices A-E and G, H, I, K, L and M were analysed in terms of taste and odour for their removal capabilities of phenol. The HWTDs were challenged with NSF recommended challenge test water spiked with 5 mg/L Phenol Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.19) in relation to manufacturer removal efficiency claims (Table 4.21). In accordance with NSF 42 the minimum removal requirement of phenol in HWTDs should be 0.25 mg/L or 42% removal. SANS 241:2006 requires ≤ 0.01 mg/L concentration of phenol in tap water to prevent any aesthetic effects.

In accordance with Figure 4.19 and Table 4.21, HWTDs A-E, G, H, I, K, L and M tested within this study had manufacturing claims of a 100% phenol removal in terms of improving the taste and odour of treated water. None of these claims could be justified from the results reported within this study, while all of the devices did manage to reduce phenol after treatment they did not fare well in terms of removing a 100% of phenol contaminants and devices I and L performed very poorly. All the devices failed to meet the NSF 42 standard of 0.25 mg/L or 95% removal and SANS 241:2006 MCL of ≤ 0.01 mg/L expectancy standard of phenol over the 3 days of testing, although device B and C, were very successful at reducing the phenol contaminant on the last day of testing. A general observation of results could be made in devices B, C, D, E and H which contained AC (most predominant), IER, sediment and UF water treatment technologies they gradually showed a removal of phenol over the 3 days of testing. The devices which contained sediment, ceramic, KDF, AC and GAC water treatment technologies showed consistent removal of phenol, whereas devices (A, L and M) which contained organic carbon and ceramic water treatment technologies performed very poorly, even though device A did reduce phenol successfully at 24hrs of testing, it then failed to meet these removal potentials over the next 2 days of testing.

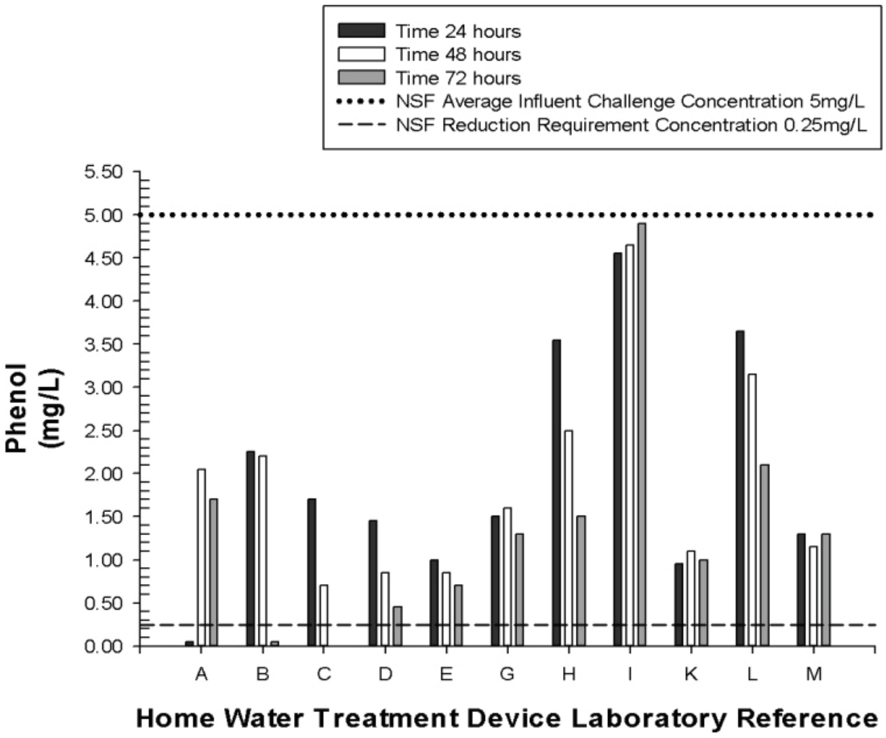

Figure 4.19 Results obtained for the removal efficiency of HWTDs for the removal of phenol in the test water to simulate taste and odour tests. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Table 4.21 Results obtained for the removal efficiency of HWTDs for the removal of phenol in the test water to simulate taste and odour tests. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
A	Organic Carbon	GF	100	99	59	66
B	AC	GF	100	55	56	99
C	IER and AC	GF	100	66	86	100
D	IER and AC	GF	100	71	83	91
E	IER and AC	GF	100	80	83	86
G	Ceramic and Sediment	GF	100	70	68	74
H	Sediment, Silver AC and UF	GF	100	29	50	70
I	Ceramic	FM	100	9	7	2
K	GAC	FM	100	81	78	80
L	Organic Carbon	FM	100	27	37	58
M	Sediment and KDF AC	FM	100	74	77	74

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

FM – faucet mounted

AC – activated carbon	**KDF** – kinetic degradation fluxion	**GF** – gravity fed
IER – ion exchange resin	**GAC** – granular activated carbon	**FM** – faucet mounted

Studies performed by Adak *et al.* (2006); McAllister (2005) and Snezana *et al.* (2008) support these findings as they reported activated carbon adsorption, reverse osmosis, distillation and IER water treatment technologies to be the most successful in reducing phenol contamination in water, while other studies performed by Varkey *et al.* (2012) suggest organic carbon and ceramic water treatment technologies to be inferior in terms of phenol removal.

Overall the findings from this study suggest that all the HWTDs tested within this study are ineffective at removing phenol contamination from tap water, to acceptable levels that would improve tap water aesthetically in terms of taste and odour and so their manufacturer's claims in terms of improving taste and odour or removing phenol contaminants are unjustified.

4.4.2 Additional Tests in Accordance with NSF (not SANS 241:2006 related)

Additional chemicals such as phosphates, silicates and calcium carbonate were tested for in terms of their addition or removal capabilities by HWTDs as they are often found in water treatment technologies that can soften water and reduce the scale formation in drinking water, which many manufacturers use as claims when selling HWTDs. These chemicals are nontoxic and so are not monitored by SANS 241:2006, however the NSF recommends these tests in terms of a performance evaluation on manufacturer claims. Note not all the HWTDs purchased for this study were tested in terms of these additional tests; only the devices which actually had manufacturing claims for the specific chemicals assays performed within this section were tested for in terms of a claim made by the manufacturer for that particular chemical removal / addition capability claim that they made reference to when utilizing their HWTDs.

4.4.2.1 Phosphates

Home water treatment devices B, C, D, E, F, K and M, were analysed in terms of their scale removal capabilities of by phosphate addition assays. The HWTDs were challenged with NSF recommended challenge test water spiked with 10 mg/L Phosphate Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.20) in relation to manufacturer removal / addition efficiency claims (Table 4.22). In accordance with NSF 42 the minimum removal / addition requirement of phosphate in HWTDs should be 0.5 -10 mg/L or in accordance with manufacturer specifications / claims.

In accordance with Figure 4.20 and Table 4.22, HWTDs B, C, D, E, F, K and M tested within this study had manufacturing claims of a 100% scale removal. All these devices succeeded very well, as they either kept the phosphate concentration within the final treated water consistent without reporting any high removal efficiency values and some of the devices even added more phosphate (above the challenge test water spike) to the water after treatment.

All the devices met the NSF 42 standard of 0.5 mg/L to 10 mg/L phosphate concentration standard expectancy, for scale removal over the 3 days of testing. Studies performed by Gulson *et al.* (1997) have reported that carbon based water treatment technologies show a low adsorption of phosphate and so succeed very well in terms of scale control in treated water.

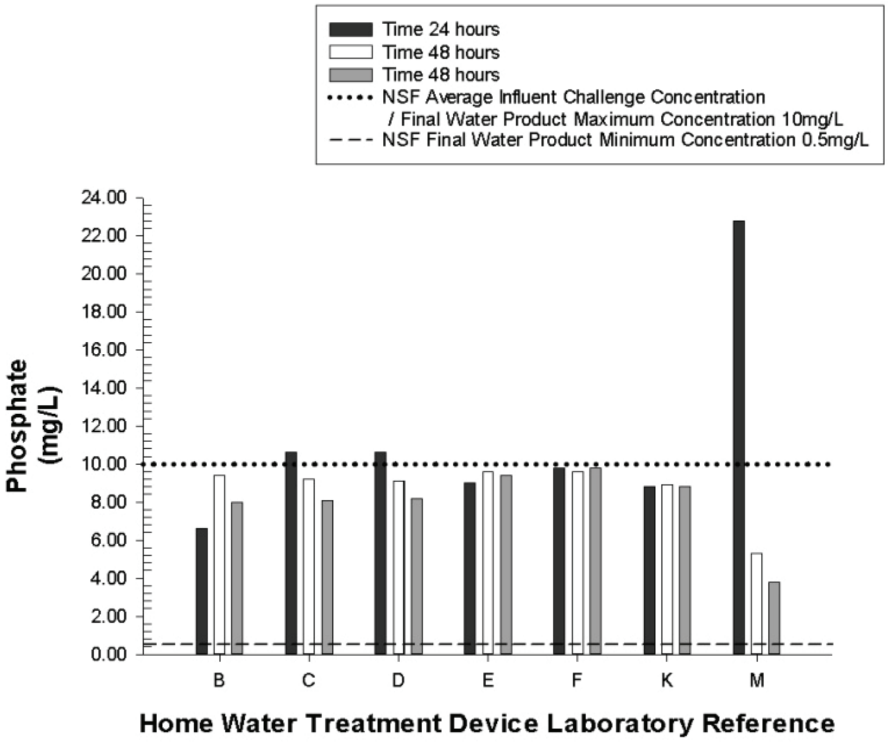

Figure 4.20 Results obtained for the removal efficiency of HWTDs for the removal of phosphate scales in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Table 4.22 Results obtained for the removal efficiency of HWTDs for the removal of phosphate scales in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
B	AC	GF	100	34	6	20
C	IER and AC	GF	100	*6	8	19
D	IER and AC	GF	100	*6	9	18
E	IER and AC	GF	100	10	4	6
F	AC	GF	100	2	4	2
K	GAC	FM	100	12	11	12
	Sediment and KDF AC	FM	100	*128	47	62

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of **scale** in the home water treatment device unless otherwise stipulated by the manufacturer.

***** – indicates final result percentage was not a removal, it was an increase (i.e. the result indicated an increase within the particular assay above the spike reference of 100% and so more of the chemical / physical compound was found within the final water quality of the home water treatment device than what was originally added to the spiked challenge test water).

AC – activated carbon	**KDF** – kinetic degradation fluxion	**GF** – gravity fed
IER – ion exchange resin	**GAC** – granular activated carbon	**FM** – faucet mounted

A concerning factor is that studies by Pravst *et al.* (2011) have shown that excessive intake of phosphate can cause secondary hyperparathyroidism and bone loss, as well as increase the risk factor of cardiovascular morbidity and mortality. This could potentially pose a problem in HWTDs that utilize phosphate addition to treated water in term of scale control. In addition studies performed by Batte *et al.* (2003); Gouider *et al.* (2009) and Sarin *et al.* (2004) have reported membrane fouling and biofilm formation due to high phosphate concentrations being present within the water treatment technology as it provides a nutrient substrate for microbial growth, this could potentially cause the device to produce bad odors, affecting the waters overall quality and aesthetics.

Overall the findings from this study suggest that all the HWTDs tested within this study are effective at keeping / adding phosphate to tap water, to acceptable levels that would improve tap water aesthetically in terms of reducing scale.

4.4.2.2 Silicates

Home water treatment devices B, C, D, E, F, K and M, were analysed in terms of their scale removal capabilities of by silicate addition assays. The HWTDs were challenged with NSF recommended challenge test water spiked with 16 mg/L Silicon Standard Solution. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.21) in relation to manufacturer removal / addition efficiency claims (Table 4.23). In accordance with NSF 42 the minimum removal / addition requirement of silicate in HWTDs should be 0.5-16 mg/L or in accordance with manufacturer specifications / claims.

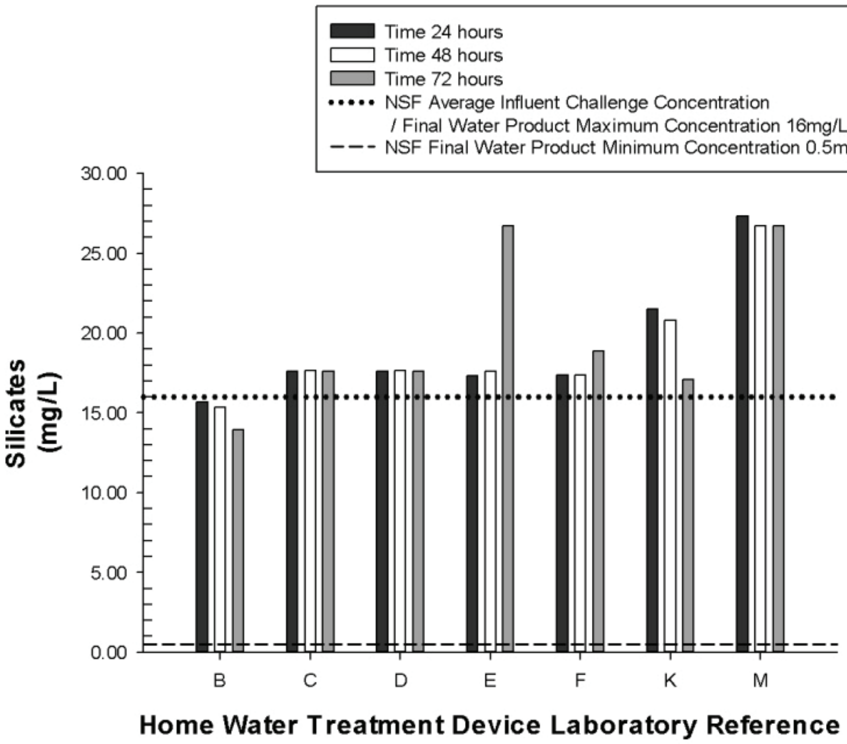

Figure 4.21 Results obtained for the removal efficiency of HWTDs for the removal of silicate scales in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

In accordance with Figure 4.21 and Table 4.23, HWTDs B, C, D, E, F, K and M tested within this study had manufacturing claims of a 100% scale removal. All these devices succeeded very well, as they either kept the silicate concentration within the final treated water consistent without reporting any high removal efficiency values and some of the devices even added more silicate (above the challenge test water spike) to the water after treatment. All the devices met the NSF 42 standard of 0.5 mg/L to 10 mg/L silicate concentration standard expectancy, for scale removal over the 3 days of testing. Studies performed by Gulson *et al.* (1997) have reported that carbon based water treatment technologies show a low adsorption of phosphate and silicate and so succeed very well in terms of scale control in treated water.

Table 4.23 Results obtained for the removal efficiency of HWTDs for the removal of silicate scales in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
B	AC	GF	100	2	4	13
C	IER and AC	GF	100	*10	*10	*10
D	IER and AC	GF	100	*10	*10	*10
E	IER and AC	GF	100	*8	*10	*67
F	AC	GF	100	*9	*9	*18
K	GAC	FM	100	*35	*30	*7
M	Sediment and KDF AC	FM	100	*71	*67	*67

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of **scale** in the home water treatment device unless otherwise stipulated by the manufacturer.

***** – indicates final result percentage was not a removal, it was an increase (i.e. the result indicated an increase within the particular assay above the spike reference of 100% and so more of the chemical / physical compound was found within the final water quality of the home water treatment device than what was originally added to the spiked challenge test water).

AC – activated carbon	**KDF** – kinetic degradation fluxion	**GF** – gravity fed
IER – ion exchange resin	**GAC** – granular activated carbon	**FM** – faucet mounted

The only concerning factor is that studies by Jugdaohsingh *et al.* (2007) have reported oral ingestion of high concentrations of silica / silicates may also cause toxicity, as it can promotes esophageal cancer, skin tumors, inflammation of the kidneys (interstitial nephritis) and liver disease. This could potentially pose a problem in HWTDs that utilize silicate addition to treated water in term of scale control.

Overall the findings from this study suggest that all the HWTDs tested within this study are effective at keeping / adding silicate to tap water, to acceptable levels that would improve tap water aesthetically in terms of reducing scale.

4.4.2.3 Alkalinity and Calcium as $CaCO_3$ (Total Hardness)

Home water treatment devices B, C, D, E and F were analysed in terms of water softening and alkalinity removal (total hardness) abilities by testing for the reduction of calcium carbonate concentration. The HWTDs were challenged with NSF recommended challenge test water spiked with 342 mg/L calcium carbonate. After the challenge the eluted challenge test water was collected from the HWTDs and the final elution concentration in mg/L was reported (Figure 4.22) in relation to manufacturer removal efficiency claims (Table 4.24). In accordance with NSF 44 the minimum removal requirement of Calcium Carbonate in HWTDs should be soft: 0 to75 mg/L; moderate: 75 to 150 mg/L; hard: 150 to 300 mg/L; very hard: above 300 mg/L or in accordance with manufacturer specifications / claims. In terms of SANS 241:2006 it requires ≤ 150 mg/L concentration of calcium carbonate in tap water to prevent any aesthetic effects.

As water moves through soil and rock, it dissolves very small amounts of minerals and holds them in solution (Herman, 1996). The two most common mineral that make water hard are calcium (in the form of calcium carbonate) and magnesium (Herman, 1996 and Snezana *et al.*, 2008). The degree of hardness becomes more prominent and greater as the calcium and magnesium content increases and hard water impacts on nearly all household cleaning tasks: dishwashing, clothes laundering and bathing (Kim *et al.*, 2011). The amount of dissolved minerals in water (degree of hardness) affects the amount of soap and detergent required to effectively clean (Sarin *et al.*, 2004). Heated hard water forms scale of calcium and magnesium minerals that can contribute to the inefficient operation of water using appliances such as irons and kettles (Sarin *et al.*, 2004).

Hard water is not a health hazard; in fact drinking hard water can contribute a small amount toward total calcium and magnesium human dietary needs (Sarin *et al.*, 2004). Even though hard water is non-toxic, SANS 241 has established a maximum contaminant level (MCL) for calcium carbonate (≤150mg/L) within municipally supplied tap water, to ensure aesthetically pleasing tap water is supplied to the South African public (SANS 241:2006). However even with this taken into consideration sometimes consumers still feel there final tap water quality is hard and dislike the scale it causes in heating appliances as well as the soap curd it causes and so turn to HTWDs to soften their tap water (Kim *et al.*, 2011).

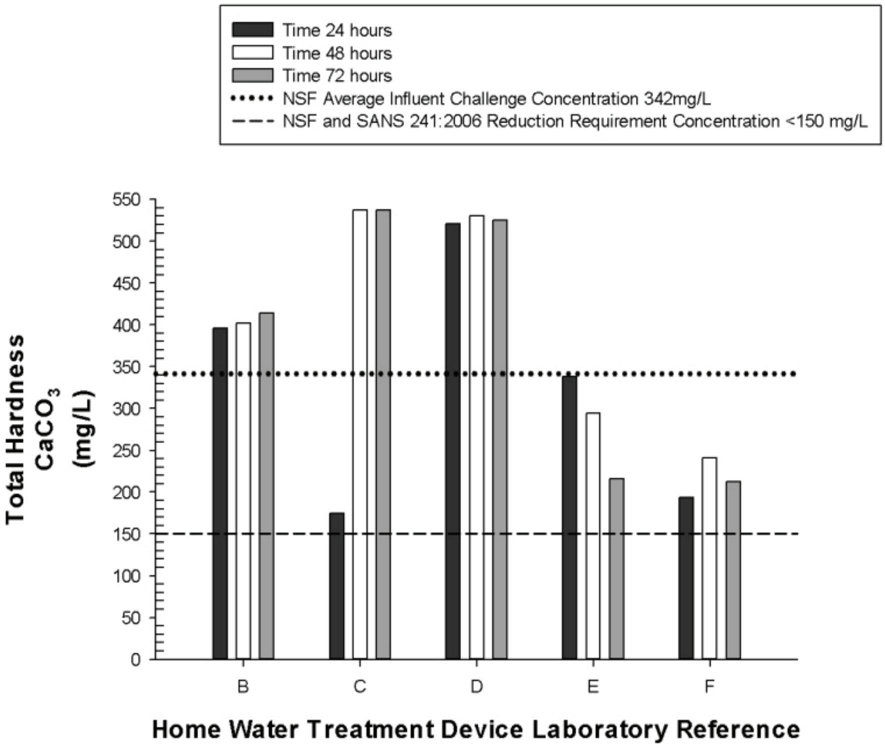

Figure 4.22 Results obtained for the removal efficiency of HWTDs for the removal of total hardness (tested as alkalinity and calcium $CaCO_3$) as in the test water. The graphs shows the removal capabilities of each of the units tested over the three days. The graph also shows the challenge concentration used as outlined by the NSF guidelines and the minimum allowable levels after the water has been treated.

Table 4.24 Results obtained for the removal efficiency of HWTDs for the removal of total hardness (tested as alkalinity and calcium $CaCO_3$) as in the test water. The table shows the removal capabilities of each of the units tested over the three days. The table shows the treatment technology, treatment mode and the manufacturers claims when compared to the actual removal efficiency (%).

HWTD	Treatment Technology	Treatment Mode	Removal Efficiency (%)			
			#Manufacturer Claim	24hrs	48hrs	72hrs
B	AC	GF	100	*16	*18	*21
C	IER and AC	GF	100	49	*57	*57
D	IER and AC	GF	100	*52	*55	*54
E	IER and AC	GF	100	1	14	37
F	AC	GF	100	44	30	38

Footnote:

– indicates100% was assumed as a manufacturer claim for removal efficiency / removal capabilities of the home water treatment device unless otherwise stipulated by the manufacturer.

***** – indicates final result percentage was not a removal, it was an increase (i.e. the result indicated an increase within the particular assay above the spike reference of 100% and so more of the chemical / physical compound was found within the final water quality of the home water treatment device than what was originally added to the spiked challenge test water).

AC – activated carbon

IER – ion exchange resin

GF – gravity fed

In accordance with Figure 4.22 and Table 4.24, HWTDs B, C, D, E and F tested within this study had manufacturing claims of a 100% calcium removal in terms of reducing the scale formation and hardness in treated water. None of these claims could be justified from the results reported, while devices E and F did manage to slightly reduce calcium carbonate after treatment they did not fare well in terms of removing a 100% of calcium contaminants and devices B and D performed very poorly as they added even more calcium carbonate after water treatment, as did device C after 2 days of testing. All the devices failed to meet the NSF 44 standard of 150 mg/L or 56% removal and SANS 241:2006 MCL of ≤ 150 mg/L expectancy standard of calcium carbonate over the 3 days of testing.

The reason for this failure to soften water could be attributed to the fact that the water treatment technologies utilized within all these devices were AC based and studies by Fengyi *et al.* (2009) have shown that AC water treatment technologies do not successfully reduce the total hardness of treated water and can sometimes decrease the binding capacity of calcium carbonate ions, as observed in devices B, C and D.

Other studies performed by Geldenhys *et al.* (2002) suggest the utilization of ion exchange cation based water treatment technologies to soften water through the use of sodium addition; device E did utilize IER water treatment technology and did manage to gradually reduce the calcium carbonate content over 3 days of testing, thus there is a possibility its IER water softening technology was cation sodium based. However, devices C and D also used IER water treatment technologies and showed a drastic increase in results in terms of adding calcium to the treated water, this result could perhaps be attributed to the fact that the IER water treatment technologies used by them was not cation sodium based, but anion exchange resin based water treatment technologies and so these devices (C and D) would only be able to remove negatively charged ions such as bicarbonate and sulphate, but not positively charged ions such as calcium (Geldenhys *et al.*, 2002). Reports by Sarin *et al.* (2004) also suggest that IER water based treatment technologies require periodic backwashing and regeneration; manufacturers of devices C, D and E did not state nor require any backwashing or regeneration of their devices and this could also attribute to their failure. The drastic increase in results for devices C and D in terms of calcium addition to the treated water could also be attributed to the fact that the water treatment technologies (i.e. filters) were exposed to rather stringent chemical testing regime in terms of pH change and chemical ions (such as iron, manganese, chromium, calcium, etc.) and this could have caused their IER to become coated or clogged, resulting in it losing its softening ability. These findings can be supported by Gulson *et al.* (1997) and Herman (1996) where it was reported that the IER sites of bench top water filter systems were overloaded with other elements such as magnesium, copper and zinc lessening their efficacy in removing other elements such as calcium.

Studies performed by Sarin *et al.* (2004) mentioned a concerning factor; IER when used as a water softening technology adds sodium ions to the final water content in order to reduce its overall hardness, however in doing so the final treated water quality has a higher sodium content and this can contribute to cardiovascular disease mortality versus the potential benefits of just drinking hard tap water.

Overall the findings from this study suggest that all the HWTDs tested within this study are ineffective at removing calcium carbonate contamination from tap water, to acceptable levels that would improve tap water aesthetically in terms of softening the water and reduce scale, some of them actually hardened the water more and so their manufacturers claims in terms of reducing water hardness are unjustified.

A summary of the results obtained from this study is shown in Table 4.25 and gives an overview of the results obtained versus the manufacturer’s claims and compared to the NSF and SANS 241 standards. This forms the basis for the conclusions drawn from this chapter and highlights the need to do more of these types of studies as discussed in future research at the end of this document.

Table 4.25 Home Water Treatment Device Result Summation of Assays, Standards (NSF, SANS 241:2006), and Manufacturer Claims

HWTD ID	**A**			**B**			**C**			**D**			**E**			**F**			**G**			**H**			**I**			**J**			**K**			**L**			**M**		
Treatment technology	**OC**			**AC**			**IER & AC**			**IER & AC**			**IER & AC**			**AC**			**C & S**			**S, AC & UF**			**C**			**KDF AC**			**GAC**			**OC**			**S & KDF AC**		
Standard / claim	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**	**N**	**S**	**M**
Bacterial	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	X	X	NC	🟥X	🟥X	🟥X	X	X	NC
Viruses	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	🟥X	🟥X	🟥X	X	X	NC	X	X	NC	X	X	NC	X	X	NC
Parasites	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	Y	🟥X	🟥X	Y*	🟥X	🟥X	Y*	X	NC	X	X	NC	X	X	NC	🟥X	🟥X	🟥X
Free chlorine	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	🟥X	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X
Conductivity	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC	/	Y	NC
High pH	X	X	NC	X	Y	NC	X	X	NC	X	Y	NC	X	X	NC	X	X	NC	Y	Y	NC	X	Y	NC	Y*	Y*	NC	Y*	Y	NC	X	Y	NC	Y*	Y*	NC	Y*	Y*	NC
Low pH value	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	X	X	NC	Y	Y	NC	Y	Y	NC	X	Y	NC	Y	Y	NC	Y*	Y	NC	X	X	NC	Y	Y	NC
Turbidity removal	X	X	NC	X	X	NC	X	X	NC	X	X	NC	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	X	X	NC	Y	Y	🟥X	🟥X	Y*	🟥X	🟥X	Y	🟥X	🟥X	🟥X	🟥X	🟥X	Y*	🟥X	🟥X	Y*	🟥X
Particle size exclusion	X	/	NC	X	/	NC	X	/	NC	X	/	NC	Y*	/	🟥X	🟥X	/	🟥X	X	/	NC	Y	/	🟥X	Y*	/	🟥X	Y	/	🟥X	🟥X	/	🟥X	Y*	/	🟥X	🟥X	/	🟥X
TDS	X	X	NC	X	X	NC	X	Y	NC	X	Y	NC	🟥X	🟥X	🟥X	🟥X	Y	🟥X	X	Y	NC	🟥X	Y*	🟥X	🟥X	🟥X	🟥X	Y	Y	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	Y*	🟥X
Fluoride	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	/	/	/	/	/	/	🟥X	🟥X	🟥X	/	/	/	🟥X	🟥X	🟥X	/	/	/
Zinc	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	Y	Y	🟥X	/	/	/	/	/	/	/	/	/	/	/	/	Y	Y	🟥X	/	/	/
Copper	/	/	/	/	/	/	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	Y	Y	🟥X	/	/	/	/	/	/	/	/	/	/	/	/	🟥X	Y	🟥X	Y	Y	🟥X
Iron	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	🟥X	🟥X	🟥X	/	/	/	/	/	/	/	/	/	/	/	/	🟥X	🟥X	🟥X	/	/	/
Lead	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X
Aluminium	/	/	/	/	/	/	🟥X	🟥X	🟥X	/	/	/	Y	Y	🟥X	🟥X	Y	🟥X	Y*	Y*	🟥X	/	/	/	/	/	/	/	/	/	/	/	/	Y*	Y*	🟥X	/	/	/
Chromium	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	🟥X	🟥X	🟥X	/	/	/	Y	Y*	🟥X	/	/	/	/	/	/	Y	Y*	🟥X	/	/	/
Manganese	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	/	/	/	/	/	/	/	/	/	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X
TOC	/	🟥X	🟥X	/	/	/	/	Y	🟥X	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	🟥X	🟥X	/	🟥X	🟥X	/	🟥X	🟥X	/	🟥X	🟥X	/	🟥X	🟥X
Taste & odour: phenol	🟥X	🟥X	🟥X	Y*	🟥X	🟥X	Y*	Y*	Y*	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X
Scale removal: phosphates	/	/	/	Y	/	Y	Y	/	Y	Y	/	Y	Y	/	Y	Y	/	Y	/	/	/	/	/	/	/	/	/	/	/	/	Y	/	Y	/	/	/	Y	/	Y
Scale removal: silicates	/	/	/	Y	/	Y	Y	/	Y	Y	/	Y	Y	/	Y	Y	/	Y	/	/	/	/	/	/	/	/	/	/	/	/	Y	/	Y	/	/	/	Y	/	Y
Total hardness	/	/	/	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	🟥X	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/

Footnotes:

NC – indicates there was no claim made by the manufacturer in terms of removal efficiency / removal capabilities of the home water treatment device, however the device was still analysed within this assay to provide further clarity in terms of the type of water quality it was delivering and if this met the standards of municipally supplied tap water within SANS 241:2006.

X – the final result did not meet the standard, however the manufacturer made no claim that their HWTD device would remove this determinant, in some cases the HWTD was still tested to see if it complied with SANS 241:2006 class I tap water.

🟥X – The final result did not meet the NSF or SANS 241:2006 standard or manufacturer claim, in terms of the HWTD effectively removing this determinant.

Y – The final result did meet the NSF or SANS 241:2006 standard or manufacturer claim, in terms of the HWTD effectively removing this determinant over all three days of testing.

Y* – the final result did meet the NSF or SANS 241:2006 standard or manufacturer claim, in terms of the HWTD effectively removing this determinant, but not over all three days of testing, further testing in terms of longevity would have to be done in order to corroborate this finding.

N – NSF Standard P231, 42, 44 or 53.
S – SANS 241:2006, class I type tap water.
MC – manufacturer claim.

/ – no claim made, no removal efficiency testing done.
OC – organic carbon
AC – activated carbon

IER – ion exchange resin
UF – ultra filtration
KDF – kinetic degradation fluxion

GAC – granular activated carbon
C – ceramic filtration
S – sediment filtration

5. CONCLUSIONS

The overview of the available home water treatment devices in South Africa shows a wide variety of devices in South Africa. It was seen that attention should be paid to the claims made by the manufacturers in their information brochures to ensure that the devices are used correctly. This includes specific flow rates for the faucet mounted devices which in most cases do not translate to the normal opening of the tap. This means that the tap can only be opened slightly which in turn influenced the volume of water that can be collected per hour. Possibly the greatest concern was the fact that all the devices tested as part of this study indicated that the device should only be used with municipal treated tap water that meets SANS241 requirements raising the question why there would be a need for the further treatment of the water. This also implies that consumers might mistakenly use these types of devices in towns where the water quality does not meet the SANS241 regulations expecting the device to treat the water.

The results from this study showed that very few of the HWTDs tested within this study met the NSF P231, 42 or 53 and SANS 241:2006 HWTD standards, however the most concerning factor was that very few of the devices tested managed to even met the removal efficiency claims their manufacturers made (Summarised in Table 4.1). This fact is very disconcerting as these results imply that the claims manufacturers make in order to sell these devices to consumers are falsified. Alternatively it can be argued that manufacturers are basing their claims on published results treatment technologies during the testing phase and assuming that this will be true for all similar treatment technologies. Another concerning factor was that in general terms a lot of the results reported on these HTWDs indicated that they tend to reduce the final water quality after treatment rather than improve it, as claimed by their manufacturers.

An overall general pattern was observed that most of the HWTDs tested within this study potentially did improve the water quality in terms of its aesthetic attributes such as reducing scale, but in terms of taste, odour, heavy metal and microbiological removal claims the devices tested performed rather poorly. Considering that these were the most common claims made by the manufacturers (their devices could remove heavy metals and pathogens, as well as improve taste and odour); this potentially is their biggest selling point / scare tactic utilized to get consumers to purchase these devices and this is rather wretched bearing in mind that their devices couldn’t even accomplish this task.

In terms of microbiological analysis ultrafiltration and sediment filtration proved to be the most successful at reducing bacteria and cysts, however none of the technologies tested were successful at reducing viruses.

In terms of physicochemical analysis most of the manufacturers of HWTDs also claimed chlorine removal or removal after treatment and most of the devices tested did succeed in reducing or removing chlorine. This was a concerning factor when related to studies performed by McLennan *et al*. (2009) and Liguori *et al*. (2010), that reported that the water produced POU devices which produced low residuals of chlorine after POU could not be deemed safe for storage as it could harbour naturally occurring faecal indicator and heterotrophic bacteria at a later stage. They reported that the water had to be consumed within 30 minutes after treatment for it still to be considered potable and not contaminated. If the findings within this study are well-founded then most of the HWTDs tested within this study for free residual chlorine need to be very carefully utilized (i.e. once chlorinated tap water has been filtered through them it needs to be consumed within 30 minutes and not stored), in order for the filtered water’s quality to be considered uncompromised. Devices which utilized ceramic, sediment, UF, KDF and GAC water treatment technologies indicated success at neutralising both acidic and alkaline waters. In terms of turbidity, mechanical removal and TDS assays UF and sediment water treatment technologies were the most successful at excluding particulate in water.

In terms of macro chemical determinant assays none of the water treatment technologies tested reported any success of reducing fluoride in water; however water treatment technologies utilizing ceramic, sediment and OC did indicate success at reducing zinc levels.

In terms of chemical micro determinant assays finding from the study suggest that HWTDs which utilize AC, IER, sediment, KDF and ceramic filtration technologies in combination effectively reduced copper contamination. None of the water treatment technologies tested, however, were effective at removing iron, manganese and lead contamination from tap water. The HWTDs technologies that utilize cationic exchange resins were successful at reducing aluminium contaminates in treated water; however the carbon based water filtration technologies were not. In terms of chromate removals in tap water HWTDs technologies that utilize carbon and dense ceramic based water treatment technologies were successful at reducing chromium contaminates from tap water.

In terms of organic chemical determinant assays finding from the study suggested that most of the HWTDs tested (especially those which utilized carbon based water treatment technologies) are infective at reducing TOC, some of them actually added more carbon to the final treated water and this is a concerning factor as carbon is a substrate source for microbes which could lead to fouling of these devices (Matilainen *et al*., 2010 and Yue *et al*., 2005). None of the HWTDs succeeded at reducing phenol from water after treatment to acceptable levels that would improve tap water aesthetically in terms of taste and odour and so their manufacturer’s claims in terms of improving taste and odour or removing phenol contaminants are unjustified.

The additional tests performed within this study were phosphate and silicate assays and overall the findings suggest that all the HWTDs tested within this study that utilized AC, IER, sediment, GAC and KDF water treatment technologies were effective at keeping / adding phosphate / silicate to tap water, to acceptable levels that would improve tap water aesthetically in terms of reducing scale. However in terms of softening water in terms of calcium carbonate reducing none of the water treatment technologies tested actually succeed.

Over all faucet mounted HWTDs performed better in terms of removal efficiency claims, in comparison to gravity fed HWTDs. This could probably be attributed to the fact that the faucet mounted water treatment technologies utilized more complex forms of water treatment technologies or more technologies in combination than the gravity fed HWTDs. The gravity fed HWTD mostly use carbon based technologies, which largely indicates poor results in comparison to claims made by manufacturers. Another concerning factor reported by Chaidez *et al*. (2004) and Kohen *et al*. (2005) was that activated carbon POU devices tend to amplify the numbers of bacteria present in tap water by promoting biofilm formation due to their freely available carbon source and so the microbiological health risk is greater, since the water quality after AC POU treatment can become compromised.

The faucet mounted HWTDs utilized water treatment technologies such as ceramic, sediment, KDF and UF. These technologies faired far better results than carbon based water treatment technologies. These findings are supported within reports made by Kaufman *et al*. (2011), which have indicated that dense ceramic clay filters with low porosity are successful at excluding bacterial and chemical contaminants in water. Another study performed by Brown et al. (2008) could probably also substantiate these results as they reported that a point of use water treatment technology utilizing ceramic filters, with silver NF and KDF coating showed 60% bacterial removal rates. On the whole though, UF reported the best results in terms of microbial, physicochemical and chemical removal assays. These findings could probably be substantiated by reports made by Li *et al*. (2008); Pryor *et al*. (1998); Stephenson *et al*. (2006) and Walsh *et al*. (2008) which have reported that UF water treatment technologies are very successful at reducing microbes and particles in contaminated water sources. Also studies performed by De Vet *et al*. (2009); Murphy *et al*. (2009) and Scouter *et al*. (2003) have reported that closely packed sediment filers were successful at reducing microbiological, as well as chemical contaminants from compromised water sources.

Largely however most of the HWTDs failed to comply with NSF P231, 42 or 53 and SANS 241:2006 POU water treatment device standards and most of them didn’t even meet the claim removals made by their manufacturers. If the removals observed are however considered for the tests performed it could be considered as successful for the treatment of water if the contamination levels are low. This is however misleading since any problems with higher than normal contamination levels will give consumers a false sense security and could contribute to health problems experienced. The fact that most of the HWTD tested are not certified and so potentially these inferior products could increase the risks of waterborne diseases and can even induce negative health impacts by reducing the quality of the current municipal tap water available to the public.

In summary, the following project objectives have been met:

1) An overview of HWTDs available in the Gauteng province and on the internet was successfully completed (Objective 1).
2) Information was obtained about the claimed purification capabilities of home water treatment devices that was selected and tested as part of this study (Objective 2).
3) The selected devices were tested using the NSF methodologies in terms of criteria specified by SANS 241 for the provision of safe potable water and claims made by the manufacturers (Objective 3).
4) All results were successfully compared with the claims made by the manufacturers and aligned with the recommendations of the NSF.

6. RECOMMENDATIONS

The results from this study showed that there is no clear correlation between the claims made by the manufacturers and the actual laboratory tests performed. It would be recommended that as many of the home water treatment devices available should be tested to confirm the claims made by the manufacturers. The research team believe that this process should be done in consultation with the manufacturers or suppliers (if they are South African) to assist them with improving the quality of their products and by implication the water quality consumed by the public.

The results showed that although the required removals as stipulated by the NSF could not be met by several of the HWTDs for specific tests, there still was a removal in most cases. This means that if the water has low levels of contamination the HWTD would possibly still be a useful addition to any household to treat their tap water. In line with this the recommendation would be to do tests with treated tap water to evaluate the performance of these devices under normal conditions.

The negative impact that treatment technologies such as activated carbon could have on the water quality should also be investigated. The recommendation is to test HWTDs used with tap water for the claimed lifespan of the treatment technologies to ensure that the devices performs effectively during the whole lifespan as claimed. In line with this it would be helpful to better understand what would happen to the water quality if the consumers did not follow suggested HWTD maintenance and replacement of HWTD parts such as the filters.

7. THOUGHTS FROM THE TEAM

Water quality and supply in South Africa as a whole is a very touchy subject and has been the topic of strikes and protests in South Africa in the last few years. With this in mind the last thing we would want is for this report to be used to add to the fights and we as a team decided to voice our opinion in this section, something not usually done as part of WRC reports. This section links up with the Volume 2 of this report and deals with the public perception of water quality and the launch of a pamphlet to assist consumers with their knowledge about water quality in South Africa.

An overarching concern is that although people have concerns about water quality it seems that they do not always have access to trustworthy information or simply do not trust the information being supplied to them. This brings to mind brand failures reported by companies such as Coca-Cola, Pepsi and others linked to a specific product or advertising campaign. There are various books that deals with this and highlight an important questions that we as the water society needs to ask ourselves: Have the “brand” of water been tarnished in South Africa, why did this happen and how can we fix it? This in itself needs a lot of research but is important for the country. We do not have the answers for this but want to use this section to highlight some of our concerns and observations that does not have concrete scientific backing. Despite this we still believe it is important that we start talking about these topics.

As a team we still believe in the work done by people in the department of Water Affairs and in the water sector as a whole. Despite this we cannot get away from the fact that there still are areas in South Africa that do experience problems with water quality. For these users we need to get practical solutions in place that can ensure that they at the very least have access to safe potable water while the water sector works on these issues. To do this we as a society will have to come together and get back to the public to help them with question, misperceptions and advice. Volume 2 of this project aimed to start doing this with giving simple information to use when they want to purchase a home water treatment device and we recommend that you read that so that information is not duplicated.

The results from this study could probably be used as a “whip” for either the water sector or suppliers of home water treatment devices. This was never the intention of the project since the project was done in the spirit of “how can we help everyone?” The points that we want to highlight will thus be given from that approach.

We as scientists, engineers, consultants, government, process operators, etc. working in the water sector need to start returning the passion for our jobs and country back into the water sector. We need people with passion that understands the need for each person in the water sector doing a specific and much needed job. We need to be open and honest about what is happening and be the first to communicate this to the public. We should be asking ourselves questions such as why are consumers rather listening to reporters or suppliers about water quality in South Africa? These are people that do not always understand what they are reading or the impact that they have on the water sector or even worse might be using information to their advantage. The one example that comes to mind form discussions during meetings for this projects are the difference between results you get with different testing methods, example total vs. residual vs. free chlorine.

We need to start working with the manufacturers and suppliers of water related projects and as part of this project we as a team will be going to the suppliers of the products tested to work on improving the products. In this spirit we wish to not only better their products but to be able to recommend products to consumers when it is really needed. We have to accept that sometimes we do need for example home water treatment devices when we have failures in water quality. We also need to get their confidence that we want to work with them and not to harm their business. It will be an interesting exercise and the team will report back on the trends we see when we engage with the manufacturers and suppliers.

We need to start talking with the public, but the public also needs to start realising that they have certain rights and responsibilities. It is interesting how much a person will research a car before they purchase it, claiming safety features, etc. needs to be to a certain standard to ensure the safety of their families. Yet they will go the nearest shop and purchase any water treatment device that looks like the best option to purify their water without much thought on the impact on their children’s health and well-being. We need to inform them of their ability to monitor their water quality online, or what they should be looking at in their homes that could influence their water quality before they start blaming everyone. Speaking from personal experience, one of the research team has been reported on “Hello Peter” for claiming that water quality in areas of South Africa is of a very good standard. The lady who lodged the complaint attacked the researcher’s qualification and gave the reasons for doing this by looking at problems with her own water. Interestingly the problem that the lady mentioned could easily be associated with faulty or failing pipes in the home but highlighted the fact that people forget to look at the whole picture and tend to focus on one possible problem, usually government.

This brings us to probably the most important role-player in the cycle, journalists. We as experts need to engage the journalists to assist them with reporting correct and accurate results and more importantly explanations for what is happening. One example is an article published online while we were writing this report stating that the “virus that causes cholera” is a problem in South Africa. Are we doing our jobs if we simply sit back and giggle at what the “silly” journalists wrote without taking the time to contact and assist them? This has serious impact on our “brand” as the water sector and has a roll-on effect to the public.

This was probably the biggest lesson we learned from this study and we trust that the results we presented will be used properly to better the water sector and not to pass the blame. We need to interact with the public and put finding into perspective. We can easily say that almost none of the devices tested worked but you should keep in mind that the testing concentrations are well above the norm of what we would find in water and considering that most of the devices have a place if the users understand the limitations of the device. We need to engage the suppliers to ensure that make founded claims and rather help them to market their product for specific needs such as removing chlorine to meet the needs of the consumer. Most importantly we need to communicate with the public so that they understand why they are using these devices and to make them aware of what the devices can actually do.

This was only an exploratory study and much more research and testing is needed to test all the devices available so that we can engage the manufacturer to assist them with their needs and give advice for improving the devices. We trust that you as the reader accepts this and reads the document in the manner that is was intended to be used.

8. REFERENCES

8.1 ACADEMIC REFERENCES

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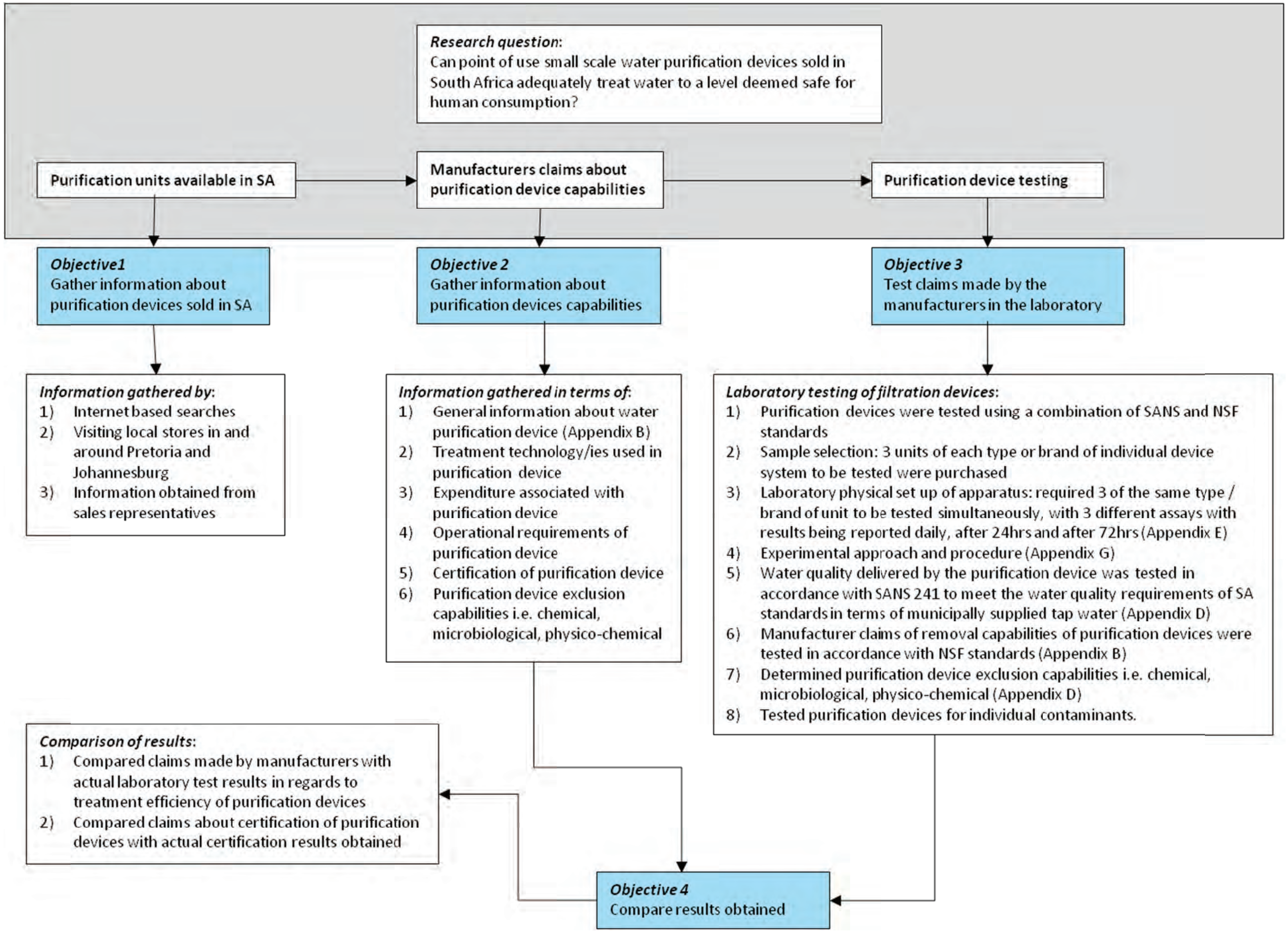
Appendix A Overview of study design that incorporates data gathering and laboratory analysis for the analysis of home water treatment devices



***Research question*:**
Can point of use small scale water purification devices sold in South Africa adequately treat water to a level deemed safe for human consumption?

Purification units available in SA

Manufacturers claims about purification device capabilities

Purification device testing

Objective1
Gather information about purification devices sold in SA

Objective 2
Gather information about purification devices capabilities

Objective 3
Test claims made by the manufacturers in the laboratory

***Information gathered by*:**
1) Internet based searches
2) Visiting local stores in and around Pretoria and Johannesburg
3) Information obtained from sales representatives

***Information gathered in terms of*:**
1) General information about water purification device (Appendix B)
2) Treatment technology/ies used in purification device
3) Expenditure associated with purification device
4) Operational requirements of purification device
5) Certification of purification device
6) Purification device exclusion capabilities i.e. chemical, microbiological, physico-chemical

***Laboratory testing of filtration devices*:**
1) Purification devices were tested using a combination of SANS and NSF standards
2) Sample selection: 3 units of each type or brand of individual device system to be tested were purchased
3) Laboratory physical set up of apparatus: required 3 of the same type / brand of unit to be tested simultaneously, with 3 different assays with results being reported daily, after 24hrs and after 72hrs (Appendix E)
4) Experimental approach and procedure (Appendix G)
5) Water quality delivered by the purification device was tested in accordance with SANS 241 to meet the water quality requirements of SA standards in terms of municipally supplied tap water (Appendix D)
6) Manufacturer claims of removal capabilities of purification devices were tested in accordance with NSF standards (Appendix B)
7) Determined purification device exclusion capabilities i.e. chemical, microbiological, physico-chemical (Appendix D)
8) Tested purification devices for individual contaminants.

***Comparison of results*:**
1) Compared claims made by manufacturers with actual laboratory test results in regards to treatment efficiency of purification devices
2) Compared claims about certification of purification devices with actual certification results obtained

Objective 4
Compare results obtained

APPENDIX B1 Chemicals and Test Kits Utilized in this Study

Product Name	Company	Catalogue Number
Aluminium Test 0.02-1.2 mg/L Spectroquant 350 Tests	Merck	1.14825.0001
Aluminium STD Solution	Merck	1.19770.0100
Brilliance *E. coli*/Coliform Agar	Quantum Biotechnologies	CM0956B
Calcium Carbonate, 99.99%	Sigma	481807-25g
Chlorine Test 0.01-6 mg/L Cl_2 Spectroquant 1200 Tests	Merck	1.00598.0001
Coliform Agar for Microbiology Chromocult	Merck	1.10426.0500
Combicheck 10 Spectroquant	Merck	1.14676.0001
Combicheck 20 Spectroquant	Merck	1.14675.0001
Combicheck 30 Spectroquant	Merck	1.14677.0001
Combicheck 40 Spectroquant	Merck	1.14692.0001
Copper Test 0.2-6mg/L Cu Spectroquant 250 Tests	Merck	1.14767.0001
Copper STD Solution	Merck	1.19786.0100
Chromate Test 0.02-6.69mg/L CrO4 Spectroquant 250 Tests	Merck	1.14758.0001
Chromate STD Solution	Merck	1.19780.0500
Dichloroisocyanuric Acid Sodium Salt Dihydrate GR for Analysis	Merck	1.10888.0100
Fluoride Test 0.10-20.0 mg/L Spectroquant 250 Tests	Merck	1.14598.0002
Fluoride STD Solution	Merck	1.19814.0500
Hanna TDS STD 800 ppm	Sigma	Z655260-25EA
Hanna TDS STD 6.44 ppt	Sigma	Z655287-25EA
Hanna pH 9.0 STD	Sigma	Z655147-500ml
Hanna pH 7.010 STD	Sigma	Z655139-500ml
Hanna pH 4.010 STD	Sigma	Z655112-500ml
Hanna Gen/Purpose Electrode Cleaning SOL	Sigma	Z655163-460ml
Humic Acid, Sodium Salt, Tech	Sigma	H16752-100g
Hydrochloric acid 37%, ACS Reagent	Sigma	320331-500ml
Hydrochloric acid 25% GR for Analysis	Merck	1.00316.1000
Iron Test 0.005-5 mg/L Fe Spectroquant 1000 Tests	Merck	1.14761.0001
Iron STD Solution	Merck	1.19781.0100
IsoFine Test Dust, 3.5 Kg	GUD Holdings (PTY) Ltd, Powder Technologies Inc (PTI)	Analysis 5420F
IsoCourse Test Dust, 3.5 Kg	GUD Holdings (PTY) Ltd, Powder Technologies Inc (PTI)	Analysis 5180C
Lead Test 0.010-5 mg/L Pb Spectroquant 50 Tests	Merck	1.09717.0001
Lead STD Solution	Merck	1.19776.0100
Manganese Test 0.05-2 mg/L Spectroquant 250 Tests	Merck	1.01739.0001
Manganese STD Solution	Merck	1.19789.0100
Phenol Test 0.002-5 mg/L Spectroquant 50 Tests	Merck	1.00856.0001
Phenol GR for Analysis	Merck	1.00206.0250
Phosphate Buffered Saline pH7.4	Sigma	P5368-10PAK
Phosphate Test 0.01-5 mg/L PO4 Spectroquant 420 Tests	Merck	1.14848.0001
Phosphate STD Solution	Merck	1.19898.0500
Photocheck Spectroquant	Merck	1.14693.0001
Pipecheck Spectroquant	Merck	1.14962.0001
Nutrient Broth 1	Sigma	70122-500G

Sea Salts	Sigma	S9883-1KG
Silicate (Silic Acid) Test 0.005-5 mg/L Si/SiO2 Spectroquant 300 Tests	Merck	1.14794.0001
Silicon STD Solution	Merck	1.70236.0100
Sodium Hydroxide Bioxtra, pellets anhydrous	Sigma	S8045-500g
TOC Cell Test 5-80 mg/L Spectroquant 25 Tests	Merck	1.14878.0001
TOC STD Solution ACC	Merck	109017.01
Total Hardness Cell Test 5-215 mg/L CaCO3 Spectroquant 25 Tests	Merck	1.00961.0001
Water GR for Analysis	Merck	1.16754.9010
Whatman Qualitative Filter Paper No 2	Sigma	Z240222-1PAK
Xtran MA03 Phosphate Free	Merck	1.07550.2500
Zinc Cell Test 0.2-5 mg/L Zn Spectroquant 25 Tests	Merck	1.14566.0001
Zinc STD Solution	Merck	1.19806.0100

APPENDIX B2 Consumables used in the Study

Product Name	Company	Catalogue Number
Autoclave Class S, 50 L	Monitoring & Control Lab (PTY) Ltd	SA300VL
Cable-Ties	Main Hardware Cc	100x2.5mm Insulock
Chemical Duty Pump 220V/50 HZ	Sigma	WP6122050
Empty Cells 16 mm With Screwcaps Spectroquant/25 units	Merck	1.14724.0001
Glass Filter Holder Assembly With Funnel, Fritted base, Stopper, Clamp, 47 mm	Millipore	XX1004700
Manifold 3 place, 47 mm, PVC	Millipore	XXX2604735
Nailgene Beaker with Handle, 3L, GRAD	Sigma	Z131008-1EA
PippettemanG Microvolume Kit	Lasec SA	IGILF1687800
PippettemanG Starter Kit	Lasec SA	IGILF16790
Pippetteman P2G	Lasec SA	IGILF144054M
Pippetteman P10G	Lasec SA	IGILF144055M
Polypropylene Carboy W/Spigot, 10 L	Sigma	Z675539-1EA
Rectangular Cells 10mm/2 units	Merck	1.14946.0001
Rectangular Cells 20mm/2 units	Merck	1.14947.001
Rectangular Cells 50mm/2 units	Merck	1.14944.0001
Scienceware Fitting Assortment Kit	Sigma	Z560758-1EA
Screw Caps for Spectroquant TOC Digestion 6PCS	Merck	173500.0001
SpinPack Magnetic Stirring Bars 2x5/16	Sigma	Z282472-1EA
Standard MF Millipore Membranes, White, Gridded 0.45um 13mm Diameter	Millipore	HAWDO1300
Stopper 8, 9.5 mm (3\8 IN.) Hole, Silicon	Millipore	XX2004718
Subseal Silicone Rubber Fit Neck	Sigma	Z279730-25EA
Swing Jaw Tubing Clamp	Sigma	Z503347-1PAk
Tips Filter Racked STCLR 01-10 µl	Lasec SA	PAXGTF-300-RS
Tips Filter Racked STCLR 20 µl	Lasec SA	PAXGTF-20-RS
Tips Filter Racked STCLR 100 µl	Lasec SA	PAXGTF-100-RS
Tips Filter Racked STCLR 200 µl	Lasec SA	PAXGTF-200RS
Tips Filter Racked STCLR 1000 µl	Lasec SA	PAXGTF-1000-RS
Toolbox Mattpro	Main Hardwear Cc	117PCE 4 Drawer
Tubing Clamps/Anchors/Cable-Ties Set	Sigma	Z256315-1SET
Tubing Silicone 1/2 IN ID	Sigma	T4789-25FT
Tubing, 3\16 IN.ID x 140CM, Silicon	Millipore	XX7100004
Vacuum Filtering Flask, 1L	Millipore	XX1004705

APPENDIX B3 Equipment used in the Study

Product Name	Company	Catalogue Number
Hanna Comb pH/EC/TDS/Temp Tester Model HI198129	Sigma	Z71057-1EA
Galaxy S RS Biotech Incubator STD 230V	New Brunswick	CO170RS-230-000
IKA C-Mag hot Plate Stirrer, 230V, UK	Sigma	Z672351-EA
Liquiport Pump, PP Head, 3 Flow, 230V	Sigma	Z671940EU-1EA
Thermoreacter TR620 Spectroquant	Merck	1.71202.0001
T-100 Turbidity Meter	Oakton Instruments	WD-35635-00
UV Vis Spectrophotometer Pharo 300 Spectroquant/1 unit	Merck	1.00707.0001
Vortex Mixer Model L46 (220V50\60HZ)	LABINCO	46000
Weigh Balance aeAdam	Lenton	ACB 600 HP