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KOMBITEK

From surface water to drinking water by combined use of filter technology and electrochemistry

MUDP-rapporter

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Indhold

1. Abstract

Limitations in drinking water resources is a major problem worldwide, particularly in arid areas. One solution for obtaining drinking water is to purify surface water to drinking water quality. The problem with current solutions for this purpose is that they either produce water in too small amounts, require bigger installations and secure infrastructure, are too expensive, or require considerable expertise to work optimally. This report describes the development of a water treatment system with a compact size and which only requirement is a power supply, making it ideal for emergency situations.

The water treatment plant consists of a flocculation tank, a filtering unit, and an advanced oxidation unit. Different secondary filtering units was also tested in the plant development, but it was found that they needed to be changed too often for field applications. In the flocculation unit, electrocoagulation was accomplished by using electrical current to generate free iron that reacts with the fine particulate material in the water. The process creates flocculates and helps to remove suspended solids to sub-micrometre levels, breaks emulsions such as oil and grease or latex, removes phosphate and lowers the particle concentration without the use of filters or the addition of separation chemicals. The filtering unit in the plant, developed by BIO-AQUA A/S, is based on flexible polymer threads, which allows for back-flushing. The advanced oxidation unit, developed by Adept Water Technologies, is based on electrolysis principles that uses naturally occurring chloride in the water, to produce a residual dis-infective effect.

The water treatment system was field tested on Danish lake water and on surface water in Hanoi in Vietnam. These field tests documented significant removal of phosphate, particulate material and TOC, and production of chlorine at > 1 mg/L even with water containing low chloride concentrations (10 mg/L). These field tests also documented a significant (5 to 8 log-units) removal of the faecal indicator bacteria *E. coli* and *Enterococcus* spp. as well as somatic coliphages. Thus, microbial water qualities obtained after treatment were acceptable or just above the international standards for drinking water (bacterial spores). The human health risks associated with consumption of treated water is considered very low to low with regards to bacterial and viral diseases.

Laboratory tests showed that organic contaminants such as pesticides can be oxidized and degraded by the AO unit, while possible formation of chlorate in the AO unit should be further explored. Initial studies indicate that human pathogenic protozoan parasites, e.g. *Cryptosporidium* spp. oocysts, may survive treatment and studies on this is ongoing.

In the end, the KOMBITEK project resulted in a mobile and inexpensive plant that can easily be installed wherever the need arises. Although the treated surface water was not visually appealing without the inclusion of secondary membrane, the water was of sufficient quality to drink. Inclusion of a ceramic filter at end of treatment line is, however, strongly recommended to improve the quality of the produced drinking water.

2. Preamble and acknowledgments

This project report is formulated in English, to allow knowledge sharing with the A-water project. The project partners would like to thank our colleagues from the Vietnam Academy of Science and Technology, Hanoi, Vietnam, including Professor Le Truong Giang and Ph.D. students Le Thi Tu Anh and Ta Thuy Nguyen. We would also like to thank our Vietnamese collaborators from the National Institute of Veterinary Research, Hanoi, Vietnam, for providing laboratory facilities available for microbiological analysis. From the University of Copenhagen, we would like to thank Professor Helle Marcussen, laboratory technicians Birgitte Boje Rasmussen, Anita S. Sandager, and Lykke Eriksen as well as Gitte Petersen, Heidi Huus Petersen and Emil Lund for laboratory assistance. The Project would also like to thank post doc. Mette Fachmann for her tireless work to set-up, proof-read and finalize the report.

3. Project Description

More than 1/3 of the earth's population has temporary or constant limitations in their access to clean drinking water. The problem is obvious in arid areas, but even in areas with a high precipitation excess, the drinking water resources can be limited. Limitations in drinking water resources can be caused by e.g. lacking purification of waste water, deficient sanitary installations, diffuse or localized pollution, or emer-gency situations where the drinking water supply breaks down e.g. due to leakage, unknown pollution sources or floods. The solutions to these limitations are to economize and protect the drinking water sources, as well as purifying low-quality drinking water to produce high-quality drinking water in a cost-effective way. In the petitioned project (KOMBITEK), we focused on producing drinking water from river water or flood water with a mobile and inexpensive plant that can easily be installed wherever the, often urgent, need arises.

We have chosen to link KOMBITEK to an ongoing applied research project ("A-Water"; see section 3.11) which aims to produce drinking water from surface water in flood areas in Vietnam. The KOMBITEK project is complimentary to the A-Water project and it builds upon the measurements and conditions in Vietnam where there is a special need for technologies like those described in KOMBITEK. The plant developed in KOMBITEK has been tested in full scale under Vietnamese conditions. The rationale for testing under these conditions is that the need for local drinking water production is far greater in areas with poor infrastructure and high growth, such as Southeast Asia and Africa. The system is, however, not limited to such conditions and it is therefore possible to use the system in other locations and under other conditions. Today there are various types of systems that can produce drinking water from contaminated water. These systems can be based on very simple principles e.g. filtration followed by chemical disinfection, reverse osmosis, membrane-filtration – often with the use of high pressure. Yet the systems are limited since they either produce water in too small amounts, require bigger installations and secure infrastructure, are too expensive, or require considerable expertise to work optimally. We have chosen to focus on a type of plant, which function is based on filtration, flocculation and electrochemical oxidation/disinfection. The plant is easy to scale, consists of robust components, is mobile, and can be operated with local expertise.

The project is conducted in collaboration with the SMV companies Adept Water Technologies A/S and BIO-AQUA A/S, and University of Copenhagen Department of Veterinary and Animal Sciences (IVS-KU) and Department of Plant and Environmental Sciences (IPM-KU).

3.1 Purpose

The projects purpose is:

To develop and test a system for purification of surface water to produce drinking water in situations with floodings or other climatic causes for failing drinking water supply.

The project includes linking of a water treatment part to remove particles; a sorption part for the purpose of removing nutrients, heavy metals, dissolved organic compounds, microorganisms and other dissolved compounds; and a disinfection and oxidation part, which reduces pathogenic and faecal indicator microorganisms and recalcitrant organic contaminations (such as pesticides, antibiotics and hormones) to ensure that the water match the quality demands for drinking water.

The above-mentioned steps plus an electrochemical disinfection step, results in a unique solution for obtaining safe drinking water with residual anti-microbiological quality, without the need of handling dangerous chemicals such as chlorine. The plant has to be mobile and be able to be installed immediately, where the only requirement is to have a power supply available. As an important subsidiary goal, the project wants to study the reactivity of oxidizing compounds formed by electrochemical disinfection against organic contaminations and infectors (WP5 and WP6). This new knowledge is unique and will maintain the Danish companies' leading position on the area.

3.1.1 Expected environmental effects

We wish to deliver a complete plant in a small container that can transform surface water to drinking water quality without any further logistic requirements (except electricity). If our aim can be reached it will be possible to provide a fast response and a decentralized implementation in the affected area/village and thereby achieve a massive reduction in the timeframe where the distressed have to drink contaminated water. In addition, the need for storage of chemicals for disinfection will be reduced and, the non-sustainable use of bottled water is avoided.

Additional environmental and health related benefits includes:

i) Fewer cases of illness due to spread of infective pathogens of human and zoonotic origin
ii) No need to establish expensive emergency supplies or to transport great amounts of water over larger distances
iii) Use of local water (recycled – important in arid areas), and a relatively low consumption of materials and energy for establishment and operation.

3.1.2 Assessment of market potential

As the technologies envisioned used has several disinfection- and logistic-related advantages, the market potential is significant. The plants we envision to produce will be able to supply an urban district or village with clean water (5-25 cubic meters per 24 hours). In Southeast Asia alone, there will be a market for thou-sands of such plants and it must be assumed that these plants, to a certain extent, also can undertake the primary water supply role, whereby the potential rises further.

Moreover, the surface water from e.g. rivers in Africa will offer similar challenges and possibilities. Conservatively put, we expect that the technology, in the short run, will be able to generate 500 sales per year. With a sales price of DKK 100.000 per plant this would generate export worth DKK 50 million. The figures for both the number of installations and the selling price has been set low, given that the exact capacity needs, and thereby price, depends on a closer study in the introductory project phase, where potential buyers and demands, needs and specification demands for the treatment technology is analyzed (WP1). In the long run – when the knowledge about the plants' stability, mobility and operation is increased, and possible modifications on the plants are carried out – a significantly larger market potential is ex-pected. This of course requires a significant information- and marketing effort. In Southeast Asia, it will be possible to achieve support from the embassies in the introductory phase. Besides, there will be focus on participating in trade fairs, congresses and relevant business networks.

The plants will have to be assembled and tested in Denmark, especially in the introductory phases. Here Adept Water Technologies A/S will have to be supported with 2-3 employees in the production and 2-3 em-ployees in the administration and sales. The actual mounting of the plant, which will happen at BIO-AQUA A/S, will furthermore cause a need for 2-5 extra employees. The work generated at the subcontractors is not included.

3.1.3 Incentive effect

The possibility for Adept Water Technologies A/S and BIO-AQUA A/S to develop and introduce a combined technology based on filtration and electrochemistry (KOMBITEK) for treatment of surface water, intended for markets primarily in Southeast Asia, were developed via an applied research project ("A Water") between Copenhagen University (KU) and Vietnam Academy of Science and Technology (VAST) (See WP3.1). This project specifically searches for partners with the same competences as Adept Water Technologies A/S and BIO-AQUA A/S; it has not been possible to identify these competences in Vietnam. At the same time, the two companies gain access to international research expertise and new knowledge about central chemical and microbiological aspects of the combined water treatment technology.

Support to the project will accelerate Danish production and export of new water technology to Southeast Asia and it will make the technology demonstration in Vietnam possible. Thus, the plant can be marketed in an emerging market. Another important incentive is to develop, test and obtain knowledge about a plant that combines Adept Water Technologies A/S and BIO-AQUA A/S's technologies since such a plant is unique on a global basis. It is expected that the plant can be applied to the production of drinking water in several different contexts with poor access to drinking water, e.g. areas with large construction works, areas affected by floods and refugee camps.

4. Project Deliverables

The project has 6 major deliverables, each described in a section in the following:

WP1. A requirement analysis and specification for the system
WP2. The development of a filtration unit for treatment of surface water
WP3. The development of an advanced oxidation unit for treatment of surface water
WP4. Integration and test of the two above systems:
  a. In Denmark
  b. In Vietnam
WP5. Effect of advanced oxidation on chemical contaminants
WP6. Effect of advanced oxidation on pathogenic microorganisms.

5. WP1: Requirement analysis and specification

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At the beginning of the project, an investigation was made in order to quantify the requirements and market potentials.

5.1 Summary regarding investigative report

The purpose of this report is to identify:
- Companies operating within the area of drinking water treatment
- Future users of electrochemical water treatment units
- Capacity and requirements to produce drinking water from surface water, e.g. in flooding situations
- Requirements of water produced by the electrochemical water treatment unit to meet national and international drinking water quality standard.

The report is based on extract from the Freedonia reports[1], internet search (Appendix), national and international drinking water guidelines and experiences from actors within the area drinking water treatment in emergency situations.

5.1.1 Growth potential within the water treatment sector

The demand worldwide for water treatment products is forecasted to total $64.9 billion in 2015; based on annual gains of 6.2% from 2010. The fastest growth of any regional market is the Africa/Mid-east and Asia region with an annual increase of 9.8% due to substantial room for growth in the underdeveloped water treatment infrastructure. In Asia alone, the annual increase is expected to be 8.1% through 2015. The fastest growing Asian markets are Indonesia, Malaysia, Thailand, Vietnam and China. Product demand by region in 2010 ($48.1 billion) was 37% for North America, 24% for Asia/Pacific, 21% for Western Europe and 18% for others. The Asia/Pacific region grew 9% from 2005 to $11.3 billion in 2010, and the industrial market counted for 51% in 2010 while the municipal was 38% and other markets 11%. The Eastern Europe market is forecasted to increase 7.5% annually to $2.9 billion in 2015 with on-going implementation of EU-level regulatory standards in several countries including Bulgaria, Czech Rep., Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.

Other potential markets are residential and commercial water filtration systems, and chemicals/equipment to treat recreational water. In addition, hotels/motels/resorts, amusement parks and health clubs are expected to increase demand for water treatment systems.

For water disinfection products, the rise in demand is expected to be 5.4% to $4.7 billion in 2014 – increas-ing use of chlorine and bromine derivatives over chlorine itself. Demand for water disinfection equipment worldwide is projected to

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[1] World Water Disinfection Products, 2011 and World Water Treatment Products, 2011 by The Freedonia Group (US).

expand 10.9% annually to $3.4 billion in 2014, where increased popularity of nonchemical disinfection such as UV treatment will be the driver. The largest market is North America ($3.0 billion in 2014). Fastest predicted increase in the Asia/Pacific region is 9.5% annually to $1.9 billion in 2014 with China being a major driver.
The worldwide demand for water disinfection products by region (2009) is: North America: 39%, Western Europe: 25%, Asia/Pacific: 22% and other regions 14%. The global rise in demand for water disinfection products is forecasted to be 7.5% annually reaching $8.2 billion in 2014. Traditional chemical disinfection technologies will account for the majority of overall demand, but demands for other types of water disinfec-tion, e.g. onsite chemical generation and nonchemical techniques, UV and ozone especially, are expected to register faster growth. Water disinfection product demand in the Asia/Pacific region is projected to advance 9.5% per year, the fastest rate of any regions representing an expected value of $1.9 billion in 2014.

Much of the growth will come in the form of a shift from use of chlorine and other commodities in favor of alternative chemicals and new types of disinfection equipment. In 2009, 59% of water treatment was done by chemical disinfection and 41% by the use of various treatment technologies. The demand for disinfection equipment alone is expected to increase 13.2% p.a. to 2014 in the Asia/Pacific region. Demands for UV treatment technologies are expected to rise 13.2 % annually to $1.7 billion in 2014 – mainly driven by the wish to consume water that has not been chemically treated. Demands for other types of treatment equipment are expected to rise 8.9% annually to $1.7 billion in 2014, including chemical generation products (7.9% p.a. in developing areas), ozone equipment (8.4% p.a.) and others. Also, here is the main demand coming from the industrial sector (52%) followed by demands for treatment of recreational water (26%; including home pools and spas) and municipal water (23%).

5.1.2 Main suppliers of water treatment products

In 2010, the world's largest suppliers on the market with a combined market share of 8.5% were General Electric (US), Nalco (US) and Dow Chemical (US) (information about these three suppliers are described in the Freedonia report).

Other large companies manufacturing water treatment products includes Arch Chemicals, Ashland, BASF, Danaher, Doosan Heavy Industries, Ebara, GDF Suez, ITT, Kemira, Kurita Water Industries, Occidental Petroleum, Pall, Pentair, Siemens, SNF, 3M, Torray Industries and Veolia Environment. Leading suppliers of disinfection products to the global market are Arch Chemicals (US), General Electrics (US), Nalco (US), Siemens (DE), Danaher (US) and ITT (US). In 2009, Arch Chemicals, General Electrics, Nalco and Siemens supplied together about 30.7 %.

5.1.3 Technologies and methods of water treatment

In 2010, water was treated by filtration (33%), chemicals (32%), membrane systems (23%) and other technologies (12 %). Disinfection are included in the category “others” and accounted for 41% of the 12% demand. The great majority of disinfection in water treatment, not using bulk and specialty chemicals, is accomplished by the use of onsite chemical generation equipment, ozone or UV radiation. Disinfection equipment will see the fastest gains of any water treatment product going forward with predicted annual growth of 10.4%.

For water disinfection products, the demand by type in 2009 was chemicals (64%) and equipment (36% thereof 44% UV). Chemicals used included chlorine, chlorine and bromine derivatives (stated to be less toxic), hydrogen peroxide and organosulfurs, with latter two being a minority.

Generally, there are several small, module-build water treatment plants on the market, which have similar characteristics as the KOMBITEK technology, meaning that they have the size of a container and are mobile (see Appendix). In these plants filtration, sedimentation, reverse osmosis, ion exchange, UV disinfection and chlorination (often with hypochlorite) are commonly used technologies. Activated carbon adsorption and use of oxidizing biocides such as chloride dioxide are also used. On-site generation of disinfection agents are rare but do exist, e.g. MIOX plants that generate disinfection substances from added salt with power being the only other supply needed. MIOX plants can function both with electric grid and solar energy (an option also provided by the company Ciemsa). Treatment capacities range from 120-4800 m3/day. Small reverse osmosis treatment technologies are produced by the Danish companies DanPure, Guldager, Silhorko, and BWT (former HOH). Guldager also produces desalination units for off-shore use.

5.2 Water quality guidelines

Several international and national guidelines have specified limits of quality parameters in drinking water. Listed below are a short summary of main drinking water guidelines, and important water quality parameters are listed in Table 5.2.1. As apparent in Table 5.2.1 the drinking water standards do not differ much from each other. The European threshold values for organic contaminants are generally the strictest; for pesticides European legislation has a common threshold for all pesticides irrespective of toxicity, while the US EPA guideline operates with standards depending on toxicity.

Table 5.2.1 - Drinking water quality values of microbiological and chemical parameters specified in selected guidelines.

. [a] Requirements when surface water is included

	Limits of quality parameters				
Quality parameters	WHO 2011	European Drinking Water Directive	Oxfam	US EPA	National rules Vietnam
E. coli, thermotolerant coliforms, faecal coliforms	0/100 mL	0/100 mL	10/100 mL	0/100 mL	0/100 mL
Enterococcus spp.	-	0/100 mL	-	-	-
Cryptosporidium[a]	-	-	-	zero	
Giardia lamblia[a]	-	-	-	zero	
Enteric viruses[a]	-	-	-	zero	
Legionella[a]	-	-	-	zero	
Pesticides (µg/L)	0.03-100	0.1 (0.5)[b]	-	≥ 0.2	0.03 – 100
Halogenated solvents (µg/L)	0.3-50	0.5-10	-	≥ 2	2 - 2000
BTX (µg/L)	10-500	≥ 1	-	5	10 - 700
Benzo(a) pyrene (µg/L)	0.7	0.01	-	0.2	0.7
Phthalates (µg/L)	8		-		8
Arsenic (µg/L)	10	10	10	6	10
Cadmium (µg/L)	3	5	-	5	3
Copper (µg/L)	2000	2000	-	(1300)[c]	1000
Lead (µg/L)	10	1	-	(15)[c]	10
Mercury (µg/L)	6	1	-	2	1
Chromium (µg/L)	50	50	-	100	50
Nickel (µg/L)	70	20	-	-	20
Chlorine (µg/L)	5000		-	4000	
Chlorate (µg/L)	700		-	-	
Chlorite (µg/L)	700		-	1000	

. [a] Requirements when surface water is included

[b] Value in brackets is the threshold value for all pesticides together

[c] The concentration at which remediative measures should be initiated

5.2.1 WHO guidelines

The World Health Organization (WHO) published the fourth edition of the Guidelines for drinking-water quality in 2011 including fact sheets on chemicals and microorganisms[2] . The majority of water treatment technologies included in this report meets the WHO guidelines for drinking water. This was also stressed in communication with representatives from the Danish Water Forum, an organization representing compa-nies and other stakeholders in the Danish water sector. It should however be noted in the WHO guidelines that microbial testing including verification, operational and surveillance monitoring, is usually limited to testing for indicator organisms. In the majority of cases, monitoring for E. coli or thermotolerant coliforms as indicator organism provides a high degree of assurance because of their large numbers in polluted waters. E. coli or thermotolerant coliform bacteria must not be detectable in any 100-ml sample in all water directly intended for drinking, treated water entering the distribution system or in treated water in the distribution system. Immediate investigative action must be taken if E. coli is detected. Viruses and protozoa are more resistant to conventional environmental conditions or treatment technologies, including filtration and disinfection, and may be present in treated drinking water even in the absence of E. coli. Under certain circumstances,

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[2] http://apps.who.int/iris/bitstream/10665/44584/1/9789241548151_eng.pdf

it may be necessary to include more resistant microorganisms, such as bacteriophages and/or bacterial spores, as indicators of persistent microbial hazards.

5.2.2 US national rules

The quality of drinking water is regulated through the Safe Drinking Water Act. This law requires US Envi-ronmental Protection Agency (EPA) to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime, with an adequate margin of safety, are called maximum contam-inant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water. EPA sets MCLGs based on the best available science to prevent potential health problems. National Primary Drinking Water Regulations (NPDWRs or primary standards) under the Safe Drinking Water Act are legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water. A list of regulated contaminants with links for more details is available[3] . EPA does not have the authority to regulate private drinking water wells, although some state and local governments do set rules to protect users of these wells.

Drinking water regulations applying to pathogens and indicators include the Total Coliform Rule, Surface Water Treatment Rule and Ground Water Rule. Total Coliform Rule, which was published in 1989, set both health goals (Maximum Contaminant Level Goals) and legal limits (Maximum Contaminant Levels) for the presence of total coliforms in drinking water. The rule applies to all public water systems. From April 1st, 2016, Public water systems (PWSs) and primacy agencies must comply with the requirements of the Re-vised Total Coliform Rule (RTCR) which replaces total coliforms with E. coli. Systems using surface water or ground water under the direct influence of surface water (GWUDI) are regulated by the Surface Water Treatment Rule (SWTR). The SWTR include monitoring of *Cryptosporidium*, *Giardia lamblia*, enteric viruses and *Legionella* and requires specific levels of reduction of these microorganisms during the water treatment plant. According to the Ground Water Rule, ground water sources are monitored for one of three faecal indicators *E. coli*, enterococci, or coliphages.

A guide to acceptance of water treatment units for compliance with the Safe Drinking Water Act microbiologically requirements has been published by EPA in 1986. The purpose of the Guide Standard and Protocol for Testing Microbial Water Purifiers[4] is to provide at least the minimum features and framework for testing a treatment unit required temporarily to treat contaminated public water supply or for emergency situations. It utilizes a performance based format and is intended to provide a realistic worst-case use of the treatment unit under study.

The company NSF International provides standards for evaluation and certification of drinking water treat-ment units. The Drinking Water Treatment Units – Health Effects (Standard 53, 2011a[5]) addresses point-of-use (POU) and point-of-entry (POE) systems designed to reduce specific health-related contaminants. The substances covered by this standard include asbestos, cysts (based on the use of microspheres or *Cryptosporidium* parvum oocysts), barium, cadmium, hexavalent and trivalent chromium, copper, fluoride, lead, mercury, nitrate, selenium, radon, turbidity, and total trihalomethanes.

5.2.3 Oxfam guideline

Oxfam[6] is an international confederation of 17 organizations networked together in more than 90 countries, as part of a global movement for change, to build a future free from the injustice of poverty. The Oxfam Public Health Engineering Team helps to provide a reliable water supply where mass displacement of people has occurred, e.g. refugee camps and relief centres. The main parameters to take into consideration in assessing water quality for immediate short-term supply in an emergency context are; suspended solids, pH, the level of faecal contamination and salinity. High iron content and chemical contamination can also be a problem. It might also be appropriate to test for chloride, fluoride, sulfate, nitrate,

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[3] http://water.epa.gov/drink/contaminants/index.cfm

[4] http://www.biovir.com/Images/pdf061.pdf

[5] http://www.documentweb.org/3031-NSF-ANSI-53-2011a.html

[6] http://ec.europa.eu/echo/files/evaluation/watsan2005/annex_files/OXFAM/OXF5%20-%20Oxfam%20guidelines%20for%20water%20treatment%20in%20emergencies.PDF

ammonia and to check water hardness. Other contaminants of concern include nickel, zinc, chromium (VI), manganese, copper, lead, mercury and organophosphates.

5.2.4 National guidelines in Vietnam

National Technical Regulation of Drinking Water Quality[7] sets limits of quality criteria for water used for drinking and processing food. The regulation applies to institutions, organizations, individuals and households who exploit, trade drinking water, including piped water providers for domestic purposes with a capacity of 1,000 m3/day or above. The regulation sets limits on perceptible parameters, inorganic constituents, organic substances incl. chlorinated alkenes, aromatic hydrocarbons, chlorinated benzenes, complex organic substances, pesticides, disinfectants and disinfectant by-products, radioactive substances and microorganisms.

National Technical Regulation on Domestic water quality[8] sets limits of quality criteria for water used for domestic use but not for direct drinking or processing food. These regulations apply for institutions, organizations, individuals and households who exploit, trade domestic water, including piped water providers for domestic purposes with capacity of less than 1,000 m3/day (hereafter called water providers) and individuals and households who exploit water for domestic purpose. Limits on few of the substances mentioned in National Technical Regulation of Drinking Water Quality.

5.3 Questionnaire summary

Interested parties within the water treatment area were interviewed based on a questionnaire. In Table 5.3.1 and 5.3.2, the main questions and answers to them are summarized.

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[7] http://www.wpro.who.int/vietnam/topics/water_sanitation/wmq_water_standards_technical_regulation_on_clean_drinking_water_quality.pdf

[8] http://www.wpro.who.int/vietnam/topics/water_sanitation/wmq_water_standards_technical_regulation_on_domestic_water.pdf

Table 5.3.1 - Questions for people located centrally within organizations operating in flooding situation

Q1 What kind of water treatment plants, if any (e.g. reverse osmosis, chemical disinfection) are being used in the areas you are familiar with today? And in what kind of situations are the plants used?

Q2 What is the optimal physical size of a water treatment plant like this? (container size, smaller, bigger?)

Q3 What is the optimal capacity (litres per day produced) of such a plant – or in other words how many people would in average be sharing supply from the same plant?

Q4 What kind of power supply is realistic to rely on in these situations? Is it possible to get fuel supply to a power generator? And is power supply and usage one of the most important factors when choosing type of water treatment plant?

Q5 What quality should the cleaned drinking water meet (e.g. WHO guideline values)?

Q6 Is it sometimes needed to produce water for several purposes – e.g. high-quality for drinking water and a lower quality for household purposes – e.g. washing of clothes?

Q7 And finally, the cost of such a plant – is a price around 17500 US$ acceptable in the situations and areas you are familiar with?

Table 5.3.2 - Answers from people located centrally within organizations operating in flooding situation.

Contact:	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Other comments
Forsvaret DK, Major Kim T. Poulsen	Reverse osmosis. Used in stationing and crisis situations	Units of container size or smaller	Today: 500 and 2000 l/day	Using diesel (500l/day□7.3kwh nominated), too expensive to get supplies, are interested in alternative power solutions (solar, wind)	Trying to meet Danish requirements, except in battle situations where NATO accept lower quality requirements for shorter periods of time	Yes, drinking water and sanitation water (have baths and toilets doing stationing)	Yes, also a bit more if alternative power sources are possible	See summary, things to consider. Will like to contribute more.
Beredsskabsstyrelsen DK	Reverse osmosis and UV disinfection. Desalination module. Used in natural catastrophes around the world, most recent with the tsunami, refugee camps, emergency hospitals	The ones Today pallet size	Today: 1200-1500 l/hr	Small engines so the power usage is relatively small and fuel supply and usage is not a problem	Trying to meet Danish requirements. Actually the plants used today produce almost sterile water – can be used medicinally.	One quality is fine – only minor problem today in the lack of taste in the almost sterile water	Price today app. 120000 Dkr (Danish produced plant – DanPure?)	Can't see how KOMBITEK contributes to the area – are satisfied with the equipment they use today.
Ms. Payden, WHO's Regional Advisor for Water, Sanitation and Health for South-East Asia Region	Reverse osmosis, slow sand filters, aeration and chlorination.	Depends on community size. Rural areas are smaller and urban areas have bigger or several treatment plants	Rural areas: approx. 2000 people Urban areas: approx. 2 million people	Diesel generators for emergency situation. Electrical power for normal situations. Power supply is one of the determining factors for installation of treatment plants especially in urban areas	Either national standards that are approved by the country or in its absence, WHO guideline values	Normally one quality of water is produced for all types of domestic uses	Seems to be expensive	Responses mostly based on the experience I had when I worked in my country before joining WHO. I am not involved in implementation of projects
Jesper Dannisøe, DWF:	Most familiar with situations where Red Cross are represented. RO plants are rare (too expensive), see often (sand-) filtration sometimes with UV disinfection. Needs of drinking water and sterile water for medic purposes.	Container size. 20 or 40 feet doesn't matter. Module build →possibility of up scaling	No such thing as "average village size" from 100 to 40000 people in refugee camps. 5-10 l per person	Solar, wind or fuel cell power supply will be highly appreciated! Should be ready for adaption to the electric grid with permanent installations.	WHO guidelines (and not a better quality than that to keep the costs down).	Produce more than one quality: sanitation use, drinking and medic.	Too expensive for many areas. Consider "pay as you use" concept with cell phone payment.	See summary: main purpose (permanent vs. emergency), design; inlet, outlet, pumps, payment. Would like to contribute more and to hear more in DWF. **Appendix 7:** Grundfos Lifelink system.

5.4 Building the requirement specification

Addressing the above, while realizing the limitations of the project, some points were taken into special consideration. These are described below

5.4.1 Technology advantages – simple logistics

The fact that the advanced oxidation unit is only dependent on electricity means that no chemical handling or logistics is required for disinfection. This advantage is considered paramount and is therefore transformed into a general requirement that the system shall run on electricity only. 100-230VAC is selected as main source, with a note that auxiliary equipment may be procured locally if need be.

5.4.2 Transportability

Infrastructure and logistics in areas with floods are typically poor. From this point of view, a maximum size of a Euro Pallet was added as a requirement. The system should also be reasonably easy to handle – meaning light construction.

The above excludes a sand filter from the list of possible solutions.

5.4.3 Capacity and Cost considerations

From the above, it is known that existing technology, delivering 1000 L/h costs less than 100.000 DKK (End-user price).

To enter a marked that has considerable competition, the preferred choice is to lower the capacity to lower the price.

A unit that can deliver an amount of water equivalent to a water tap (300-600 L/h) must be considered suffi-cient.

5.4.4 Treatment goal

The designed unit should be able to be: transported to a flooding area, unloaded, plugged into mains, connected to the water source, and deliver water of a good palatability and safe to drink, regardless of the microbiological composition, while any effect on the chemical composition of the water should also be beneficial.

6. WP 2. Development of filtration unit for treatment of surface water

Major contributors: Erik Jürgen-Jessen and Tore Svendsen, BIO-AQUA A/S

Surface water contains both organic and inorganic material. Typically, the particles found in surface waters are very small particles, which require a very fine filtration to be removed. Such fine filtration is unfortunately expensive in terms of both CAPEX and OPEX, and typically requires skilled technicians for operation and maintenance. The overall purpose of the KOMBITEK project was to establish a much simpler system for filtration of the water.

6.1 Coagulation

The first step in the process was to develop a simple system for coagulating the particles in the water, thereby enabling the use of large pore filters. Coagulation or flocculation (both names used interchangeably in the report) can be done by applying a number of different techniques, often a liquid is dosed into the water, either a metal, salt or a polymer, neutralizing the surface charge of the particles and thereby ena-bling the formation of larger particles or flocs that easily can be removed by filtration. With the aim of developing a simple technique for treating the water, the use of external chemicals would be a strong barrier for the application of the system in the grid areas. Alternative technologies for flocculation was therefore investigated, and the advanced oxidation was evaluated as being the most suitable technology. Electrocoagulation ("electro", meaning to apply an electrical charge to water, and "coagulation", meaning the process of changing the particle surface charge, allowing suspended matter to form flocs or agglomerates) is an advanced and economical water treatment technology. It helps remove suspended solids to sub-micrometre levels, breaks emulsions such as oil and grease or latex, and oxidizes and eradicates heavy metals from water without the use of filters or the addition of separation chemicals. Coagulation is one of the most important physiochemical reactions used in water treatment. Ions (heavy metals) and colloids (organic and inorganic) are mostly held in solution by electrical charges. The addition of ions with opposite charges destabilizes the colloids, allowing them to coagulate.

An electrocoagulation system essentially consists of pairs of conductive metal plates in parallel, which act as monopolar electrodes. It furthermore requires a direct current power source and a resistance box to regulate the current density and a multimeter to read the current values. The conductive metal plates are commonly known as "sacrificial electrodes." The sacrificial anode lowers the dissolution potential of the anode and minimizes the passivation of the cathode. The sacrificial anodes and cathodes can be of the same or of different materials. In the current setup plates of cast iron was applied as these can be purchased all over the world. During electrolysis, the positive side undergoes anodic reactions, while on the negative side, cathodic reactions are encountered. The released ions neutralize the charges of the particles and thereby initiate coagulation. The released ions remove undesirable contaminants either by chemical reaction and precipitation, or by causing the colloidal materials to coalesce. In addition, as water containing colloidal particulates, oils, or other contaminants move through the applied electric field, there may be ionization, electrolysis, hydrolysis, and free-radical formation which can alter the physical and chemical properties of water and contaminants. As a result, the reactive and excited state causes contaminants to be released from the water and destroyed or made less soluble.

A simple, but effective system applying DC power to metal plates separated by plastic was built. Initial testing showed good visual flocculation of the fine particular material in the water. The system was constructed such that the number of metal plates could be regulated to the actual water. A submersible pump was used to feed the overall unit. From this pump the water enters a 150-mm pipe, where the electro-coagulation unit is mounted.

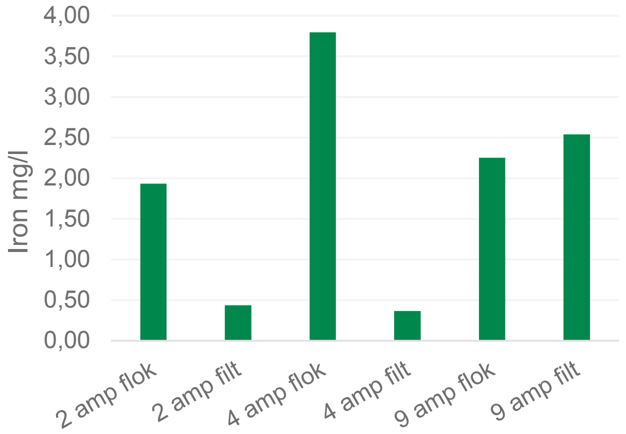


Figure 6.1 – Comparison of free iron content before and after filtration at different current densities. Ampere is abbreviated to amp. “flok” is the free iron content at the flocculation step and “filt” is at the filtering step.

In Figure 6.1, a comparison of the free iron content before and after filtration is shown. These values were used to adjust the electrical current in the electrocoagulation system. From Figure 6.1 it is clear that at both 2 and 4 Ampere most of the iron is removed by the filter, whereas so much is dosed at 9 Ampere that the filter could not remove it all. 4 Ampere was considered optimum and used for this specific water in the following experiments.

6.2 Filtration

Many different filtration techniques are commercial available on the market, but only very few are widely accepted as good solutions for “of the grid solutions”. BIO-AQUA A/S has been working on a special type of filters, called flexible filters. These filters consist of polymeric threads, when these are compressed by the water pressure they form a filter cake, and when the water passes this cake particles are retained in the filtration cake. The filters are thereby dead-end filters, which normally has the disadvantage that they cannot be back-flushed. The current filters however have the advantage that by reversing the flow, the polymeric threads are straightened and by applying water and a little bit of air, the fibers are cleaned. The overall concept can be seen in the Figure 6.2

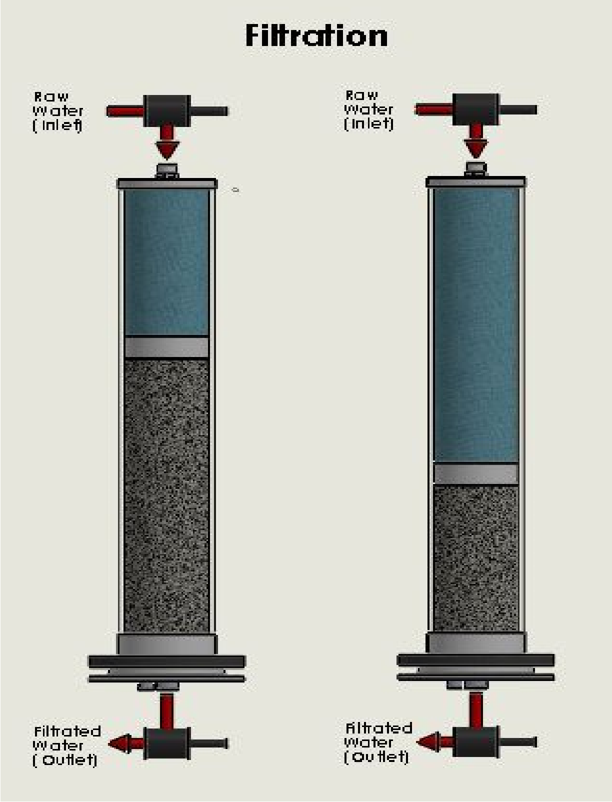


Figure 6.2 – Flexible filters with polymeric threads that are compressed during filtration.

The packing density and the diameter of the fibers determines the filtration degree of the filters. In the beginning of a filtration period the filtration cake is more open, whereas it will gradually close more when material is deposited on the filters. The pore size is therefore not an accurate number, but more an estimate. In order to determine how fine particles are removed by the filters, a number of experiments where conducted. In these experiments the pilot filtration unit was places on the lake shore and water was pumped into the unit. By comparing the quality (visually) from the flexible filters with the quality of water filtered through syringe filters with fixed pore sizes (0.45 µm, 2 µm, 5 µm, 10 µm) it was possible to estimate the pore size of the filters. This comparison revealed that the apparent pore size of the filters was 5 µm. The results also indicated that there is a strong development in quality of the permeate (treated water) over time, as the cake layer builds up. A comparison of ingoing and treated water can be seen in the picture below (Figure 5.3).

Figure 6.3 – Water from the filtration process. The bottle on the left (blue cap) contains a sample of ingoing water, while the bottle on the right (clear cap) contains filtered water.

This test also established that the finest flexible filter should be applied. The pilot unit (see Figure 6.4) was initially equipped with a pump giving 1.2 bar and 760 L/h. When applying the finest filters, the flow from these filters was too low and it was therefore decided to increase the filter size and the pump capacity to a pump giving 1.5 bar and 940 L/h.

In the ongoing test, after implementation of the larger filter and the 5 µm flexible filter, good results were obtained with the lake water (see results in work package 6). However, in a test with a combination of lake water and pig slurry, the combined electro coagulation and filtration could not remove the yellowish color of the water, which was probably caused by urine in the pig slurry. Different settings of the electroflocculation was investigated and some of these resulted in visible color-reductions, but none of the settings were able to entirely remove the yellowish color. There were not any bacteriological problems with the water, but in order to reduce the color the possible of implementing a ceramic membrane of 0.04 µm was investigated.

Figure 6.4 – The pilot filtration unit.

A ceramic membrane is a very durable membrane. The applied membrane was from the Danish company LiqTech, it was an OD 300 x 1165 mm silicium carbide membrane with 3 mm inner channels (see Figure 6.5).

The membrane was mounted after the existing equipment of the pilot unit, so it functioned as a final polishing of the water. The membrane was operated in crossflow mode, LiqTech recommends a 2 m/s crossflow, but due to the implementation in an existing setup the crossflow fluctuated from 0.8 to 2.2 m/s. During initial testing with the membrane it was evaluated whether the membrane should be mounted before or after the chlorination system. The test results indicated that the degree of fouling was considerately reduced when operating the membrane on water that already had been chlorinated.

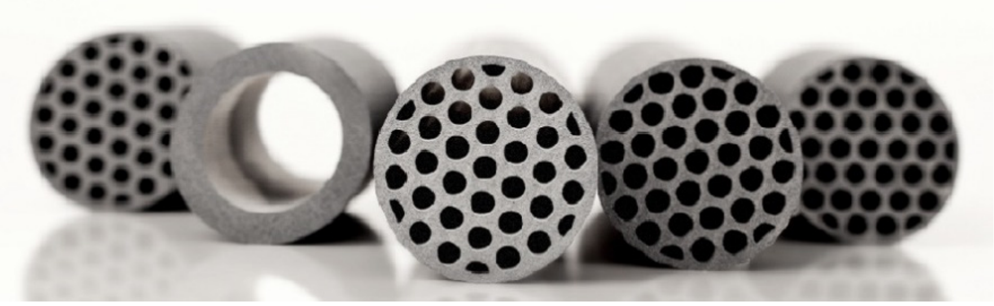
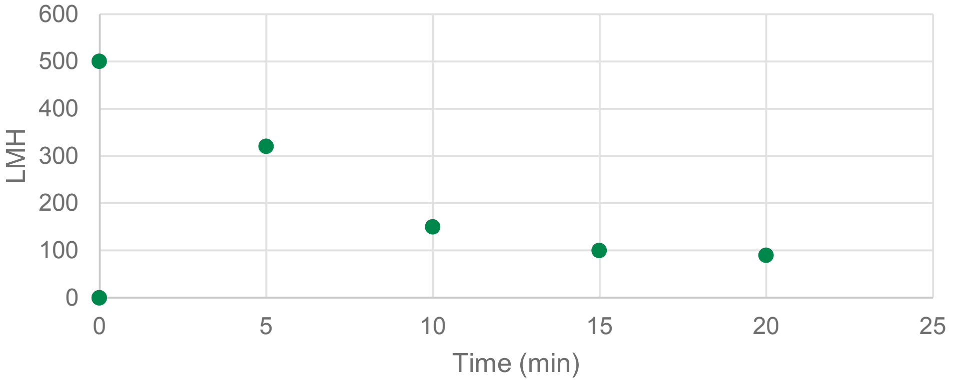


Figure 6.5 – The LiqTech ceramic membrane used to reduce the color of the filtered water.

Application of the membrane on the combined water showed an excellent water quality (< 5 NTU in turbidity) and no color. The disadvantage of the membrane was the fouling, where primarily organic particles built up on the membrane surface and limited the flow through the membrane. Due to the high amount of particular matter in the incoming water, a very rapid decline in membrane flux was observed and already within 20 minutes the flow was reduced to less than 100 L/m2h (see Figure 6.6).

Figure 6.6 - The decline in membrane flux (LMH = L/m2h) over time.



Back-flushing had some positive effect on the membrane flux, but it would be necessary to chemically clean the membrane at least daily, and it was evaluated that this was too often for a real application. The membrane was therefore not included in the final setup. Instead, it was decided that as long as the bacterial data of the water was satisfying, the quality criteria of the water was fulfilled. Obviously, a lager membrane would solve this problem.

6.3 WP2 Conclusion

Although the treated surface water was not visually appealing without the secondary membrane, the water was of sufficient quality to drink and the problems with flow through the silicium carbide membrane could be solved by increasing the size.

7. WP3: Development of advanced oxidation unit for treatment of surface water

Major Contributor: Poul Fogh, Adept Water Technologies A/S

7.1 Electrolysis for disinfection

The technology of electrolysis is several hundred years old. The basic principles of applying it directly in drinking water, however, is new. Drinking water contains different salts e.g. sodium chloride. The BacTerminator® advanced oxidation technology can use the naturally occurring chloride to form chlorine (see Figure 7.1). This principle is explained below:

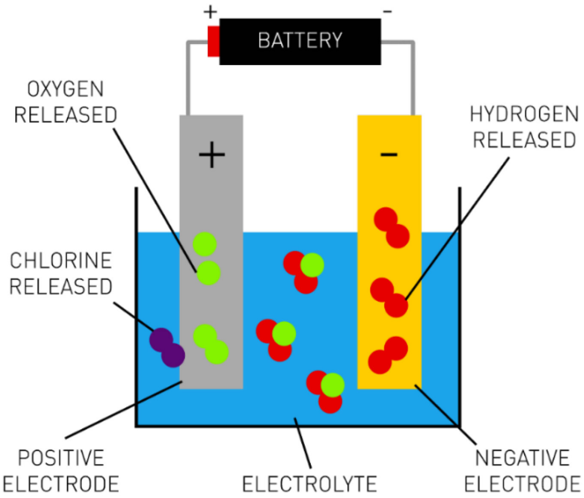


Figure 7.1 – Figure of an electrolysis cell (modified from http://www.square1energy.com/elect101a.html)

By passing an electrical current through water, the following electrochemical reactions will occur:

At the cathode (-) – electrochemical reduction:

$$2H_2O + 2e- \rightarrow H_2 + 2OH-$$

At the anode (+) – electrochemical oxidation:

$$H_2O \rightarrow \frac{1}{2}O_2 + 2H+ + 2e-$$

$$2Cl- \rightarrow Cl_2 + 2e-$$

Chlorine gas will further react with water in the anode region:

$Cl_2 + H_2O$ □ HOCI + Cł + H^+

The above reaction means that half the consumed chloride will be returned to the water, thus reducing the change in salt content.

Note that the chlorine production in the electrolysis unit is proportional to the electrical current in the system.
The voltage is needed to overcome the electrochemical reactions and the conductivity of the water, which is inversely proportional to the salt content.

The chlorine in the water has a formulation depending on the pH of the water as shown in Figure 7.2. Of the dissolved disinfectants, hypochlorous acid (HOCl) is the most potent.

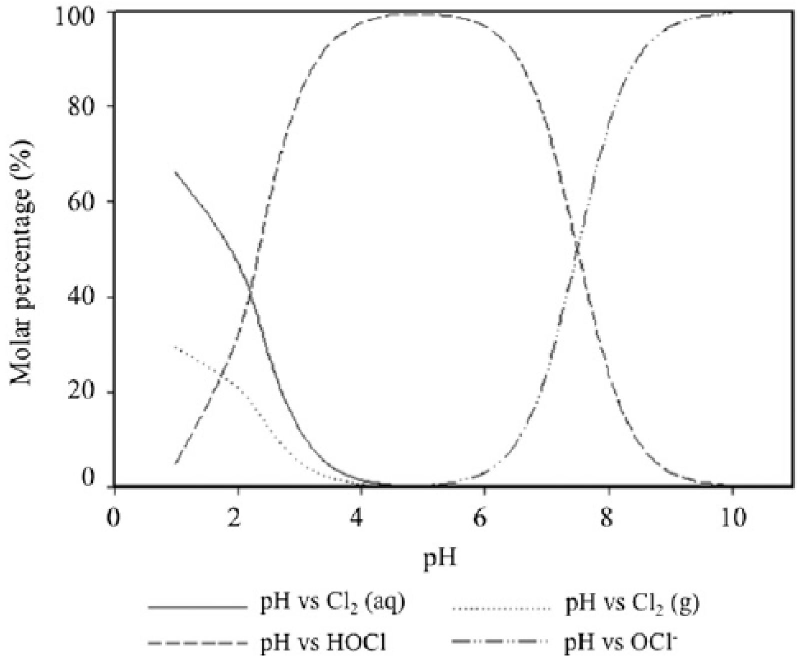


Figure 7.2 – The pH dependency of chlorine in water (https://www.researchgate.net/publication/275167870)

As the anode process (where the chlorine is formed) also has a low pH, the efficiency of immersing the electrodes into the water stream is higher than if the chlorine was added.

7.1.1 Advanced Oxidation unit

While Adept Water Technologies A/S had worked for some 8 years using electrolysis as basis for disinfection, and thus had a good understanding the chemistry and process, the relative efficiency estimation and the design of a system for this type of application was yet to be done. As cost was an important parameter, the design was shifted from a multicomponent chamber design of 20 parts of plastic or metal, half of which were specially made for the task and requiring an expensive 11-wire connection (see Figure 7.3A), to a 6-part PVC chamber, where most parts were modified standard parts (see Figure 7.3B). Electronic control and interface were also simplified and cost was reduced. The resultant system was developed as a smaller version of the, at the time, brand new second generation of the BacTerminator®. The developed electrochemical unit will, from this point on, be referred to as Advanced Oxidation (AO) unit.

Figure 7.3 - Pictures of the old AO system (A) and the new design (B). In the old system metal parts cover 4 plastic parts, which are kept together by nuts and bolts. The new and larger design version uses bolts to keep the top to the chamber.

The initial and already performed transfer to a new design style reduced cost around 70%, but the initial models made were targeted at much higher capacities. Making a system for surface treatment with the small capacity required adapting commercial off-the-shelf-power supply units to a custom-made electrode chamber and electrode plates.

7.2 Design challenges

In order to design the AO unit, the following prerequisites were needed.

1. Determine the combination of voltage, current and electrode area
2. Determine any safety/longevity features needed
3. Design an electrode chamber that is compact, affordable and has good flow characteristics – and has familiarity with the above shown “new generation”
4. Implement the control – and allow for integration with the filter solution in the KOMBITEK module.

7.2.1 Task 1

A rule of thumb is that in clean water a current of about 30 Ampere (A) is required to produce 1 ppm of free chlorine in a flow of 1 cubic meter per hour (1000 L/h).

With a flow that is expected to be from 300-600 L, a current of 30 A will generate 2-3 ppm of chlorine, which is considered sufficient for the prototype. In case higher capacity is needed, the electrodes will be designed for 50-80 A, and a new power supply can be added.

The voltage to deliver this current will, if the standard electrode current density of Adept Water Technologies A/S is chosen, in Danish drinking water, require less than 12V to achieve. However, surface water may have a much lower salt content and thus require higher driving potentials. 24VDC is the next industry standard voltage, and is deemed sufficient. A new adjustable 24V 7-32 A power supply was procured and tested as part of the project.

Since such a power supply was available from several commercial vendors, it seemed unnecessary to deviate from the standard electrode distance (which require 0.1mm filtering) and area. (price-wise optimized). In order to prepare for all eventualities, the system was designed with two electrode sizes, a short one and a long one, the difference being ~40% area. Both were tested, and the short length was pre-ferred for the KOMBITEK device, at the chlorine production was deemed sufficient.

7.2.2 Task 2

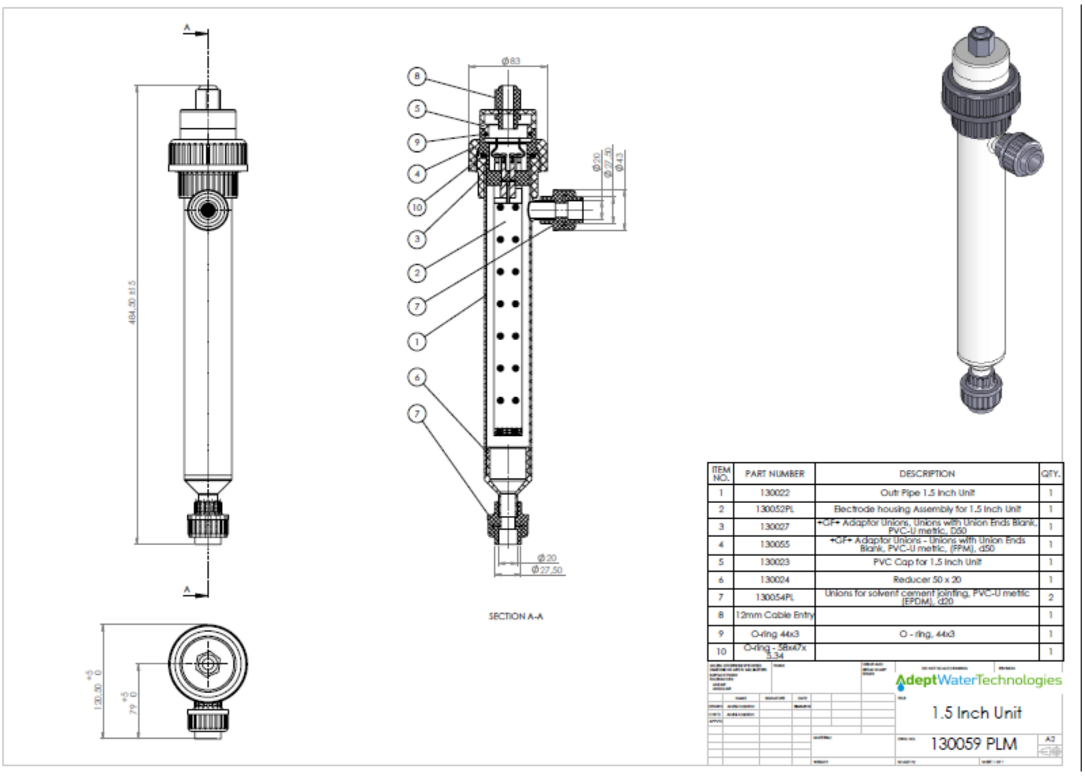
Apart from filtering, fouling of the electrodes occur if limescale may precipitate or organics may be oxidized from the electrode surface and “burn” to the surface. Reversing the current periodically will help remove the limescale, and this, plus cooling of the entire electrodes, will alleviate the risk of fouling.

Further, a thermo switch and a current sensor are added to the design in order to monitor short circuits or chlorine production failures.

Note: As this project began in 2013, specialized hardware for thermo-switching and current sensing was only just becoming available, and thus at the time it was a considerable risk to integrate these features in a comparatively low-cost and -capacity unit.

7.2.3 Task 3

. The design resembled the existing larger BacTerminator® AO units, but added the novelty of a thread-based closure (see Figure 6.4), as opposed to the nuts and bolts used in previous designs (see figure 6.3B).



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	130022	Outr Pipe 1.5 Inch Unit	1
2	130052PL	Electrode housing Assembly for 1.5 Inch Unit	1
3	130027	+GF+ Adaptor Unions, Unions with Union Ends Blank, PVC-U metric, D50	1
4	130055	+GF+ Adaptor Unions - Unions with Union Ends Blank, PVC-U metric, (FPM), d50	1
5	130023	PVC Cap for 1.5 Inch Unit	1
6	130024	Reducer 50 x 20	1
7	130054PL	Unions for solvent cement jointing, PVC-U metric (EPDM), d20	2
8	12mm Cable Entry		1
9	O-ring 44x3	O - ring, 44x3	1
10	O-ring - 58x47x 5.34		1

Figure 7.4 – New AO unit with thread-based closure.

7.2.4 **Task 4**

Apart from measuring the electrical current and regulating the power supply, all other operations rely on simple on/off settings, and thus even the simplest PLCs can operate such a system. A Siemens LOGO! 0BA6 and display was chosen to operate this, and expanded to control the valves and pumps of the system as well.

Once produced and tested, the system was joint with the filter unit of BIO-AQUA to produce the KOMBITEK system.

7.3 **WP3 Conclusion**

With basis in Adept Water Technologies BacTerminator® an advanced oxidation AO system for use in the transportable water treatment plant was developed. The electrode fouling was much lower than expected, and the lifetime and performance of the system must be considered sufficient for any emergency situation

8. WP4: Integration and test of system in Denmark and Vietnam

This work package initially required the combination of the AO unit from WP3 with the filter unit from WP2 and test of this. The initial tests were performed without microbiology and chemical testing, but had the purpose of:

- Determining the flow system
- Testing the function of the electro-flocculation and the advanced oxidation unit
- Programming the PLC and testing valves and general functionality.

Following this, tests were made with the secondary filter, using contaminated lake water as described in WP6. Once the system had been developed to maximum performance, the system was shipped to Vietnam, where tests were performed with water from a fish pond; water that resembled contaminated surface water.

8.1 Process design logic

The necessity of being self-sustained implies a simple logic for operation. Firstly, water must be available for filter flushing. This must be made before clean water is produced for consumption. Once the filters start showing signs of clogging, the flushing must be made.

8.1.1 General remarks

The hardware developed under WPs 2 and 3 were quickly joined and testing commenced roughly according to original schedule. Several iterations of the process system were made in order to optimize the functionality. The focus, as shown in the development history below, was to optimize the water's clearness.

8.2 System operation description and development history

The first system design was as shown below. The system has four operating modes:

- Flush tank filling
- Operation
- Flush cycle part 1
- Flush cycle part 2

8.2.1 Part 1: Flush tank filling:

This is done when the filter is at the cleanest point, in order to decrease any risk of contamination during the flush.

The water is pumped by P1 to the flocculation tank, which is kept full and the excess water returned to the pond. From here a pump press the water through the main filter (F1) and on through the AO unit and into the storage tank

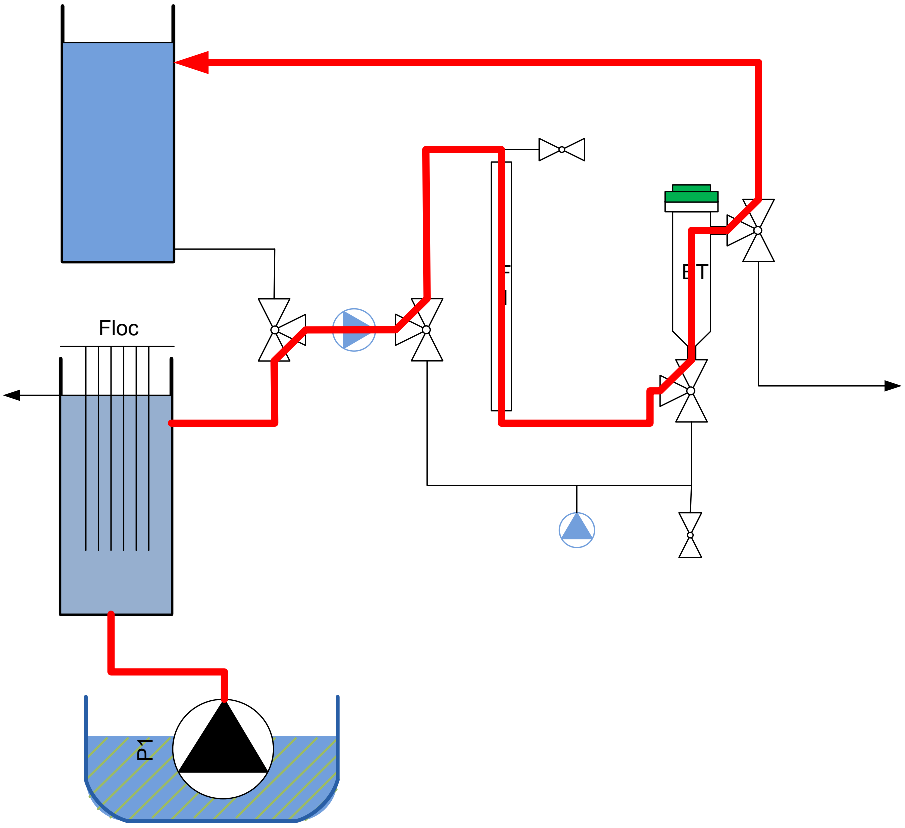


Figure 8.1 – Flow diagram for the filling of the flush tank. P1 is the pump for inlet water and F1 is the BIO-AQUA A/S filtering unit. BT is the AO unit and Floc is the flocculation tank.

8.2.2 Part 2: Water treatment:

This is done after the filter flush tank is filled until the filters clog.
The water is pumped by P1 to the flocculation tank, which is kept full and the excess water returned to the pond. From here a pump press the water through the main filter (F1) and on through the AO unit to a delivery point.

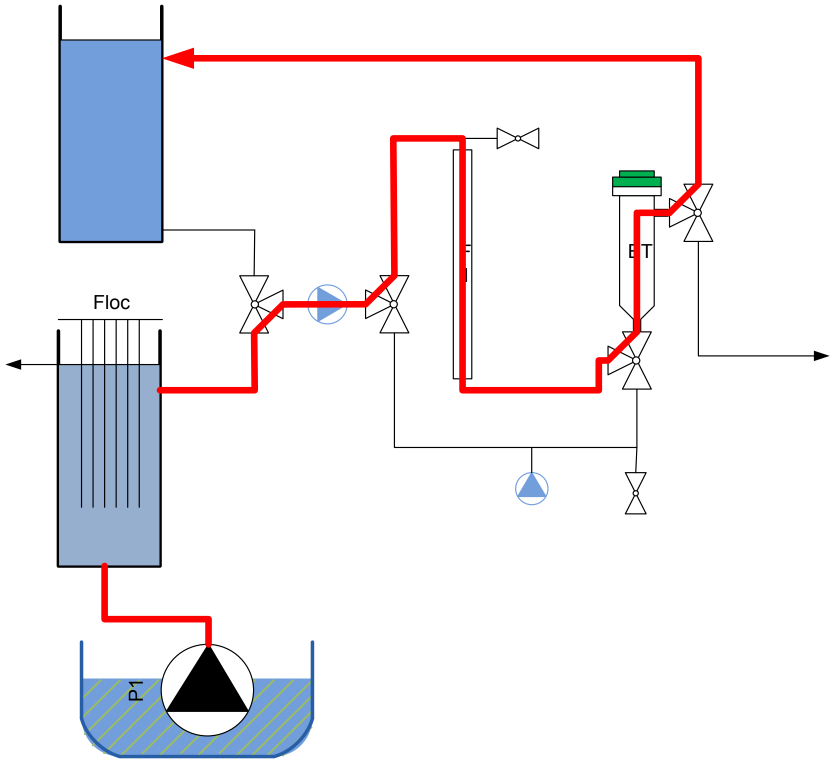


Figure 8.2 - Flow diagram for the water treatment process. P1 is the pump for inlet water and F1 is the BIO-AQUA A/S filtering unit. BT is the AO unit and Floc is the flocculation tank

8.2.3 Parts 3 & 4: Flushing:

This is a two-step process. In the first, the flush water from the flush water tank is lead backwards through the filter and then to drain. In the second, fresh, filtered water is flushing the part of the water system now occupied by flush water.

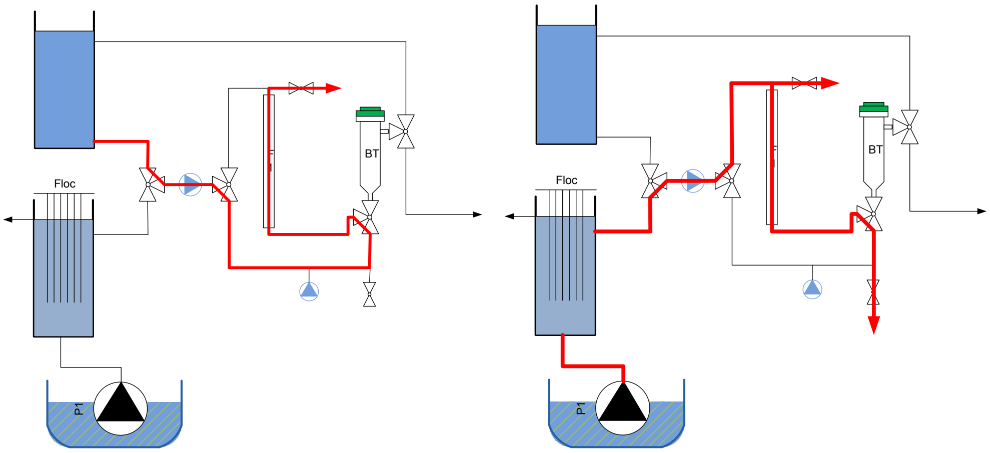


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Figure 8.3 – Flow diagram for the two-step flushing process. P1 is the pump for inlet water and F1 is the BIO-AQUA A/S filtering unit. BT is the AO unit and Floc is the flocculation tank

The general conclusions were:

- The mechanical reliability of the flocculation and the primary filter were very good
- The mechanical reliability of the AO unit was acceptable, but scaling and overheating turned out to be a problem due to poor control. Further, the polarity reversal technology was not quite reliable
- The perceived quality of the water was too low, and a secondary filter was deemed necessary.

The problems with water quality and overheating, prompted modifications and several secondary filters and installations were attempted..

8.3 Secondary filter selection

8.3.1 Configuration 1: Addition of a SiC (LiqTech) filter in series with the first filter

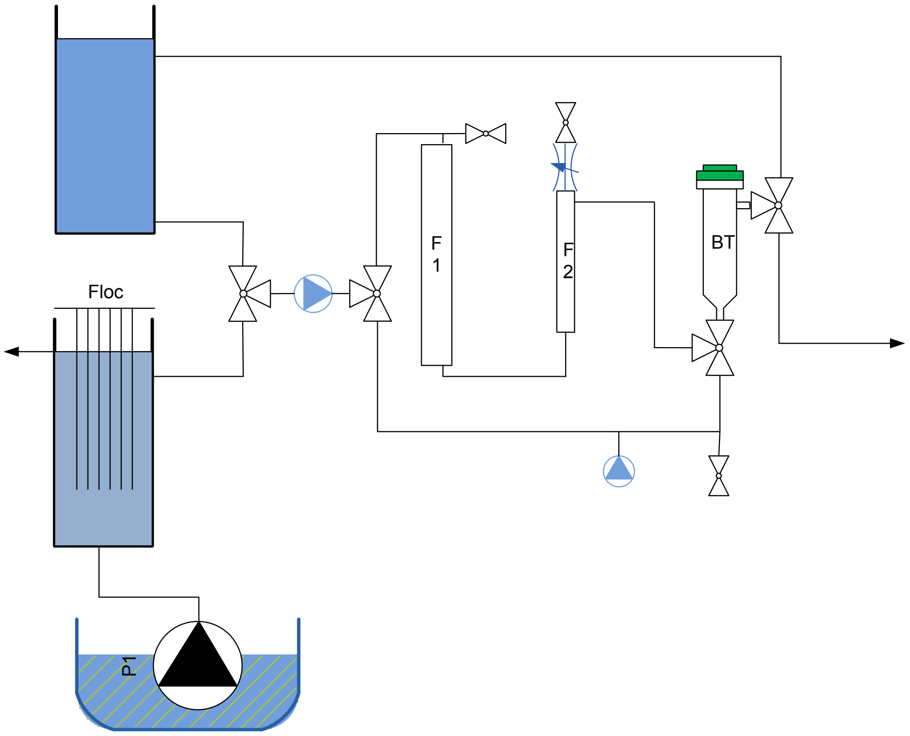


Figure 8.4 - Flow diagram for the inclusion of a SiC filter in the water treatment setup. P1 is the pump for inlet water. BT is the AO unit, Floc is the flocculation tank, F1 is the BIO-AQUA A/S filtering unit and F2 is the LiqTech filtering unit.

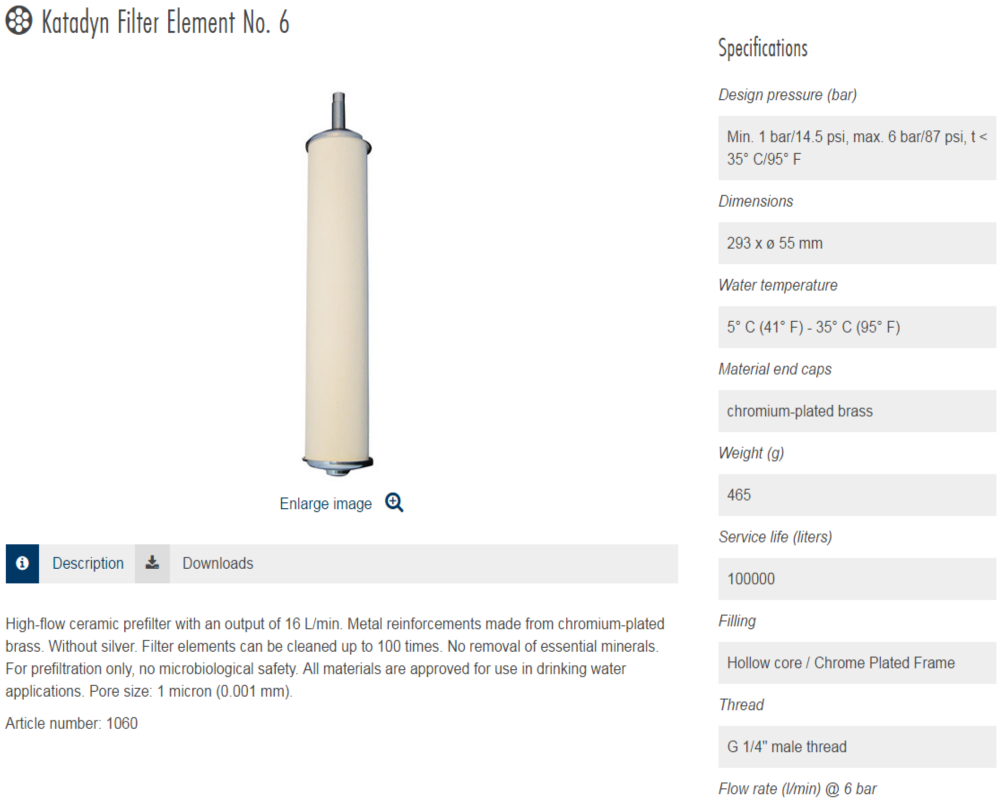
In this configuration, the AO unit treated less water, as the secondary filter was of the cross-flow type. This increased the possible chlorine concentration and the water was, based on a visual inspection, deemed of good quality.

Though the filter was included in the flushing loop, the filter fouled very quickly, and even with an enlarged filter flush tank, it was not possible to clean it sufficiently to avoid clogging.

8.3.2 Configuration 2: Using a Katadyn filter as secondary filter.

The Katadyn type ceramic filter is made for fine filtering of the water. Filters of type #6 and type #55 was purchased from Katadyn. The type #55 has been removed from the market, but was basically a cul-de-sac filter type, where no outlet end fitting is required. Thus, also, no return flush was possible. The data sheet of the type #6 is shown in the right-hand side of figure 8.5.

Figure 8.5 – Katadyn Filter #6 picture and specifications.



Katadyn Filter Element No. 6

Enlarge image

Description Downloads

High-flow ceramic prefilter with an output of 16 L/min. Metal reinforcements made from chromium-plated brass. Without silver. Filter elements can be cleaned up to 100 times. No removal of essential minerals. For prefiltration only, no microbiological safety. All materials are approved for use in drinking water applications. Pore size: 1 micron (0.001 mm).

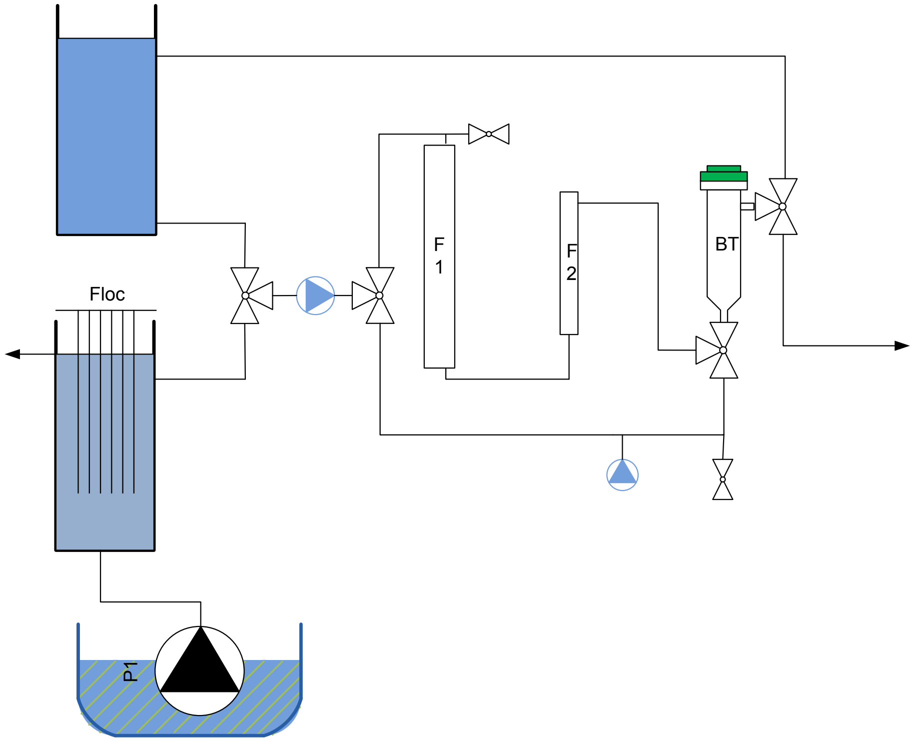
Article number: 1060

Specifications

Design pressure (bar)	Min. 1 bar/14.5 psi, max. 6 bar/87 psi, t < 35° C/95° F
Dimensions	293 x ø 55 mm
Water temperature	5° C (41° F) - 35° C (95° F)
Material end caps	chromium-plated brass
Weight (g)	465
Service life (liters)	100000
Filling	Hollow core / Chrome Plated Frame
Thread	G 1/4" male thread
Flow rate (l/min) @ 6 bar	

The Katadyn filters were arranged in a fashion similar to the SiC membrane, but with no cross flow, as the filters were not designed for this:

Figure 8.6 - Flow diagram for the inclusion of a Katadyn filter in the water treatment setup. P1 is the pump for inlet water. BT is the AO unit, Floc is the flocculation tank, F1 is the BIO-AQUA A/S filtering unit and F2 is the Katadyn filtering unit.



These filters clogged after less than 20 L of operation, and proved very hard to clean (grinding with sand paper on the outside), and were quickly abandoned as a solution

8.3.3 Configurations 3 & 4: Rearranging the SiC filter for better flushing

In an attempt to solve the cooling problem with the advanced oxidation unit and use the bubbles generated from this to keep the secondary filter clean, the advanced-oxidation unit was placed upside down, and the SiC filter placed just after this. The idea being, that the gasses formed would keep the secondary filter cleaner, allowing for a longer operation between flushing. Further, the pump- and filter-size was increased.

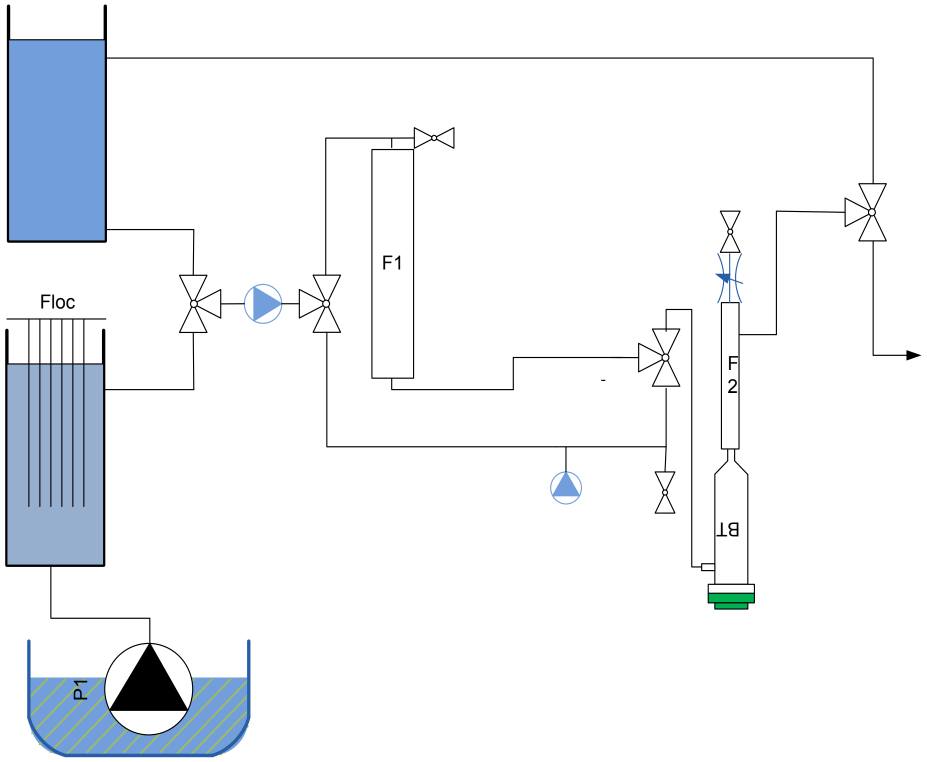


Figure 8.8.7 - Flow diagram for rearranged inclusion of a SiC filter in the water treatment setup. P1 is the pump for inlet water. BT is the AO unit, Floc is the flocculation tank, F1 is the BIO-AQUA A/S filtering unit and F2 is the LiqTech filtering unit.

This configuration worked quite well, but did not allow for back flushing of the secondary filter. A manual backflush filter was added. And thus, the configuration became:

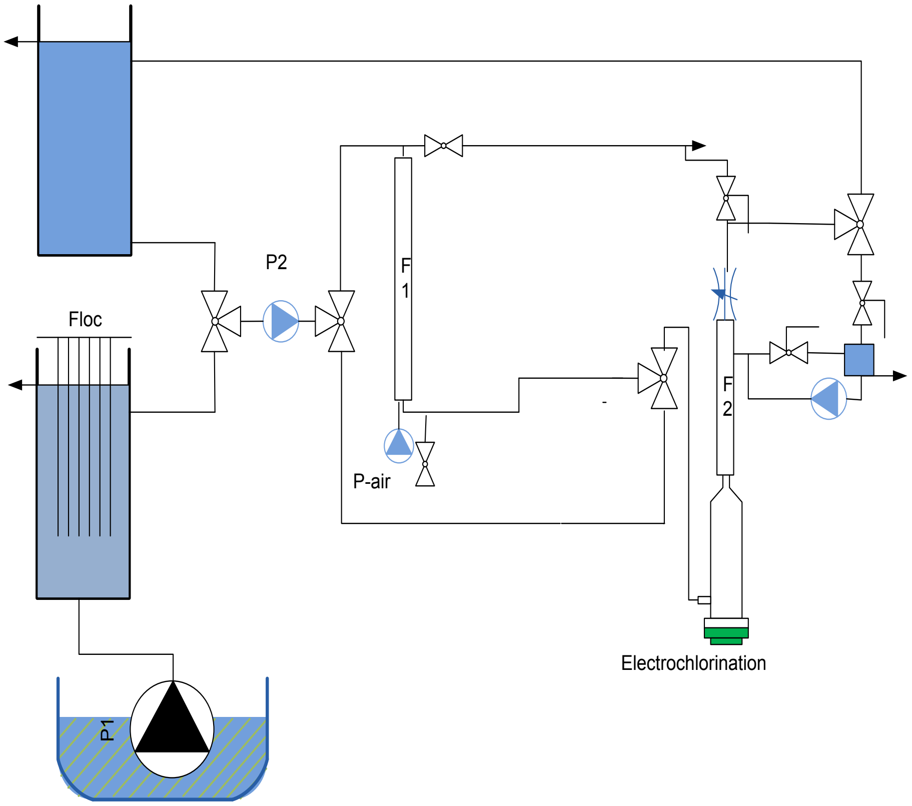


Figure 8.8 – Flow diagram for rearranged SiC filter setup with backflush configuration. P1 is the pump for inlet water. BT is the AO unit, Floc is the flocculation tank, F1 is the BIO-AQUA A/S filtering unit and F2 is the LiqTech filtering unit. P2 delivers water from the flocculation tank to the filters and P-air pumps in air during the flushing.

At this point, about a year extra had been spent (albeit at low speed) to investigate and improve the quality of the water, and the budget for both partner companies were already well and truly spent. Thus, the need for a more powerful pump, which would have improved the backflush, was dropped, as this would have meant strengthening the entire pipework to handle higher pressures

8.4 Specifications

8.4.1 Major parts list

Table 8.4.1 – Information on supplier and specifications for major components.

Component	**Detailed information**
Feed pump (Submersible)	Grundfos Unilift. Flow > 1000L/h @ 5 m suction height
Electroflocculation	BIO-AQUA A/S EC-01
Power supplies	Flocculation: MeanWell HCG-320H-12A Advanced Oxidation: MeanWell RSP-750-24 12VDC for valves and pump 24VDC for PLC
Valves (7 in total)	Belimo R2025-S2 types
Filtration pump	Flojet Quad II 12 V
Filter	BIO-AQUA A/S Flexible filter 1.0 µm
Back blowing compressor	Charles Austen 12 V
Advanced oxidation	Adept Water Technologies 1½” disinfection unit
Ceramic membrane	Liqtech 0.04 µm SiC ceramic membrane
Manual valves	Ø 25 mm GPA PVC
Piping	Ø 25 mm GPA PVC
Water tanks	PP, custom made by BIO-AQUA A/S
Electric Cabinet	Siemens PLC with Siemens Logo HMI in a Rittal enclosure

8.4.2 Plant specifications

Size:	80 x 120 cm x 220cm
Weight:	50kgs
Power:	230VAC – max ~ 2kW. (Can easily be configured for 110V operation as well)
Cost as built:	85.000DKK* (“single build” incl. parts and manpower)

*Simplification and mass production will reduce the price with an estimated 30%.

8.5 Test overview

The system was tested in two different environments in Denmark before being shipped to Vietnam. Close to BIO-AQUA A/S is a small pond that was used for initial testing. In order to get a different organic load and a typical “city lake” environment, Emdrup Sø was used for testing (see Figure 8.9).

Figure 8.9 – Satellite photo of Emdrup Lake[9]

Initial tests were performed at to Adept Water Technologies A/S in Herlev, with lake water that had been transported to the site, but in the final tests on Danish lake water, the entire system was transported to Emdrup Lake and, powered by a generator, tested directly with lake water.

Table 8.5.1 provides an overview of the tests. In addition, sampling was attempted on 4th of September 2014 from Lake 2, but was terminated due to lack of chlorine production in test unit. On early February 2015 sampling was attempted from Emdrup Lake, but stopped due to oil contamination of the lake water, originating from the tank of the water truck.

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[9] https://www.google.dk/maps/place/Emdrup+S%C3%B8/@55.7227584,12.5486126,441m/data=!3m1!1e3!4m13!1m7!3m6!1s0x465252695b36d0b1:0x38804cd1b9c7735b!2sEmdrup+S%C3%B8!3b1!8m2!3d55.7227594!4d12.5489338!3m4!1s0x465252695b36d0b1:0x38804cd1b9c7735b!8m2!3d55.7227594!4d12.5489338?hl=da

Table 8.5.1 Overview of the tests

Tests:	Date for test:	Sample type:	Configuration:
Test 0	June 10th, 2014	Water from a lake close to BIO-AQUA A/S (lake 1). Only few samples were taken and analysed for microorganisms. Main purpose: to test the functionality of the filter unit of the water treatment unit.	1
Test 1	July 1st, 2014	Water from a lake close to BIO-AQUA A/S (lake 1). Only few samples were taken. Main purpose: to test the functioning of the different parts of the water cleaning unit.	1
Test 2	August 21st-25th, 2014	Water from another lake close to BIO-AQUA A/S (lake 2). Main purpose: to test the effects of the filters, the flocculation unit and the electrolysis cell.	1
Test 3	February 16th, 2015	Water from Emdrup lake, tested at Adept Water Technologies A/S and slightly manipulated by adding pig slurry to increase number of bacteria and pathogens in the water.	2
Test 4	June 2nd, 2015	Water from Emdrup lake, tested at Adept Water Technologies A/S. Again, pig slurry was added but this time at two different concentrations. Concentration 1: 0.1 ‰ pig slurry Concentration 2: 1.0 ‰ pig slurry	3
Tests w/o sampling	August 2015, November 2015 February 2016	Water from lake 2	Configurations 3 and 4. Filter size increased, pump capacity increased. Cleaning cycle tank volume and parameters modified.
Test 5	April 29th, 2016	Water from Emdrup lake. This time no pig slurry was added to the water. Testing was made at Emdrup lake	4 with and without secondary filter inserted
Test 6	Week 43-44, 2016 – in Hanoi	Field test from a fish farm, outskirts of Hanoi.	4

8.6 WP4 Conclusion

Different configurations of the pilot plant were tested on Danish lake water, before the pilot plant was tested on surface water in Hanoi, Vietnam. The final configuration was based on a primary filtering through the polymer thread-based BIO-AQUA A/S filter and a secondary filtering through a silicium carbide membrane (LiqTech). This configuration worked quite well, but did not allow for back flushing of the secondary filter. Therefore, a manual backflush filter was added. This backflush could have been improved by adding a more powerful pump, but this was not done as it would have meant strengthening the entire pipework to handle higher pressures.

9. WP5: Effect of advanced oxidation on chemical contaminants

Major contributor: Hans Christian Bruun Hansen, Department of Plant and Environmental Sciences, University of Copenhagen

In this work package, focus has been on the effect of the water cleaning unit on the chemical composition of the treated water (for effects on the water microbiology see WP6). This included optimization of the water cleaning unit (see above), 7 field tests and laboratory testing on how the electrolysis cell works in presence of different water compositions and in presence of organic contaminants. The subtasks have been:

- Optimization of the filtration and AO units at Adept Water Technologies A/S and BIO-AQUA A/S. This is reported in the WPs 2 to 4.
- Field tests of the water cleaning unit for Danish and Vietnamese surface waters; chemical analyses.
- Lab test of the performance of the AO unit for different water compositions.
- Lab test of degradation of organic contaminants in the AO unit.
- A risk assessment in regard to using AO for water treatment.
-

The water cleaning unit, which was tested in WP5, performs these overall cleaning operations in sequence (see WP2-4 for details):

- **Electrocoagulation**: Fe(II, III) released from Fe electrodes causing flocculation of humic materials, binding of phosphate etc. to form small particles
- **Filtration** I: A polymer filter retains particles in the native water and particles formed by coagulation
- **Electrolysis**: In an electrolysis cell (BacTerminator® AO unit) active chlorine (chlorine and hypochlorous acid) is formed by electrochemical oxidation of chloride; the active chlorine kills microorganisms. Water is electrolyzed, forming hydrogen, oxygen, and low concentrations of oxidants (like hydrogen peroxide)
- **Filtration** II (optional): A ceramic filter is to retain particles down to 0.1 micrometer.

9.1 Field tests on Danish and Vietnamese surface waters; chemical analyses

During the development of the water treatment unit, 7 tests on natural waters have been performed (see Table 8.5.1 in section 8.5).

Below the chemical test results will be presented and the results discussed. There were no test results from Test 0. The methods that have been used are standard methods:

EC:	Determined using an electrical conductivity cell
pH:	Determined using a combination electrode, calibration with standard buffers
TOC:	Determination of the total organic carbon dissolved in the water. Samples have been filtered (0.45 um regenerated cellulose membrane) and the instrument compensates for inorganic carbon in the sample
Cations:	Mg^{2+}, Ca^{2+}, Na^{+}, K^{+} (magnesium, calcium, sodium and potassium). Determined by ICP-OES on filtered and acidified samples; applies both to major cations and trace cations.
Anions:	Cl^{-}, SO_4^{2-}, NO_3^{-} (chloride, sulfate, nitrate). Determined by ion chromatography
Chlorine:	Cl_2 Determined colorimetrically using Hach-Lange instrument
Phosphate:	PO_4^{3-} Determined by the molybdate method and spectrometry
Alkalinity:	Determined by Gran titration

Particulate matter: Determined by filtration on fiberglass filters.

9.2 Test 1

This test was carried out at BIO-AQUA A/S in a lake hereafter referred to as Lake 1. The testing had a short duration and only few samples were taken. This was the first test of the instrument and the main purpose was to test the functioning of the different parts of the water treatment unit. The chemical analyses were kept few and hence there were no measurements of major cations in the water. The processed water samples were added sodium thiosulfate to preserve the samples for microbiological analyses. Results appear from Table 9.2.1.

Table 9.2.1 – Results from chemical analysis of water from BIO-AQUA A/S Lake 1.

Sample type	Cl_2	pH	EC	TOC	Alkalinity	Cl^-	SO_4^{2-}	NO_3^-
	[mM]		[μS/cm]	[mM CO_2]	[mM HCO_3^-]	[mM]	[mM]	[mM]
Lake water		8.38	270	0.13	2.09	0.72	1.12	0.00
Lake water added sodium sulfite (microbiology)		8.38	265	0.16	2.05			
Low AO current, 0-1min	0.015	8.27	270		2.20	0.72	1.05	0.00
Low AO current, 10min	0.015	8.29	265	0.14	2.10			
Low AO current, 30min	0.012	8.27	265	0.14	2.11			
Low AO current, 60min	0.005	8.28	268	0.13		0.70	1.07	0.00
High AO current, 0min	0.047	8.31	284	0.14		0.72	0.90	0.00
High AO current, 10min	0.032	8.21	279	0.13				
High AO current, 30min	0.022	8.21	274	0.15				
High AO current, 60min	0.020	8.30	275	0.13				
High AO current, 1 day	0.001	8.15	270	0.17	2.30	0.70	1.01	0.00

9.2.1 Summary of results from Test 1:

- The water in BIO-AQUA A/S Lake 1 was low in TOC, and rather dilute (low EC). It had a high pH and a relatively high alkalinity. The lake water appeared "clean" (had little nitrate), and was visually clear with hardly any particles.
- Water treatment hardly affected the water composition
- The concentration of active chlorine dropped with runtime of operation indicating that the electrodes were getting fouled. The most extreme was seen after operation for 1 day where there was barely any chlorine produced.
- Measurements were also carried out for chlorate and perchlorate, but all measurements were below the detection limit of the instrument.

9.3 Test 2

This test was carried out also at BIO-AQUA A/S but on another lake hereafter referred to as Lake 2. The configuration of the instrument for this test was the same as for Test 1 (see also Table 8.5.1). The main purpose of this testing was to test the effects of the filters (Filter 1, Filter 2), the flocculation unit and the AO unit. The effect of storing the water was investigated.

Table 9.3.1 - Test 2. Composition of water from BIO-AQUA A/S Lake 2 after different run time and instrument settings (average values of duplicate or triplicates)

Sample type	Cl_2	pH	EC	TOC	Alkalinity	Cl^-	SO_4^{2-}	NO_3^-	Mg^{2+}	Ca^{2+}	Na^+	K^+	PO_4^{3-}
	[mg/L]		[µS/cm]	[mM CO_2]	[mM HCO_3^-]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[µg/L]
Lake water		7.31	442	0.01	4.23	13.5	14.6		9.49	91.80	18.73	0.74	32.9
Filter1 + AO + Filter2, direct sample	0.61	7.38	434	0.01	4.25	13.3	14.6	0.001	9.71	88.24	19.23	0.91	10.5
Filter1 + AO + Filter2, sample after rest for 10 min	0.32	7.30	433	0.01	4.09	13.3	14.4		9.46	88.75	18.73	0.87	13.5
Filter1 + AO + Filter2, sample after rest for 30 min	0.26	7.37	433	0.01	4.18	13.3	14.4		9.52	90.18	18.71	0.83	13.8
Filter1 + AO + Filter2, sample after rest for 60 min	0.45	7.33	433	0.01	4.05	13.3	14.4		9.44	88.66	18.62	0.82	14.0
Filter1 + AO + Filter2, restart 15 min, direct sample	0.55	7.26	427	0.01	4.12	13.0	14.5		9.32	87.05	18.62	0.83	13.7
Filter1 + AO + Filter2, restart 25 min, direct sample	0.51	7.25	460	0.01	4.09	12.9	14.5	0.220	9.24	86.91	18.67	0.82	15.6
Flocculation unit alone, after 15 min		7.34	467	0.01	4.29	13.6	14.4	0.235	9.50	90.01	18.80	0.83	30.5
Flocculation unit alone, after 25 min		7.32	440	0.01	4.69	13.5	14.5		9.61	91.43	18.80	0.83	27.9
After backflush, after 30 min, direct sample		7.68	439	0.01	4.60	13.5	14.5		9.62	91.23	19.25	0.84	22.1
Final flush, after 30 min, direct sample	< 0.2	7.45	438	0.01	4.61	13.4	14.5		9.69	89.51	18.67	0.88	20.5
Filter1 + AO + Filter2, direct sample		7.36	440	0.01	4.56	13.4	14.6	0.166	9.64	91.03	19.14	0.82	22.0

9.3.1 **Summary of results from Test 2:**

- The lake water from BIO-AQUA A/S Lake 2 had a higher pH than water from Lake 1 (Test 1). The salt concentration was considerably higher, and particularly the alkalinity was higher and Mg/Ca bi-carbonate makes up a substantial part of the lake water. The chloride concentration was approxi-mately the same as for Lake 1, while the sulfate concentration was lower. The phosphate and nitrate concentrations were low, and the lake water was hardly eutrophied.
- Water treatment hardly affects the overall water composition of major constituents.
- Water treatment significantly reduced the concentration of phosphate, almost by 70 %. However, the flocculation unit alone was not enough for removing phosphate and full effect was only seen with both filters installed.
- There was a tendency for the electrolysis to generate low concentrations of nitrate
- Perchlorate and chlorate were also determined; all measurements were below detection limit except for the sample from "restart 25 min" where a chlorate concentration of approx. 1 mg/L was determined in duplicate.
- Chlorine concentration levels appear to decrease in the treated water relatively fast. The concentration of active chlorine is 0.5 - 0.6 mg Cl2/L immediately after the AO unit has been passed; after resting the water sample for 30 mins the value had halved; the value for the water sample measured 1 h after passage of the AO unit however has a higher content of chlorine, which may be due to sample contamination. A more careful analysis is needed to test how fast chlorine degasses/ decompose in the samples.

9.4 **Test 3**

Tests 3 and 4 were both performed on water sampled from Emdrup lake (Copenhagen). The water was brought to Adept Water Technologies A/S and added pig slurry (10 L pig slurry per 1000 L water) in order to increase the number of bacteria and pathogens in the water, and hence more clearly to see the effect of the water treatment (and in particular the disinfection unit) on bacterial numbers (see WP6). The lake waters mixed with pig slurry are called containers 1 and 2, respectively. For this test the instrument configuration was the same as for Tests 1 and 2 (Table 8.5.1).

Table 9.4.1 - Test 3. Sample ID, sampling plan, chlorine produced, pH, EC, TCO and alkalinity of Emdrup Lake water added pig slurry (container 1 and 2)

Sample type	Runtime [min]	Rest time [min]	Cl_2 [mg/L]	pH	EC [µS/cm]	TOC [mM CO_2]	Alkalinity [mM HCO_3^-]
Lake water – container 1	0	0	-	7.71	1180	0.84	5.14
Lake water – container 1	60	0	-	7.71	1150	0.68	4.76
Lake water – container 2	0	0	-	7.77	1120	0.72	4.98
Lake water – container 2	60	0	-	7.75	1140	0.66	4.73
Filter 1 + AO + Filter 2	1	0	3.84	7.53	752	0.78	5.12
Filter 1 + AO	15	10	0.45	8.22	1160	0.87	-
Filter 1 + AO	15	30	0.2	8.23	1150	0.87	-
Filter 1 + AO	15	60	0.2	8.21	1150	0.88	-
Filter 1 + AO	15	0	0.5	8.13	1160	0.87	4.52
Filter 1 + AO	25	0	0.5	8.16	1100	0.82	-
Filter 1 + AO	55	0	0.8	8.24	1100	0.66	-
Filter 1 + AO	75	0	1	8.24	990	0.56	-
Filter 1 + AO	120	0	0.6	8.24	1000	0.61	-
Filter 1 + AO	175	0	0.8	8.29	1060	0.68	-
Floc. + filter 1 + AO + Filter 2	15	0	-	7.91	1150	0.73	5.12
Floc. + filter 1 + AO + Filter 2	25	0	-	7.93	1100	0.58	-
Floc. + filter 1 + AO + Filter 2	55	0	-	7.9	1040	0.41	-
Floc. + filter 1 + AO + Filter 2	75	0	-	7.85	991	0.36	-
Floc. + filter 1 + AO + Filter 2	175	0	-	7.89	1070	0.47	-
Back-flush and flush	10	0	-	7.87	1130	0.71	-
Back-flush and flush	175	0	-	7.82	1070	0.46	4.51
Back-flush, flush and flush	175	0	-	7.97	946	0.95	4.6

Table 9.4.1 - Test 3. Concentrations of major cations and anions in the pig slurry amended Emdrup Lake water under different instrument conditions.

	Cl^-	SO_4^{2-}	NO_3^-	Mg^{2+}	Ca^{2+}	Na^+	K^+	PO_4^{3-}
Sample type	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[µg/L]
Lake water – container 1	250	43.9	-	9.6	91.4	-*	12.3	3500
Lake water – container 1	226	43.6	-	9.1	90.4	-	10.4	260
Lake water – container 2	235	43.6	0.06	9.0	88.0	-	10.3	2860
Lake water – container 2	224	43.5	0.19	8.9	89.3	-	9.9	2500
Filter 1 + AO + Filter 2	87.2	53.7	0.07	18.0	70.0	-	2.5	145
Filter 1 + AO	227	43.6	2.40	8.9	81.6	-	10.0	405
Filter 1 + AO	225	43.5	2.42	8.9	81.8	-	10.0	449
Filter 1 + AO	225	43.8	2.44	8.9	81.5	-	10.0	399
Filter 1 + AO	226	43.6	2.46	9.2	84.0	-	10.6	405
Filter 1 + AO	223	43.7	2.44	9.0	84.6	-	9.9	349
Filter 1 + AO	197	42.9	2.51	8.5	86.3	-	8.3	273
Filter 1 + AO	182	43.5	2.52	8.2	84.5	-	7.2	137
Filter 1 + AO	190	43.5	2.55	8.2	84.1	-	7.5	370
Filter 1 + AO	204	43.4	2.47	8.4	84.6	-	8.5	308
Floc. + filter 1 + AO + Filter 2	229	43.7	-	9.4	81.0	-	10.3	523
Floc. + filter 1 + AO + Filter 2	218	43.2	0.14	8.7	84.1	-	9.1	161
Floc. + filter 1 + AO + Filter 2	191	42.3	0.47	8.3	84.9	-	7.5	64.7
Floc. + filter 1 + AO + Filter 2	181	42.5	0.84	8.1	85.4	-	6.5	72.4
Floc. + filter 1 + AO + Filter 2	203	43.3	0.99	8.2	83.4	-	7.7	101
Back-flush and flush	220	44.3	-	9.8	79.7	-	9.7	421
Back-flush and flush	203	43.5	0.84	8.3	84.4	-	7.7	91.2
Back-flush, flush and flush	168	47.8	2.04	11.0	70.4	-	7.0	217

*Na concentrations exceeding range (dilution not performed)

9.4.1 Summary of results from Test 3:

- The Emdrup Lake water with added pig slurry was very salty (extremely high EC) and contained substantial amounts of NaCl (in fact Na exceeded the concentration of the highest standard), but also high concentrations of Ca and Mg, and high alkalinity (HCO3-) was found. The water had a very high pH. As expected the addition of pig slurry caused a substantial increase in TOC and phosphate concentrations
- As seen in previous tests the water treatment had hardly any effect on the concentrations of major cations, as well as chloride, sulfate and bicarbonate.
- The water treatment caused pH in the treated water to increase
- The chlorine concentration in the water decreased when the treated water had time to rest, probably due to degassing
- There was a significant effect on nitrate concentrations, with higher nitrate concentrations in the treated water than in the untreated water, even up to 1 - 2 mg/L.
- The water treatment had a very significant effect on phosphate; filtration using Filter 1 alone caused a 10-fold decrease and when flocculation and Filter 2 was included the concentrations decreased almost by a factor 20 compared to untreated. There was a trend of increasing phosphate removal with runtime, probably attributed to filters trapping smaller and smaller particles over time.
- Flocculation plus filtration also removed organic matter (TOC), but to a lesser extent than observed for phosphate
- After back flushing and flushing some concentrations was found to be temporarily higher, e.g. phosphate and TOC
- The chlorine production seemed constant during runtime
- Perchlorate was below detection, while chlorate analyses were erroneous.

9.4.2 Conclusions from Test 3:

- The unit was efficient to reduce concentrations of phosphate and to some extent TOC
- There was a tendency for the unit to increase the concentrations of nitrate
- Chlorine production from the electrolysis cell was not affected by runtime, even for the relatively dirty and difficult water.

9.5 Test 4

Test 4 was a more comprehensive test compared to Test 3. Again, the Emdrup lake water had been added pig slurry. This time two different concentrations, either 1 L or 10 L pig slurry pr. 1000 L water, was tested. The test monitored the effect of run time, settings of the electrolysis unit, the flocculation unit and the effect of the filter (Filter 1, the polymer filter) separately. Also, the effect of back-flushing was evaluated.

Table 9.5.1 - Test 4. Effect of the water treatment plant settings and runtime on production of chlorine, pH, EC, TOC and alkalinity for Emdrup lake water added pig slurry (PS) at two different concentrations (1 L PS and 10 L PS).

	Runtime	Rest time	Current	Flow	Cl_2	Total Cl_2	pH	EC	TOC	Alkalinity
Sample type	[min]	[min]	[A]	[L/h]	[mg/L]	[mg/L]		[µS/cm]	[mM CO_2]	[mM HCO_3^-]
Lake water (a)	-	-	-	-	-	-	7.83	491	1.09	3.47
Lake water (b)	-	-	-	-	-	-	7.83	453	1.07	-
Lake water + 1 L PS (a)	-	-	-	-	-	-	7.91	483	1.09	3.42
Lake water + 1 L PS (b)	-	-	-	-	-	-	7.80	611	1.10	-
Lake water + 10 L PS (a)	-	-	-	-	-	-	7.48	704	1.75	3.95
Lake water + 10 L PS (b)	-	-	-	-	-	-	7.73	653	1.59	-
Filter + AO, 1 L PS	12	0	24	200	0.3	0.7	7.96	311	1.30	3.90
Filter + AO, 1 L PS	12	30	-	-	0.8	0.35	8.04	395	1.19	-
Filter + AO, 1 L PS	12	60	-	-	0.4	0.5	8.03	432	1.19	-
Filter + AO, 10 L PS	12	0	22	220	0.05	0.6	7.91	514	2.00	3.89
Filter + AO, 10 L PS	12	30	-	-	0.1	1	7.04	523	2.00	-
Filter + AO, 10 L PS	12	60	-	-	0.4	0.75	7.99	533	2.02	-
Between filter and AO 1 L PS	12	0	-	-	-	-	7.98	462	1.10	3.86
Between filter and AO 1 L PS	36	0	-	-	-	-	8.00	457	1.05	-
Between filter and AO 1 L PS	48	0	-	-	-	-	7.96	467	1.06	-
Between filter and AO 1 LPS	60	0	-	-	-	-	7.95	473	1.03	-
Filter + AO, 1 L PS	36	0	-	200	0.08	1.15	8.04	453	1.25	-
Filter + AO, 1 L PS	48	0	14	220	0.4	0.8	8.03	465	1.25	-
Filter + AO, 1 L PS	60	0	22	240	0.0	0.8	8.08	479	1.21	-
Between filter and AO 10 L PS	12	0	30	220	0.075	0.75	7.73	548	1.60	3.81
Between filter and AO 10 L PS	36	0	-	190	0.025	0.75	7.71	565	1.46	-
Between filter and AO 10 L PS	48	0	-	240	0.05	1	7.76	580	2.32	-
Between filter and AO 10 L PS	60	0					7.58	587	2.31	-
Filter + AO 10 L PS	36	0					7.94	580	2.07	-
Filter + AO 10 L PS	48	0					7.94	658	2.37	-
Filter + AO 10 L PS	60	0					7.96	667	2.39	-
Without flocculation	72	0	27	180	0.05	0.75	7.96	657	2.03	41.4
Without flocculation	76	0					7.70	790	1.55	-
Back-flush, flush 1, 1 L PS	29	0					7.85	663	1.14	-
Back-flush, flush 1, 1 L PS	48	0					7.82	650	1.09	-
Back-flush, flush 1, 10 L PS	29						7.69	779	1.60	-
Back-flush, flush 1, 10 L PS	60						7.63	808	1.64	-

Table 9.5.2 - Test 4. Chemical monitoring data for the water treatment process on Emdrup Lake water added pig slurry (PS) at two different concentrations (1 L PS and 10 L PS).

	Cl^-	SO_4^{2-}	NO_3^-	Mg^{2+}	Ca^{2+}	Na^+	K^+	Particulate	PO_4^{3-}
Sample type	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[µg/L]
Lake water (a)	109	37.6	0.11	7.5	77.5	58.1	5.6	50.3	349
Lake water (b)	110	37.5	0.08	7.5	77.3	57.8	5.5		344
Lake water + 1 L PS (a)	111	37.3	0.06	7.5	77.4	60.4	5.8	71.7	541
Lake water + 1 L PS (b)	115	37.4	0.10	7.5	77.4	60.5	5.6		539
Lake water + 10 L PS (a)	151	37.3	0.07	7.8	77.7	-	8.5	205	1765
Lake water + 10 L PS (a)	152	37.2	0.00	7.8	78.1	-	8.5		-
Filter + AO, 1L PS	106	39.7	0.78	9.0	77.8	61.2	5.6	-	417
Filter + AO, 1L PS	107	39.7	0.73	8.9	77.5	60.9	5.5		425
Filter + AO, 1L PS	106	39.5	0.68	9.0	77.9	61.1	5.5		423
Filter + AO, 10L PS	137	38.6	0.40	8.5	76.9	78.1	7.8	54.9	904
Filter + AO, 10L PS	138	38.7	0.40	8.5	76.6	77.6	7.8		886
Filter + AO, 10L PS	139	38.6	0.41	8.4	76.8	78.4	7.8		933
Between filter and AO 1L PS	111	39.7	0.60	8.8	78.1	60.6	5.4	22.8	284
Between filter and AO 1L PS	112	36.5	0.16	7.7	75.8	59.8	5.4		50
Between filter and AO 1L PS	113	37.1	0.11	7.5	76.2	60.4	5.3		66
Between filter and AO 1L PS	115	38.7	0.23	8.1	76.5	60.6	5.4	25.9	123
Filter + AO, 1L PS	105	37.2	0.61	7.8	75.3	59.4	5.3		130
Filter + AO, 1L PS	109	36.5	0.40	7.5	75.1	59.3	5.4		156
Filter + AO, 1L PS	111	38.9	0.71	8.4	76.8	61.3	5.5	25.4	241
Between filter and AO 10L PS	146	37.6	0.15	8.2	76.4	79.1	7.7	65.5	644
Between filter and AO 10L PS	148	39.9	0.04	9.0	77.5	81.1	7.9		606
Between filter and AO 10L PS	154	37.7	0.28	7.7	75.5	-	8.3		222
Between filter and AO 10L PS	153	37.5	0.12	7.7	75.5	82.2	8.4	99.2	966
Filter + AO, 10L PS	139	40.8	0.76	9.4	78.1	81.3	8.0		1050
Filter + AO, 10L PS	149	38.0	0.30	7.8	76.2	82.7	8.4		278
Filter + AO, 10L PS	149	37.8	0.30	7.7	76.4	83.0	9.4	105	277
Without flocculation	139	41.1	0.89	9.6	77.8	80.5	7.8		220
Without flocculation	154	39.1	0.04	8.1	77.6	82.7	8.1		226
Back-flush, flush 1, 1L PS	116	37.6	0.09	7.5	76.8	60.2	5.3	-	180
Back-flush, flush 1, 1L PS	117	37.8	0.07	7.5	76.9	60.8	6.0	-	297
Back-flush, flush 1, 1L PS	153	36.9	0.03	7.7	76.6	83.2	8.2	-	833
Back-flush, flush 1, 1L PS	154	36.9	0.05	7.7	76.6	82.7	8.2	-	627

9.5.1 **Summary of results of Test 4:**

- In Test 4 the Emdrup Lake water had a pH similar to that in test 3, but the salt concentration was substantially lower this time (June in test 4, compared to February for Test 3). The chloride concentration was only about 1/3 of the concentration in Test 3 and also the concentrations of the major cations and the alkalinity was less than in Test 3. Nitrate concentrations were low, but phosphate concentrations extremely high. The lake water also contained considerable amounts of particulate matter and the TOC was relatively high considering that these are filtered samples.

- When the water was added pig slurry, then the salt concentrations increased slightly, the TOC, concentration of particulate matter and phosphate increase markedly.
- The filter retains phosphate, but not as markedly as was seen in test 3; there is no clear effect of the flocculation unit, but may be due to too short time to observe the effect.
- The filter clearly retains particulate matter and removes 50 to 75 % of particulate material; the effect on TOC removal however is insignificant.
- After back-flushing, concentrations of certain solutes such as phosphate temporarily increases.
- As seen in other tests nitrate concentrations may increase during the water processing; the effect is less marked in Test 4 compared with Test 3.
- The concentrations of total chlorine are not strongly affected by the current settings. There is no clear effect of chlorine measurement in the treated water depending on resting time opposite to what has been seen in previous tests.
- No perchlorate could be determined; some samples appeared to have elevated chlorate levels and this issue should be paid further attention.

9.5.2 **Conclusions from Test 4:**

- The lake water is clearly less salty than in February during Test 3 - probably an effect of less NaCl that has been washed into the lake from the surrounding roads and paved surfaces. However, the water is more eutrophied and contains more phosphate in June compared to February.
- The test confirms more or less the results from Test 3. The cleaning unit removes phosphate and particulate matter, but the effects is not so marked as in Test 3
- There is an indication of nitrate generation during water treatment, but nitrate concentrations are low

9.6 Test 5

This test was carried out as the final test on Emdrup Lake water before shipping the instrument for comparative test on lake water in Hanoi (Test 6). The final configuration of the unit comprised of flocculation, filter, electrolysis cell and optional a ceramic filter after the electrolysis cell (Table 8.5.1). Compared with Tests 3 and 4, no pig slurry was added to the lake water. Results of the testing are displayed in the three tables below.

Table 9.6.1 - Test 5. Instrument settings, chlorine produced and pH, EC, TOC and alkalinity of the water for treated and untreated water.

Sample no	Sample type	Run time [min]	Current [A]	Cl_2 [mg/L]	pH	EC [µS/cm]	TOC [mM CO_2]	Alkalinity [mM HCO_3^-]
103	Treated water	5	20	0.5-0.8	8.37	589	0.81	3.82
104	Treated water	5	10	0.5-0.8	8.25	6077	0.81	3.68
105	Treated water	60	20	0.5-0.8	8.36	605	0.89	3.75
106	Treated water	60	10	0.5-0.8	8.32	597	0.81	3.63
107	Untreated lake water	70	-	0.5-0.8	8.22	574	0.86	3.63
108	Untreated lake water	70	-	0.5-0.8	8.28	588	0.84	3.60
109	Treated water	90	20	0.5-0.8	8.30	603	0.81	3.59
110	Treated water	120	20	0.5-0.8	8.29	604	0.80	3.75
111	Treated water	120	20	0.5-0.8	8.27	603	0.80	3.59
112	Treated water	120	10	0.5-0.8	8.31	604	0.81	3.63
113	Back flush, before air flush	130	0	0.5-0.8	8.24	599	0.84	362
114	Back flush, with air flush	135	0	0.5-0.8	8.18	601	0.84	3.66
115	Treated water after back flush	140	20	0.5-0.8	8.28	598	0.90	3.71
116	Treated water with ceramic membrane inserted	10	20	0.5-0.8	8.72	635	1.04	4.39
118	Lake water	-	-	0.5-0.8	8.37	609	0.85	3.62

Table 9.6.2 - Test 5. Major cations and anions in the water and effects on iron, phosphate and particulate matter.

Sample No.	Sample type	Cl^- [mg/L]	SO_4^{2-} [mg/L]	NO_3^- [mg/L]	Mg^{2+} [mg/L]	Ca^{2+} [mg/L]	Na^+ [mg/L]	K^+ [mg/L]	Iron [mg/L]	PO_4^{3-} [µg/L]	Particulate material [mg/L]
103	Treated water	104	28.2	0.16	7.8	76.3	50.1	4.2	43.4	14.0	1.39
104	Treated water	101	28.2	0.18	7.4	75.8	50.7	4.2	48.8	13.8	0.52
105	Treated water	101	28.2	0.23	7.6	73.8	49.2	4.2	39.6	16.7	0.80
106	Treated water	103	28.2	0.10	7.4	75.6	50.8	4.1	65.6	12.0	0.50
107	Untreated lake water	99	28.2	0.08	7.3	75.0	50.0	4.1	29.1	21.2	0.00
108	Untreated lake water	105	28.2	0.07	7.4	75.0	50.0	4.0	28.8	24.3	0.00
109	Treated water	100	28.2	0.12	7.4	75.2	50.4	4.0	50.9	12.2	0.16
110	Treated water	101	28.2	0.12	7.3	74.6	50.1	4.0	68.4	11.5	0.00
111	Treated water	100	28.2	0.15	7.3	75.2	50.5	4.0	53.8	11.4	0.37
112	Treated water	99	28.2	0.13	7.5	75.7	50.8	4.0	68.1	12.0	0.69
113	Back flush, before air flush	102	28.5	0.10	7.4	75.4	50.6	4.0	52.2	-	1.35
114	Back flush, with air flush	102	28.6	0.11	7.4	75.4	50.4	3.9	31.9	25.1	1.42
115	Treated water after back flush	99	28.2	0.12	7.4	75.3	50.6	4.1	115	24.5	0.63
116	Treated water with ceramic membrane inserted	100	28.3	0.15	7.6	75.2	66.8	4.2	25.4	205	0.00
118	Lake water	101	28.2	0.06	7.5	76.3	50.8	4.0	30.5	28.7	0.32

Table 9.6.3 - Test 5. Concentrations of arsenic, manganese and zinc in lake water and treated water.

Sample No.	**Sample type**	**Arsenic** [µg/L]	**Manganese** [µg/L]	**Zinc** [µg/L]
103	Treated water	5.35	12.5	1.08
104	Treated water	-	15.9	1.51
105	Treated water	3.16	7.85	3.06
106	Treated water	-	14.3	1.24
107	Untreated lake water	4.48	0.59	2.94
108	Untreated lake water	-	0.80	2.32
109	Treated water	-	6.49	0.99
110	Treated water	1.50	6.72	1.06
111	Treated water	-	9.17	0.97
112	Treated water	2.40	12.2	1.60
113	Back flush, before air flush	3.05	0.53	1.59
114	Back flush, with air flush	4.53	0.53	2.84
115	Treated water after back flush	-	7.23	9.56
116	Treated water with ceramic membrane inserted	-	2.75	28.4
118	Lake water	-	2.43	-

9.6.1 **Summary of results of Test 5:**

- In general, the lab analyses performed well, but determination of particulate material has a high uncertainty (about 0.5 mg/L). Some of the phosphate determination seems erratic and carry over effects may have been present.
- The lake water had a high salt concentration (also seen as a high electrical conductivity), not at least NaCl. Concentrations of calcium, magnesium, sulfate and bicarbonate (alkalinity) were also high. The lake water pH was high indicating equilibrium with calcite ($CaCO_3$). The TOC concentration in the water was at an intermediate level. Phosphate concentrations were unex-pectedly low, and the nitrate concentration was also low
- Runtime and current did not have a significant influence on production of active chlorine, probably because of the high chloride concentration in the lake water
- There was a tendency of higher pH in the treated water compared to the raw water
- The water treatment process clearly reduced the phosphate concentration. The increased iron con-centration was attributed to the iron released from the electro coagulation unit; and similarly, for the manganese concentration. As expected there were no effects of the water treatment process on the concentrations of major cations and anions. Interestingly there seemed to be a tendency for slightly higher nitrate concentrations in the treated water compared with the lake water, which may be due to electrolysis of nitrogen containing compounds in the raw water. There was a tendency for higher concentrations of particulate material in the treated water than the lake water, but the effect was not significant. However, it is possible that the advanced oxidation unit causes flocculation of humic compounds in the lake water, forming particles which are too small to be caught in the polymer filter.
- As expected the backflush water contained much particulate material. The samples for TOC were filtered before TOC determination which explains why TOC concentrations did not increase even though the concentration of particulate material increased.
- After backflush the treated water had increased phosphate and iron concentrations, and was there also a tendency for higher manganese and zinc concentrations. This was probably due to effects of turbulence and "weathering" during the back-flushing operation.
- The ceramic filter increases the pH and alkalinity in the treated water, and the membrane releases substantial amounts of phosphate (which probably is short term). The ceramic filter should have had a flushing operation before use, but it did clearly remove particulate material.
- Chlorate (data not shown) could not be detected above the limit of detection.

9.6.2 Conclusions from Test 5:

- The water treatment unit removed phosphorus
- At the high chloride concentrations in the lake water there was no reason to run at higher current than 10 A, as this current produced sufficient concentration of active chlorine
- The ceramic filter should be properly flushed before use and should be inserted for removal of par-ticulate material. The ceramic filter had a clear effect on removal of particulate material.
- The treated water had low concentrations of iron which might give rise to low concentrations of precipitates in the treated water upon oxidation

9.7 Test 6

The last test was carried out on water from a small lake/fish pond in Hanoi. Ideally, the water should have been flooding water. However, the fish pond water was not widely different to flooding water in composition. The configuration of the water cleaning unit was the same as for Test 5. The test was carried out over 2 days. The BAC unit was applied a current of 18 A (4.9 V), and the flow generally was around 150 - 200 L/h when the ceramic filter was not inserted. Results of the test are given in the tables below.

Table 9.7.1 - Test 6. Sampling, pH, EC, TOC, alkalinity and chlorine production before and during the different steps of water treatment for tests carried out in Hanoi.

Sample type	Day	Runtime	Cl_2	pH	EC	TOC	Alkalinity
		[h]	[mg/L]		[µS/cm]	[mM CO_2]	[mM HCO_3^-]
Lake water, untreated	1	0		7.44	195	1.61	1.44
After flocculation unit	1	0	0	7.60	195	1.64	
After polymer filter	1	0	-	7.64	194	1.55	
After full treatment	1	0	-	7.53	195	1.55	
After flocculation unit	1	1	2.5	7.48	196	1.61	
After polymer filter	1	1	2.5	7.48	198	1.52	
After full treatment	1	1	2.5	7.43	193	1.65	1.50
Lake water, untreated	1	2	3	7.30	197	1.58	1.50
After flocculation unit	1	2	3	7.42	195	1.57	
After polymer filter	1	2	3	7.47	196	1.59	
After full treatment	1	2	3	7.46	194	1.55	
After reflush, after flocculation unit	1	4	4	7.52	195	1.53	
After reflush, after polymer filter	1	4	4	7.49	196	1.55	
After reflush, after full treatment	1	4	4	7.61	195	1.55	1.55
After full treatment with ceramic filter	1	1		7.43	193	1.50	
Flush water	2	0		7.33	200	10.6	
Lake water, untreated	2	1	2.5	7.17	206	1.52	1.57
After flocculation unit	2	1	2.5	7.19	203	1.45	
After polymer filter	2	1	2.5	7.18	204	1.49	
After full treatment	2	1	2.5	7.22	198	1.38	1.56
After full treatment	2	2	2.5	7.23	196	1.37	
After flocculation unit	2	3	2	7.16	200	1.34	
After polymer filter	2	3	2	7.17	202	1.38	
After full treatment	2	3	2	7.25	198	1.43	
After full treatment	2	4	2.5	7.27	197	2.96	
Lake water, untreated	2	5	4	7.54	200	1.37	1.53
After flocculation unit, after reflush	2	5	4	7.46	199	1.37	
After polymer filter, after reflush	2	5	4	5.59	199	1.30	
After full treatment, after reflush	2	5	4	7.53	194	1.31	1.51

Table 9.7.2 - Test 6. Concentration of major cations and anions including particulate matter in raw water and treated water at different cleaning steps for the test carried out in Hanoi.

Sample	Cl^-	SO_4^{2-}	NO_3^-	Mg	Ca	Na	K	Fe	Particulate	PO_4^{3-}
	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[mg/L]	[µg/L]	[mg/L]	[µg/L]
Lake water, untreated	13.8	17.9	00.09	6.3	22.4	8.4	5.2	7.38	10.5	14.3
After flocculation unit	13.2	17.5	0.007	6.1	22.0	8.1	5.0	8.16		14.9
After polymer filter	13.3	17.7	0.012	6.2	22.5	8.1	5.0	18.4		14.2
After full treatment	13.5	17.6	0.032	6.0	21.7	8.2	5.0	27.8		22.3
After flocculation unit	13.3	17.4	0.127	6.0	21.8	8.1	5.0	13.2		14.3
After polymer filter	13.9	18.1	0.013	6.1	21.9	8.2	5.0	3.86		14.7
After full treatment	24.0	18.2	0.109	6.0	21.6	8.2	5.1	43.8		23.6
Lake water, untreated	14.1	18.3	0.006	6.4	22.2	8.2	4.9	7.97		20.1
After flocculation unit	13.6	17.6	0.100	6.1	21.9	8.2	5.0	6.83		15.0
After polymer filter	13.6	17.8	0.010	6.0	21.8	8.1	4.9	7.45		14.7
After full treatment	12.5	17.7	0.082	6.2	21.8	8.2	5.0	26.8		24.3
After reflush, after flocculation unit	13.0	17.3	0.011	6.4	23.7	8.3	5.0	15.2		15.0
After reflush, after polymer filter	13.4	17.8	0.061	6.0	21.7	8.1	5.0	4.51		25.6
After reflush, after full treatment	12.6	17.8	0.078	6.0	22.0	8.1	5.0	6.05	3.660	25.6
After full treatment with ceramic tiler	12.0	17.8	0.127	5.6	21.5	8.1	5.0	1.22		23.2
Flush water	13.4	17.2	0.072	6.4	22.1	8.1	4.9	16.1		15.5
Lake water, untreated	14.2	17.8	0.051	6.5	22.0	8.2	4.8	5.74	14.3	15.5
After flocculation unit	13.5	16.9	0.062	6.4	21.7	8.2	4.8	6.47		14.9
After polymer filter	13.6	17.1	0.060	6.4	21.9	8.1	4.9	15.3		41.1
After full treatment	12.9	17.1	0.106	6.3	21.4	8.1	4.8	42.2	3.60	26.5
After full treatment	12.8	17.3	0.092	6.1	21.1	8.1	4.9	34.0		36.8
After flocculation unit	13.1	16.8	0.056	6.2	21.6	8.2	4.8	12.5		15.5
After polymer filter	13.5	17.3	0.061	6.2	21.8	8.2	4.9	10.6		22.1
After full treatment	12.7	17.1	0.111	6.3	21.5	8.1	4.9	49.9		33.8
After full treatment	12.7	17.0	0.116	6.2	21.4	8.1	4.9	41.6		-
Lake water untreated	14.0	17.8	0.058	6.3	21.8	8.3	4.9	10.0	2.80	14.7
After flocculation unit, after reflush	13.6	17.1	0.077	6.3	21.7	81.	4.9	10.4		14.8
After polymer filter, after reflush	13.7	17.3	0.057	6.2	21.7	8.2	4.8	11.3		14.8
After full treatment, after reflush	12.4	17.2	0.116	6.3	21.3	8.3	4.9	27.6	4.40	27.2

Table 9.7.3 - Test 6. Trace metal concentrations in raw water and treated water at different steps of processing for the test performed in Hanoi.

Sample	Al [µg/L]	Cd [µg/L]	Cr [µg/L]	Mn [µg/L]	Ni [µg/L]	Zn [µg/L]
Lake water, untreated	33.2	-	0.15	1.95	-	5.50
After flocculation unit	25.3	-	-	5.39	4.67	1.64
After polymer filter	34.7	0.39	0.13	21.4	15.6	3.32
After full treatment	18.3	0.39	-	24.2	4.41	3.74
After flocculation unit	23.4	-	-	11.6	1.04	-
After polymer filter	18.9	0.4	0.07	20.6	8.56	4.46
After full treatment	18.5	-	0.31	15.0	2.18	1.8
Lake water, untreated	28.5	0.23	-	24.1	-	-
After flocculation unit	26.7	0.26	0.23	19.5	1.38	0.69
After polymer filter	17.4	0.29	0.11	22.2	11.0	2.64
After full treatment	26.6	-	0.10	4.31	1.22	2.29
After reflush, after flocculation unit	38.5	0.35	-	16.4	-	3.8
After reflush, after polymer filter	20.5	-	-	14.9	2.67	2.63
After reflush, after full treatment	21.2	0.27	-	2.42	-	1.25
After full treatment with ceramic filter	-	-	-		-	-
Flush water	22.0	0.28	-	42.9	3.31	2.79
Lake water, untreated	18.2	-	-	39.4	-	0.67
After flocculation unit	15.2	0.12	-	37.0	1.66	-
After polymer filter	20.4	-	-	49.0	6.60	4.09
After full treatment	16.3	-	-	6.98	3.06	3.17
After full treatment	16.3	0.55	0.13	5.35	1.53	2.16
After flocculation unit	19.0	0.34	-	23.9	-	0.07
After polymer filter	15.9	-	0.22	34.2	3.3	3.24
After full treatment	20.2	0.47	-	7.15	1.1	2.98
After full treatment	20.9	-	0.36	8.12	-	2.05
Lake water, untreated	16.7	-	0.09	31.3	0.62	1.38
After flocculation unit, after reflush	21.2	0.18	-	16.8	1.3	0.25
After polymer filter, after reflush	16.5	-	0.12	24.1	10.9	4.66
After full treatment after reflush	24.7	-	-	5.87	1.06	2.04

9.7.1 **Summary of results from Test 6:**

- The Hanoi pond water was low in salts (low EC), but high in TOC, higher than seen for the Emdrup Lake water. The pH was neutral to slightly alkaline, but the alkalinity was low. Correspondingly also the concentrations of major cations and anions were lower, and e.g. the chloride concentration was only about a tenth of the chloride concentration in Emdrup Lake. Nitrate and phosphate levels were low, and the concentration of suspended particulate matter was unexpectedly low.
- The lake water appeared to contain low concentrations of iron (probably kept in solution by the high TOC). Manganese was also detectable.
- Chlorine production was high even though the chloride concentrations in the lake water was low.

- The full water treatment appeared to reduce the concentration of TOC slightly, but the result was not significant. There was a clear reduction in concentration of suspended particles during treatment. The raw water phosphate concentrations were so low that water treatment hardly affected the phosphate concentration in the fully treated water.
- The nitrate concentrations in the treated water were low throughout, and there was no indication that water treatment caused the nitrate concentration to increase.
- The iron concentration persistently increased in the fully treated water; generally, the concentration increased from less than 10 µg/L to 40 µg/L. The increase was not detected as an effect of the advanced oxidation unit, but appeared to be caused by the electrolysis unit. The effect was highly significant.
- With respect to trace metals, Al was slightly reduced during water cleaning. Cadmium, Cr and Zn concentrations were low throughout and data were quite variable with no significant effect of the water treatment. The raw water Ni concentration were below detection limit, but interestingly it increased during water treatment, after passage of the polymer filter. Manganese concentration was variable, but appeared to be reduced during the water treatment.
- Chlorate concentration (data not shown) generally had a high background value (clearly an interference in the ion chromatography of chlorate). Interestingly the monitored concentrations were, in most cases, increasing during passage of the electrolysis cell which most likely was due to chlorate production, or alternative that more of the interfering compound was produced during water treatment.

9.7.2 Conclusions from Test 6:

- The Hanoi water was soft, non-salty, with high TOC but very little nitrate and phosphate, and thus very different from Emdrup Lake water.
- The water cleaning had clear effects on particle and TOC removal, no clear effects on removal of trace metals, which were, however, only found in low amounts, and for iron there appeared to be a production originating from the electrocoagulation.
- There were indications that chlorate might be produced during electrolysis, but measurements should be repeated to confirm that.

9.8 General discussion of field tests of the AO unit

The compact water treatment unit has been designed to be robust, cheap and to comprise relatively simple cleaning steps. The electro coagulation unit that releases iron to the water is important to cause particle generation for subsequent removal in filters. These particles can contain all sorts of contaminants that sorb to particles, including both metal ions and organic contaminants. As all analyses have been performed on filtered samples we cannot document the fraction of contaminants removed with particles. However, for both the Emdrup Lake water and the water from Hanoi, the cleaning unit removes particles, up to 75 % in case of high particle loads. Effects on TOC removal is variable but usually less than 50 %. When a ceramic filter is included after the electrolysis cell, particle concentrations become much lower and the turbidity visually appears to become removed.

The major cations and anions are - as expected - unaffected by the water cleaning process, and hence salty water in is also salty water out. Water pH and alkalinity is hardly affected. There are no significant effects on removal of trace elements. For the iron concentrations, they may increase after the electro coagulation unit, but in other cases, iron concentrations decrease during filtration, or as seen for the Hanoi water it markedly increases after passing the electrolysis cell. There are indications that small amounts of nickel appear to be released from the polymer filter, but this needs further investigation.

The filter unit has a marked effect on removal of phosphate, given the phosphate concentrations in the raw water is not too low. Hence, for waters with high concentrations of phosphate like the Emdrup water (and in particularly pig slurry amended water) phosphate removal is substantial. For waters with low concentrations of phosphate as the Hanoi waters, no significant effects are seen.

For some waters, low concentrations of nitrate appear to be generated during water treatment. This is particularly seen for the Emdrup Lake water added pig slurry and one suggestion is that the nitrate arises from oxidation of other nitrogen solutes (probably ammonium) in the electrolysis unit. In all cases perchlorate was below detection limits. Chlorate is apparently seen in all water samples but the data are hampered by interferences. However, if raw water and treated water are compared, there are clear indications that chlorate is produced during processing, and this should need further analysis.

In all cases the electrolysis unit has produced active chlorine (free chlorine and hypochlorous acid) at levels of about 1 mg/L or higher even though chloride concentrations in the raw water has been low as in the BIO-AQUA A/S and Hanoi waters. The major part of chlorine degas from the treated water within 1 - 2 h. We have not performed analysis of chlorination byproducts which may form during the electrolysis. They probably form, but we believe they are below threshold concentrations.

In conclusion, the chemical analyses document that the water cleaning unit can remove particles, it can remove phosphate, and to some extent TOC. For production of water without turbidity a ceramic filter is needed, albeit with the expense of significantly reduced flow due to the back pressure of the ceramic filter. The water cleaning unit does not affect the general water composition and salt content of the water, and has no significant effects on removal of heavy metals. The electrolysis unit produces active chlorine above a concentration of 1 mg/L even for low chloride waters. Concerns may be due to formation of chlorate.

9.8.1 Lab test: Performance of the AO unit for different water compositions

The purpose of these experiments was to evaluate how different water compositions affect formation of active chlorine and also to determine if chlorate is produced. All experiments were performed with a small AO unit used for lab tests - and kindly supplied by Adept Water Technologies A/S. A large number of experiments were performed using sodium chloride electrolyte only (at different concentrations), sodium chloride added sodium sulfate or sodium carbonate at various concentrations. In addition, experiments were performed to document if the presence of organic solutes affect the chlorine production. For this purpose, we were testing the presence of phenol, acetate, glucose and natural dissolved organic matter (DOM). All experiments were carried out in a setup where the influent was pumped through the electrolysis cell. Initially, a number of experiments were performed in order to determine the concentration of active chlorine as a function of flow and current.

The results are quite extensive and will be published as a journal paper (in prep). Some main results from the study are given below.

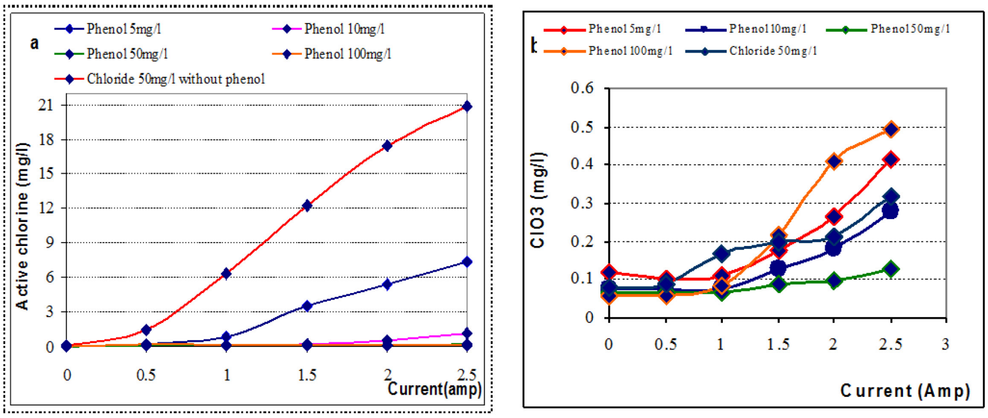


Figure 9.1 - Example of data from investigations of water compositional effects on chlorine production in the Adept Water Technologies A/S AO unit. Effect of phenol (0 - 100 mg/L) on the formation of chlorine (left) and chlorate (right) depending on current (electrodes 165 cm^2 each). The concentration of chloride in all experiments was 50 mg/L (NaCl) (Nguyen et al., 2017).

Electrolysis causes formation of active chlorine, but also chlorate. The concentration of chlorate is typically about 10 % of the active chlorine produced, depending on the current density. The presence of nitrate and sulfate depress the formation of active chlorine, and more so for sulfate than for nitrate. Hence, 50 mg sulfate per liter can depress chlorine production by almost 10 times, and it has almost the same depressing factor for formation of chlorate. Nitrate is less competitive, and typically reduces the chlorine production by a factor of 2. Bicarbonate was not found to have any significant depressing effect on chlorine production and neither did cations, e.g. calcium show any effect on chlorine/chlorate production.

For the organic solutes, some were found to have strong depressing effects, others not. For instance, even 5 mg/L of phenol more than halved the concentration of active chlorine and 10 mg/L of phenol almost halted chlorine production. The effects on chlorate were not proportional as seen for the salt anions, and at higher phenol concentrations chlorate concentrations were higher than in absence of phenol. No significant effects on chlorine production were found in the presence of acetate but depressing effects on chlorate formation was found. The presence of glucose had the interesting effect to significantly increase the production of active chlorine at low concentrations (< 1 mg/L) while depressing chlorine production at higher glucose concentrations. The presence of DOC had similar effects as phenol (and DOC does in fact contain many phenolic groups) causing strong depression of chlorine formation; 50 ppm DOC (in terms of carbon) caused a 10-fold decrease in chlorine production. Effects on chlorate production were not significant.

In conclusion, the water composition seems to play a strong influence on the concentration of produced chlorine and chlorate. Sulfate and nitrate clearly compete with formation chlorine at the electrode or sulfate and nitrate intermediates may degrade active chlorine. Nitrate concentrations are seldom very high except for certain waste and runoff waters. However, sulfate concentrations in natural waters may reach the concentrations that we have tested. Also, the effect of phenolic groups and DOC needs attention as these substances are naturally present in water and could strongly affect formation of chlorine. Finally, the study demonstrates that formation of chlorate in concentrations up to about 1 mg/L may be expected depending on water composition, flow and current density. In these investigations we did not monitor the formation of chlorinated organics. They certainly will form, but the topic has had much focus already in previous research, and we decided not to go into further investigations on that topic.

9.8.2 Lab test: Degradation of organic contaminants in the AO unit

In these investigations focus has been on the possible electrolytic degradation of organic contaminants present in the water. As shown by the study above, phenol and DOC had a strong effect on electrolysis and indicates that these organic solutes can be electrolytically oxidized (or reduced). Hence, we have carried out investigations of the electrochemical degradation of the pesticide fenobucarb. Fenobucarb is often used in rice fields and is a common contaminant in flooding waters in e.g. Vietnam, where the water cleaning unit is intended to be used. The setup with the electrochemical cell was similar to the setup described above, but now with the water circulating. Because of the heat from the electrodes the water reservoir was thermostated. The investigations were performed as part of an MSc thesis work, and below the thesis abstract is given.

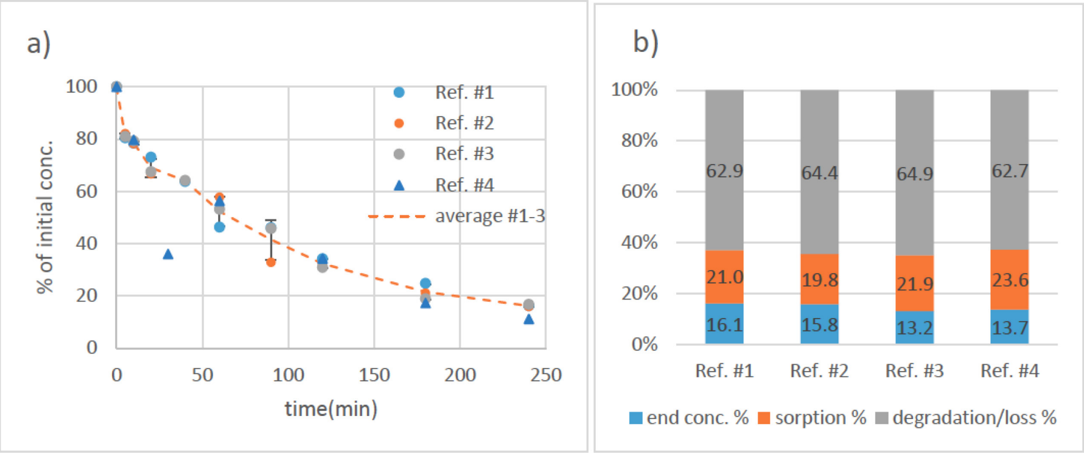


Figure 9.2 - Example of data from studies of degradation of fenobucarb using the Adept Water Technologies A/S AO electrolysis cell. Initial concentration of fenobucarb 5 mg/L, flow of 100 ml/min, electrolyte of 5mM Na_2SO_4, current density of 6 mA/cm^2. a) Removal of fenobucarb over time in 4 different experiments, b) mass balance; degradation and adsorption at end of experiment (Schultz, 2016).

In a number of electrochemical experiments, the pesticide fenobucarb was degraded during 4h electrolysis with an electrochemical cell coupled to a reservoir. The following operating parameters were tested: current density (0, 6, 12 and 24 mA cm^{-2}), flow rate (20, 50 and 100 ml min^{-1}), concentration (1 and 5 mg L^{-1}) and supporting electrolyte (Na_2SO_4, $NaHCO_3$ and NaCl). Aside from the studied parameters, the system was affected by basic electrolysis and adsorption to plastic in the tubes and the cell. Due to the big impact of adsorption the cell and tubes were extracted with acetonitrile after each experiment to account for the mass balance.

There was no observed difference on fenobucarb degradation between 6 mA cm^{-2} and 12 mA cm^{-2}, but increasing the current density to 24 mA cm^{-2} resulted in a significantly faster removal of fenobucarb. There was a similar removal rates for the 2 different initial concentrations, but for the lower concentration a higher percent of the adsorption consisted of adsorption. The flow rate did not change the removal rate significantly and flow rate did not cause differences in the mass balances. Na_2SO_4 electrolyte had a faster removal and higher degradation than the $NaHCO_3$ electrolyte. In both experiments three metabolites were observed, one of them was identified as 2-(1-methylpropyl) phenol. Using NaCl as supporting electrolyte resulted in a fast and total removal of Fenobucarb (except the adsorbed fraction), but an unidentified (possibly chlorinated) metabolite accumulated during the experiment (Andrea Schultz, 2016)

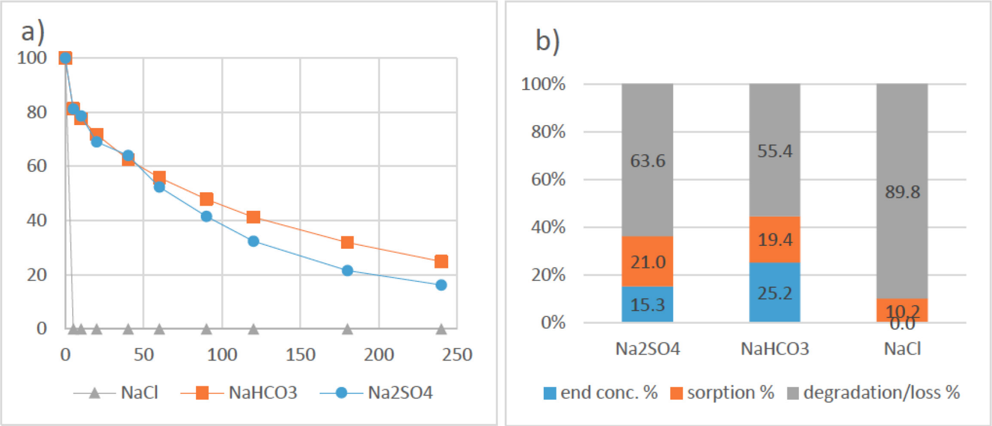


Figure 9.3 - Effect of electrolyte (concentrations of 5 mM) on the degradation of fenobucarb. a) rate of electrochemical degradation, and b) mass balance at end of experiment. Initial concentration of fenobucarb in 5 mg/L, current density 6 mA/cm2 and flow is 100 mL/min (Schultz, 2016). Note the marked effect of NaCl electrolyte

In conclusion degradation of fenobucarb takes place in the electrolysis cell; other pesticides may also degrade electrochemically, and the specific molecular structure and presence of functional groups may have a strong effect on degradation rates. The degradation of fenobucarb is fairly slow, but in presence of chloride in the supporting electrolyte the degradation is fast. The metabolite(s) forming in presence of chloride electrolyte has not yet been identified but most likely is a chlorinated metabolite as it only forms in the chloride containing electrolyte. So degradation takes place, but undesired metabolites may form. In natural waters this may be different because, as seen under 5.3 the water contents of salts, DOC and other organic solutes may strongly affect the specific outcome of the electrolysis.

9.8.3 **Risk Assessment of the chemical quality of the produced water**

A full risk assessment of the water cleaning unit cannot be carried out as we have no data for the possible organic metabolites that may form. The fenobucarb study however shows that metabolites do form, in particular in presence of chloride, where most likely chlorinated fenobucarb metabolites are formed. This is also most likely to happen in the presence of other organic substrates present in the raw water such as DOC. Also, low molecular weight chloro substituted aliphatics and carboxylic acids like chloroform or chloro-acetic acids may form, but we have not measured for that, and a full assessment requires a more extended study. The metabolites forming may be harmful or not - depending on the exact molecular configuration, the concentration of the metabolites and their toxicity profiles.

Chlorate seems to be produced; the evidence from study 5.3 is rather clear. As mentioned the formation depends strongly on the specific conditions such as current density of the electrodes, the flow, the water composition including electrolyte concentration, presence of organic solutes and other factors. The different tests of the equipment carried out points also to chlorate formation, but data are of poorer quality as an interfering substance hampers the detection of chlorate, but in general the chlorate signal from treated water is higher than for the raw water intake. Concentrations are in general below 1 mg/L. A more detailed analysis is needed in order to document and understand chlorate production in more detail.

There are indications that nitrate may be produced electrochemically for certain waters that contain nitrogen containing substrates that can be oxidized to nitrate, e.g. ammonium. The effect is not evaluated to have any effect on the produced water quality.

The treated water contains chlorine - typically in the low mg/L range. This is not widely different from chlorine concentrations in chlorinated drinking water, but gives an off taste. There may also be lower concentrations of iron, which has no effect on health, but may also give an off-taste.
The cleaning unit has no clear effect on the concentrations of trace metals, and in cases where the raw water has too high concentrations of such constituents, the produced water also has too high concentrations of these constituents.

Finally, the processed water contains particles, in particular when the ceramic filter is not included. The particles comprising organic and inorganic particles will contain adsorbed inorganic and organic contaminants. How much this will be has not been determined in this project.

In conclusion, the water cleaning unit clearly performs very well with respect to production of chlorine (im-portant for disinfection), removal of phosphorus and partial removal of particles. It does have a number of challenges that need to be addressed for improving the water cleaning unit. A main focus should be to re-move particles in the inlet water and to include filters at end of process lines that can sorb both inorganic (e.g. heavy metals) and organic (e.g. organic contaminants including chlorinated byproducts) contaminants. Chlorate production probably can be reduced via electrode design and electrolysis conditions, while chlorinated byproducts may be removed by a filter (e.g. activated carbon) at end of the water treatment line. An activated carbon filter will, however, also remove the post treatment disinfective effect.

9.9 **WP5 Conclusion**

The compact water treatment unit has been designed to be robust, cheap and to comprise relatively simple cleaning steps. The electro coagulation unit that releases iron to the water is important to cause particle generation for subsequent removal in filters. These particles can contain all sorts of contaminants. As all analyses have been performed on filtered samples we cannot document the fraction of contaminants removed with particles. However, for both the Emdrup Lake water and the water from Hanoi, the cleaning unit removes particles, up to 75 % in case of high particle loads. Effects on TOC removal is variable but usually less than 50 %. When a ceramic filter is included after the electrolysis cell particle concentrations become much lower and the turbidity visually appears to become removed.

The major cations and anions are - as expected - unaffected by the water cleaning process, and hence salty water in is also salty water out. Water pH and alkalinity is hardly affected. There are no significant effects on removal of trace elements. For the iron concentrations, they may increase after the electro coagulation unit, but in other cases, iron concentrations decrease during filtration, or as seen for the Hanoi water it markedly increases after passing the electrolysis cell. There are indications that small amounts of nickel could be released from the polymer filter.

The filter unit has a marked effect on removal of phosphate, given the phosphate concentrations in the raw water is not too low. Hence, for waters with high concentrations of phosphate like the Emdrup water (and in particularly pig slurry amended water) phosphate removal is substantial. For waters with low concentrations of phosphate as the Hanoi waters, no significant effects are seen.

For some waters, low concentrations of nitrate appears to be generated during water treatment. This is seen in particular for the Emdrup Lake water added pig slurry and one suggestion is that the nitrate arises from oxidation of other nitrogen solutes (probably ammonium) in the electrolysis unit. In all cases perchlorate was below detection limits. Chlorate is apparently seen in all water samples but the data are hampered by interferences. However, if raw water and treated water are compared, there are clear indications that chlorate is produced during processing, and this should need further analysis.

In all cases the electrolysis unit has produced active chlorine (free chlorine and hypochlorous acid) at levels of about 1 mg/L or higher even though chloride concentrations in the raw water has been low as in the BIO-AQUA A/S and Hanoi waters. The chlorine appears to degas from the treated water within 1 - 2 h, but data are not conclusive. We have not performed analysis of chlorination byproducts which may form during the electrolysis. They probably form, but we believe they are below threshold concentrations.

In conclusion, the chemical analyses document that the water cleaning unit can remove particles, it can remove phosphate, and to some extent TOC. For production of water without turbidity a ceramic filter is needed, however with the expense of significantly reduced flow. The water cleaning unit does not affect the general water composition and salt content of the water, and has no significant effects on removal of heavy metals. The electrolysis unit produces active chlorine above a concentration of 1 mg/L even for low chloride waters. Concerns may be due to formation of chlorate and possibly nitrate.

10. WP6: Effect of advanced oxidation on pathogenic microorganisms

Major contributors: Anita Forslund and Anders Dalsgaard, Department of Veterinary and Animal Sciences, University of Copenhagen

10.1 Tasks in WP6

The focus in this work package was to determine how effective the water cleaning unit was at removing microbiological contaminants from the treated water (water chemistry parameters are addressed in work package 5 (WP5)). The activities conducted were coordinated with tasks in WP5. WP6 activities included optimization of the water cleaning unit, five field tests and laboratory testing on how the AO unit performed with different water compositions and in presence of organic contaminants. Thus, the subtasks were:

- 6.1 Optimization of the filtration and AO units at Adept Water Technologies A/S and BIO-AQUA A/S. This is reported in the section describing the work of Work packages 2 to 4
- 6.2 Field tests of the water cleaning unit utilizing surface water samples from Denmark and Vietnam; microbiological analyses done at University of Copenhagen and National Institute of Veterinary Research, Hanoi, Vietnam
- 6.3 Laboratory test of the performance of the AO unit determining the effect of different water compositions on disinfection
- 6.4 Laboratory test of the performance of the AO unit for direct disinfection as well as determination of disinfection capacity of selected pathogens done at different retention times
- 6.5 Microbial risk assessment of the water treatment unit

10.2 Field tests on Danish and Vietnamese surface waters; microbial analyses

During the development of the water cleaning unit, 7 tests on natural waters have been performed. Note that the configurations of the system for the tests are described in the table in section 8.5.1.

Microbiological test results are presented and discussed below. We used the following standard microbiological methods:

Total viable bacteria, 22°C and 37°C	DS/EN ISO 6222 2000
E. coli and coliforms	DS/EN ISO 9308-1 2001
Enterococcus spp.	DS/EN ISO 7899-2 2000
Clostridium spp.	DS 2256 1983
Aerobic spores	Østensvik et al, JAM 2004, 96, 987-993
Somatic coliphages	DS/EN ISO 10705-2 2001

Microbial drinking water requirements in Denmark are specified in Table 10.2.1.

	CFU*	Water quality requirements	
		Values at water work	Values at consumer
Coliform bacteria	Per 100 mL	Not detectable	Not detectable
E. coli	Per 100 mL	Not detectable	Not detectable
Enterococcus spp.	Per 100 mL	Not detectable	Not detectable
Total viable bacteria at 22°C	Per mL	50	200
Total viable bacteria at 37°C	Per mL	5	20
C. perfringens, incl. spores (surface water)	Per 50 mL	Not detectable	Not detectable

Table 10.2.1 - The microbiological quality requirements for drinking water according to Danish standards (BEK nr 802 af 01/06/2016 Bekendtgørelse om vandkvalitet og tilsyn med vandforsyningsanlæg).
*Colony forming units

The water cleaning unit tested consists of the following cleaning operations in sequence:

- **Electrocoagulation**: Fe (II, III) released from Fe electrodes causing flocculation of humic materials, binding of phosphate etc. to form small particles
- **Filtration I**: A polymer filter retains particles in the native water and particles formed by coagulation
- **Electrolysis**: In an electrolysis cell (AO unit) active chlorine (chlorine and hypochlorous acid) is formed by electrochemical oxidation of chloride; the active chlorine inactivates microorganisms. Water is electrolysed forming hydrogen and oxygen as are low concentrations of oxidants (like hydrogen peroxide)
- **Filtration II** (optional): A ceramic filter retains particles larger than 0.1 µm.

10.3 **Test 0**

The test examined the capacity of the polymer filter to remove selected bacteria from lake water (Lake 1). The bacteria determined were selected according to those included in the Danish microbiological quality requirement testing of drinking water (Table 10.2.1).

Sample type	Total viable bacteria 22°C	Total viable bacteria 37°C	*E. coli*	Coliform bacteria	*Enterococcus* spp.	*C. perfringens*	*C. perfringens* spores
	[cfu/mL]	[cfu/mL]	[cfu/100 mL]	[cfu/100 mL]	[cfu/100 mL]	[cfu/mL]	[cfu/mL]
Lake water	1.3×10^4	1.1×10^4	12	6.3×10^4	59	<1	<1
After polymer filter	<1	0.9	<1	<1	<1	<1	<1

Table 10.3.1 - Microbial concentration of bacteria in water from Lake 1, before and after filtering through a polymer filter.

10.3.1 **Summary of results from Test 0**

- The initial total concentration of bacteria in the lake water was above the requirements set for drinking water
- The concentrations of the faecal indicator bacteria, E. coli and Enterococcus spp., were just above the detection limit of 1 cfu/100 mL
- *Clostridium perfringens* was not detected in the lake water
- The filter unit was able to reduce the concentration of bacteria by approximately 4-log units.

10.4 **Test 1**

Lake water (Lake 1) was treated in the water cleaning unit consisting of the polymer filter and the AO unit. Approximately 95% of the water was bypassed the polymer filter. The AO unit was running at maximum current (32A). After treatment, water samples were stored up to one hour to test the residual effect of active chlorine on subsequent bacterial die-off during storage. Two treatment scenarios were tested:

Max current:	All water samples were treated in the AO unit at maximum current.
Mixed water:	Untreated water was mixed with the treated water (maximum current) from the AO unit with time interval set as 10 s switch time.

In test 0, no *Clostridium perfringens* vegetative cells and spores was detected in the lake water. Analyses of *C. perfringens* spores were therefore substituted with analysis for aerobic spores, associated with *Bacillus* spp.

Table 10.4.1 - Bacterial concentration in lake water before water treatment and after water storage for 0-60 min.

Sample type	Storage time	Total viable bacteria 22°C	Total viable bacteria 37°C	*E. coli*	*Enterococcus* spp.	Aerobic spores	Cl^-	Active Cl_2
	[min]	[cfu/mL]	[cfu/mL]	[cfu/100 mL]	[cfu/100 mL]	[cfu/100 mL]	[mg/L]	[mg/L]
Lake water		30	99	38	32	33	30.8	
Max current	0	<1	0.5	<1	<1	0.9		3.30
	10	<1	0.5	<1	<1	2.7		2.26
	30	<1	<1	<1	<1	<1		1.55
	60	<1	<1	<1	<1	3.2		1.39
Mixed water	0	<1	<1	<1	<1	0.9		1.07
	10	0,5	<1	<1	<1	1.8		1.09
	30	<1	<1	<1	<1	3.6		0.87
	60	<1	<1	<1	<1	5.0		0.33

10.4.1 **Summary of results from Test 1**

- Initial concentration of bacteria in lake 1 was below 100 cfu/mL for total viable bacteria and 100 cfu/100 mL for faecal bacterial indicators
- A 1.5-2 log unit reduction of all bacteria was determined immediately after treatment
- Bacterial regrowth during storage was not seen
- Active chlorine had limited effect on the numbers of aerobic spores.

10.5 **Test 2a**

As the concentration of faecal bacterial indicators and total viable bacteria was low in Lake 1 (less than 100 cfu/100 mL and 100 cfu/mL, respectively) it was difficult to measure any reduction in bacterial concentrations as an effect of treatment. Water samples were collected from a new lake (Lake 2) located near BIO-AQUA A/S with the aim to locate a lake with water containing bacteria in concentrations high enough to measure significant reductions after treatment in the water treatment unit.

Table 10.5.1 - Bacteria concentration (-groups) in water from lake 2 and estimated reduction (log-unit) following treatment

Sample type	Total viable bacteria 22°C	Total viable bacteria 37°C	*E. coli*	Coliform bacteria	*Enterococcus* spp.	Aerobic spores	*C. perfringens*	*C. perfringens* spores
	[cfu/mL]	[cfu/mL]	[cfu/100 mL]	[cfu/100 mL]	[cfu/100 mL]	[cfu/100 mL]	[cfu/50 mL]	[cfu/50 mL]
Lake water	2.05×10^{5}	1.82×10^{5}	3.55×10^{4}	1.04×10^{6}	3.96×10^{3}	5.27×10^{2}	25	11
Limit of detection	1	1	1	1	1	1	1	1
Possible log-unit reduction	5-log	5-log	4-log	6-log	3-log	2-log	1-log	1-log

10.5.1 Summary of results from Test 2a

- In contrast to water from Lake 1, bacterial concentrations found in the Lake 2 was high enough to measure reductions up to 6 log-units
- The concentrations of *C. perfringens* and *C. perfringens* spores were estimated to be too low to allow for continued analyses of these microorganisms and such analyses were therefore excluded in the further tests.

10.6 Test 2b

This test was carried at Lake 2 near BIO-AQUA A/S. The main purpose of this testing was to test the effects of the filters, the flocculation unit and the electrolysis cell (AO unit).

Table 10.6.1 - Concentration of bacteria in lake water from Lake 2 and after treatment, including after back-flush and storage.

Sample type	Running time	Storage time	Total viable bacteria 22°C	Total viable bacteria 37°C	*E. coli*	Coliform bacteria	*Enterococcus* spp.	Aerobic spores	Active Cl_2
	[min]	[min	[cfu/mL]	[cfu/mL]	[cfu/100 mL]	[cfu/100 mL]	[cfu/100 mL]	[cfu/100 mL]	[mg/L]
Lake water			6.67×10^{2}	1.33×10^{3}	<1 *	7.36×10^{3}	93.9	1.03×10^{2}	
Filter 1 + AO + filter 2	0	0	1	<1	<1	<1	<1	<1	0.66
	0	10	0.5	1	<1	<1	<1	0.5	0.30
	0	30	3.5	<1	<1	<1	<1	<1	0.22
	0	60	0.5	<1	<1	<1	<1	0.5	0.21
	15	0	<1	0.5	<1	<1	<1	1	
	25	0	0.5	0.5	<1	<1	<1	1	
Back-flush, first flush	30	0	4.86×10^{3}	3.87×10^{3}	36	3.09×10^{3}	36.4	4.54×10^{2}	
Back-flush, final flush	30	0	4.09×10^{2}	2.73×10^{2}	<1 **	<1 **	<1 **	1.02×10^{2}	
Filter 1 + AO	0	0	4.01×10^{1}	6.76	<1	<1	<1	30.8	1.06

*Detection limit 1 cfu/mL **Detection limit 1 cfu/10 mL

10.6.1 Summary of results from Test 2b

- The concentration of bacteria was reduced 2-3 log units when the water treatment unit included both filter 1 and 2
- Faecal indicator bacteria were not detected in samples collected after the water treatment unit, but limited regrowth of total viable bacteria was seen after storage
- The storage time had some effect on the concentration of aerobic spores
- Removal of filter 2 lowered the removal of bacteria by 1-2 log units
- Concentration of bacteria in water collected after the first flush of the filters was higher than in lake water indicating up-concentration of bacteria in the filters
- All bacteria were not eliminated from the filters during flush-back of filter 1.

10.7 Test 3

Water was sampled from Emdrup Lake and brought to Adept Water Technologies A/S in two 1000 L containers. Here the lake water was manipulated by adding pig slurry in order to increase the number of bacteria and pathogens in the water. This spiking was done to allow determination of the effect of the water treatment (and in particular the disinfection unit) on bacterial numbers (see below). Pig faeces were diluted in 0.9% saltwater, and filtrated to remove larger particles. The volume of pig slurry added to each container was 10 L.

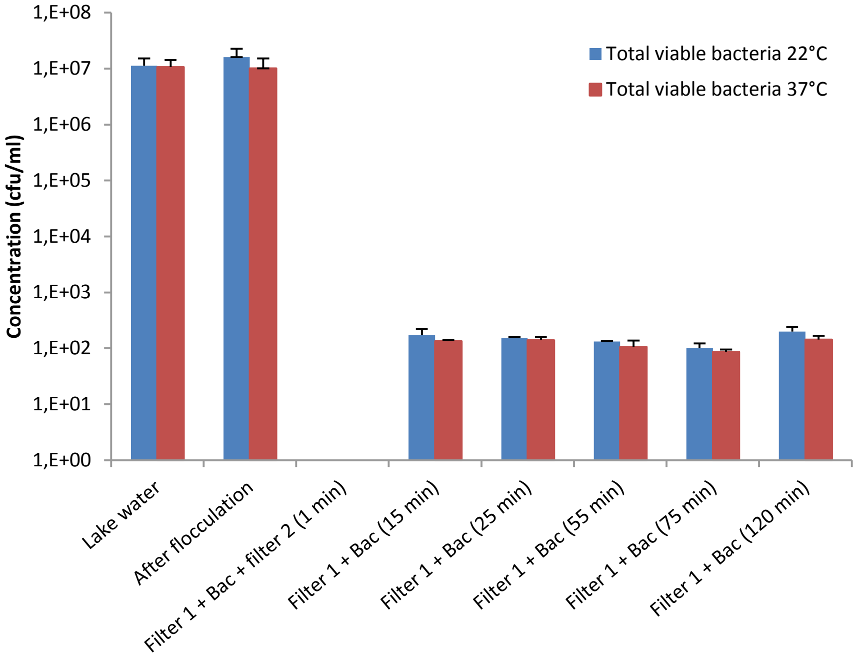


Figure 10.1 - Concentration of total viable bacteria in lake water (log-scale), after flocculation and in final treated water at different runtimes (min.) of up to 120 min. Filter 2 was removed from the water treatment unit after 10 min.

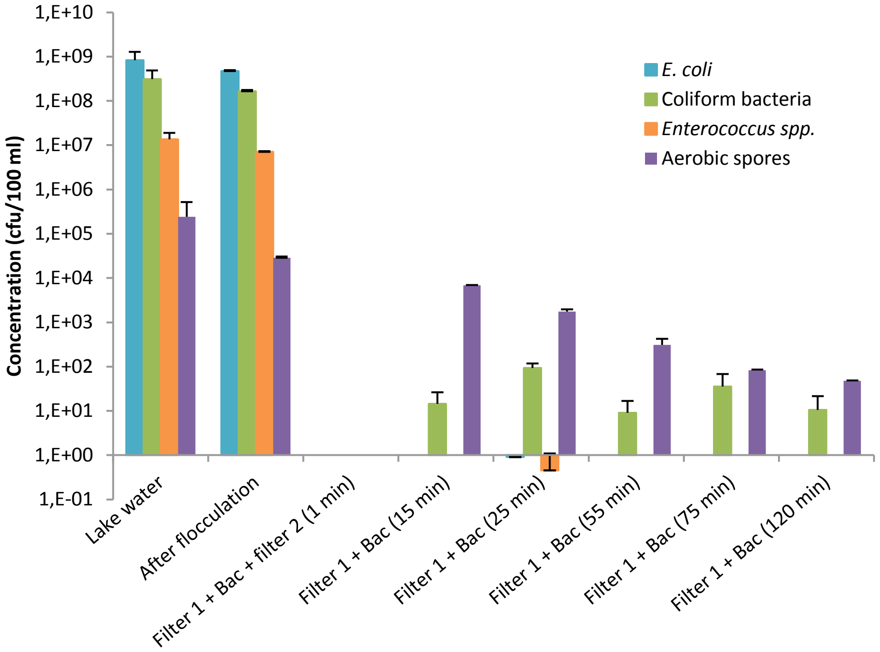


Figure 10.3 - Visual illustration of lake water after different treatment steps. Filter 1 is the BIO-AQUA A/S polymer thread filter, Bac is the AO unit and Filter 2 is the LiqTech membrane.

Figure 10.2 - Concentration of *E. coli*, coliform bacteria, *Enterococcus* spp. and aerobic spores in lake water (log-scale), after flocculation and in final treated water at different runtimes (min.). Filter 2 was removed from the water treatment unit after 10 min.

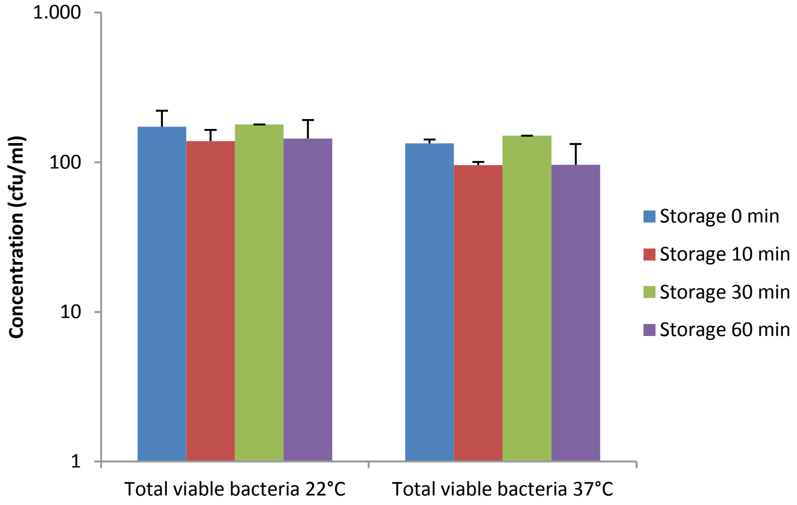


Figure 10.4 - Concentration of total viable bacteria at different storage durations with lake water treated through Filter 1 and the AO unit. Water samples were collected 15 min after start of the experiment.

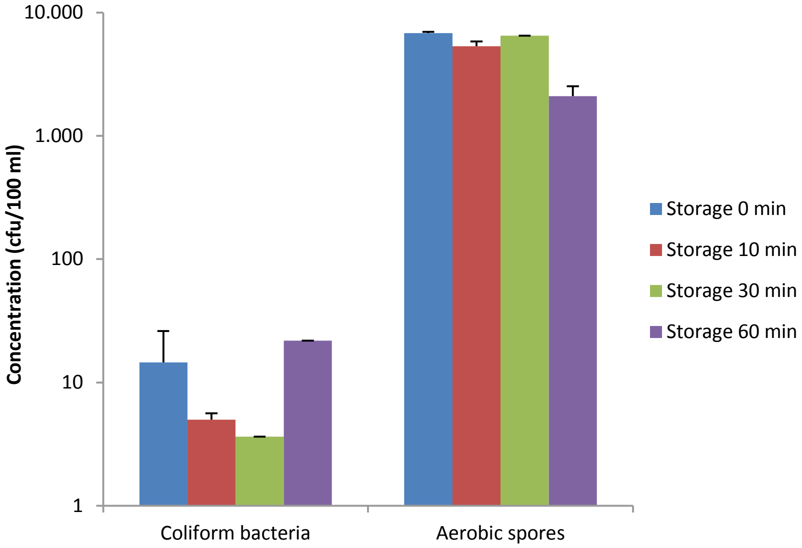


Figure 10.5 - Concentration of coliform bacteria and aerobic spores at different storage durations with lake water treated through Filter 1 and the AO unit. Water samples were collected 15 min after start of the experiment.

10.7.1 Summary of results from Test 3

- Flocculation did not decrease the concentration of bacteria
- The configuration of the water treatment unit, Filter 1, the AO unit and Filter 2, decreased the concentration of all bacteria to below the detection limit corresponding to an 8 log-unit reduction
- Filter 2 clotted after 10 min and was therefore removed from the treatment unit
- Low concentrations of total viable bacteria were detected with the water treatment unit configuration, filter 1 and AO unit and almost all *E. coli* and *Enterococcus* spp. were removed
- The concentration of aerobic spores and coliform bacteria was less affected by the water treatment unit
- The concentration of bacteria was unaffected by runtime of up to 120 min. Storage of treated water for up to 1 h did not further reduce the concentration of bacteria probably due to a decreased chlorine concentration.

10.7.2 Main conclusion from Test 3:

The unit is efficient in reducing the concentration of bacteria with reduction depending on filter capacity, but with the concentration of bacteria being unaffected by runtime.

10.8 Test 4

Test 4 was a more comprehensive test compared to test 3. As for test 3, Emdrup lake water was added pig slurry. This time at two different concentrations, i.e. 1 L pig slurry per 1000 L lake water (0.1‰ pig slurry) or 10 L pig slurry pr. 1000 L lake water (1‰ pig slurry). The test was done to monitor the effect of runtime, current settings of AO unit, and the effect of Filter 1.

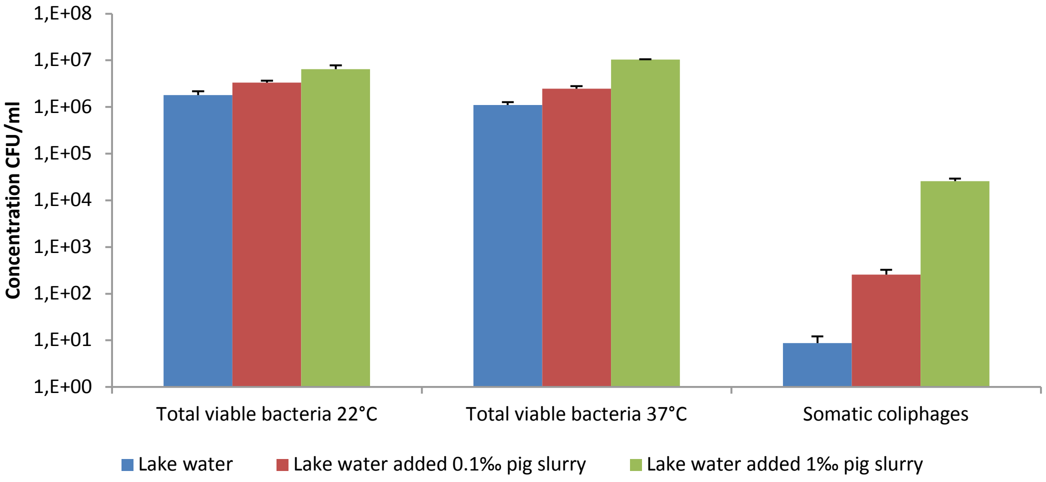


Figure 10.6 - Concentration of total viable bacteria and somatic coliphages in lake water, lake water added 0.1‰ pig slurry and lake water added 1‰ pig slurry.

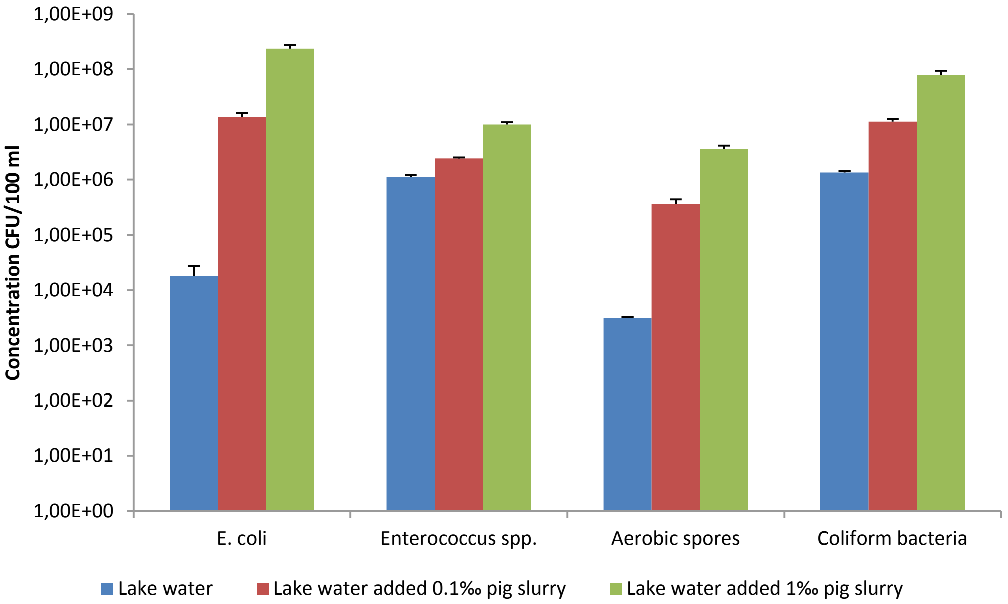


Figure 10.7 - Concentration of E. coli, Enterococcus spp., aerobic spores and coliform bacteria in lake water added different concentrations of pig slurry.

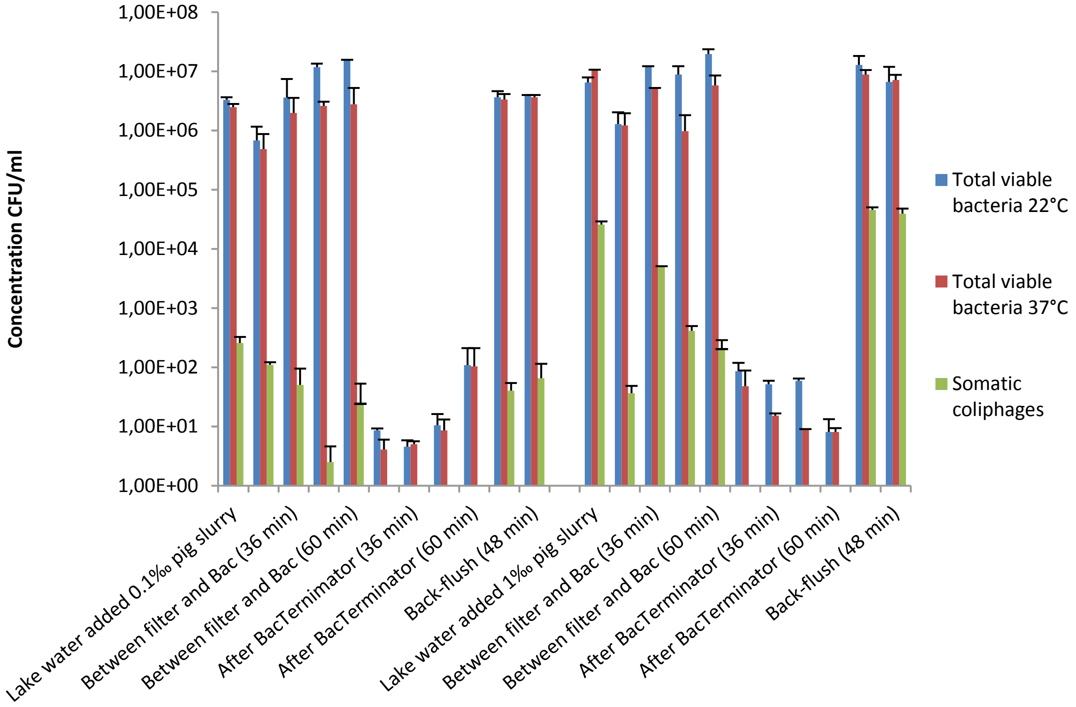


Figure 10.8 - Concentration of total viable bacteria and somatic coliphages in lake water added 0.1‰ and 1‰ pig slurry and after polymer filter, AO unit (Bac) and in back-flush at different runtimes (min).

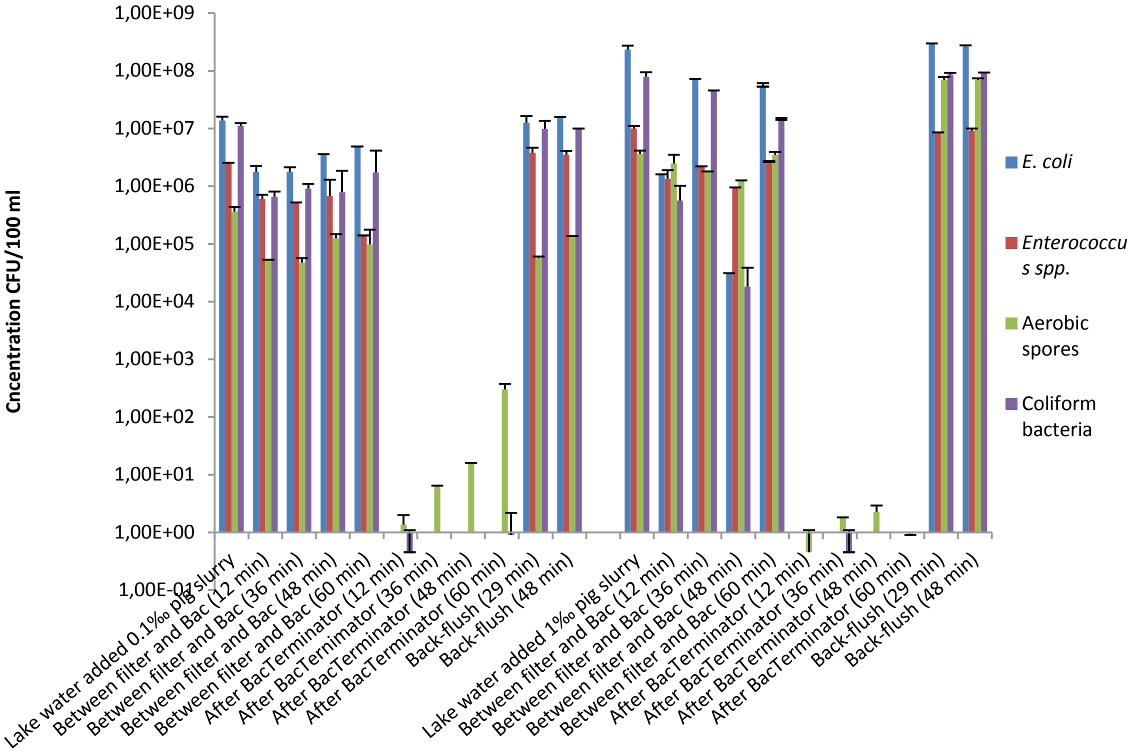
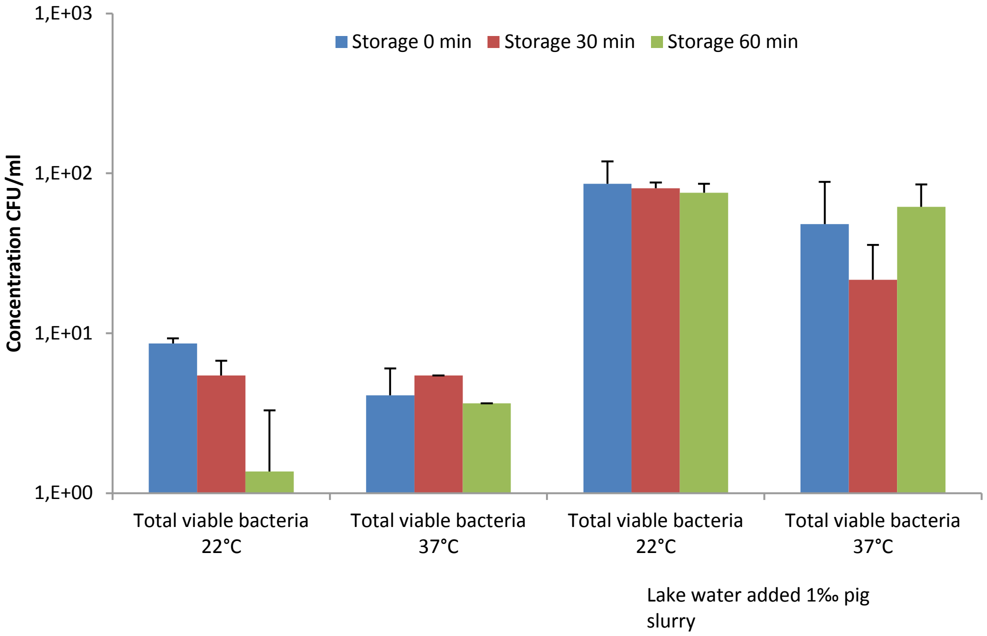


Figure 10.10 - Concentration of E. coli, Enterococcus spp., aerobic spores and coliform bacteria in lake water added 0.1‰ and 1‰ pig slurry and after treatment by the polymer filter, in the AO unit (Bac) and in back-flush water at different runtimes (min).

Figure 10.9 - Concentration of total viable bacteria at different storage durations after lake water was treated in the polymer filter and in the AO unit



10.8.1 **Summary of results from Test 4**

- The water treatment unit was able to reduce the bacterial concentration with 5 to 8 log-units
- The polymer filter did not decrease the bacterial concentration significantly
- After the AO treatment, *E. coli*, *Enterococcus* spp. and somatic coliphages were not detected while coliform bacteria were detected sporadically just above the detection limit
- Low concentration of aerobic spores (1-100 cfu/100 ml) were detected after the AO treatment
- Back-flush water and lake water added pig slurry had similar bacterial concentrations
- As observed in test 3, runtime up to 60 min did not affect the concentration of bacteria
- Increasing the concentration of pig slurry by 10 times did not affect the treatment capacity of the AO unit
- Storage of treated water for up to 1 h did not further reduce the concentration of bacteria probably due to a decreased chlorine concentration.

10.8.2 **Main conclusion from Test 4**

The unit is efficient reducing the concentration of bacteria in lake water with high concentration of faecal material with the bacterial concentration being unaffected by runtime.

10.9 **Test 5**

This test was carried out as the final test using water from the Emdrup Lake water before shipping the treatment unit for comparative test experiments in Hanoi, Vietnam. The final configuration of the unit comprised of flocculation, Filter 1, electrolysis cell and a ceramic filter after the electrolysis cell (only in some tests). In contrast to test 3 and test 4, no pig slurry was added to the lake water. Results of the testing are showed in the two figures below.

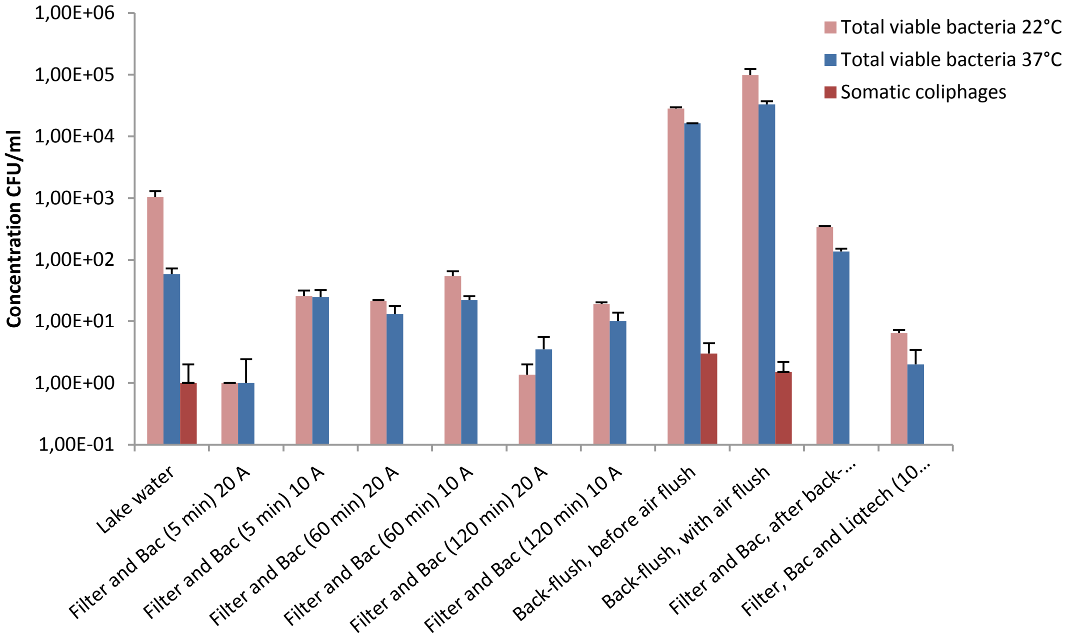


Figure 10.11 - Concentration of total viable bacteria and somatic coliphages in lake water, treated lake water and back-flush water. Water treatment included polymer filter, AO unit (Bac) and/or LiqTech filter with different running times (min) and at 10 A and 20 A current.

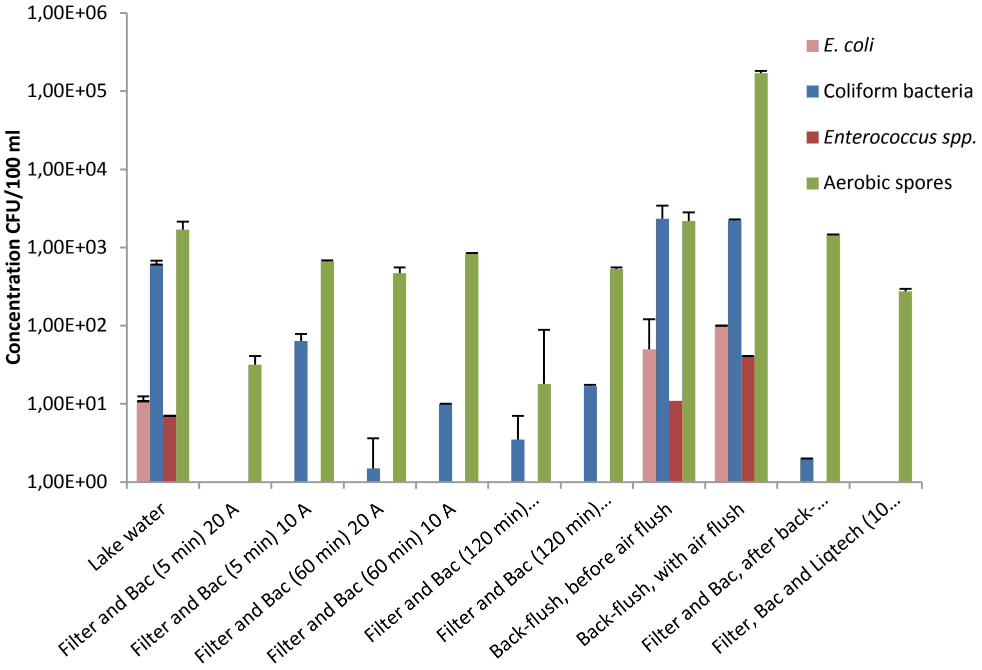
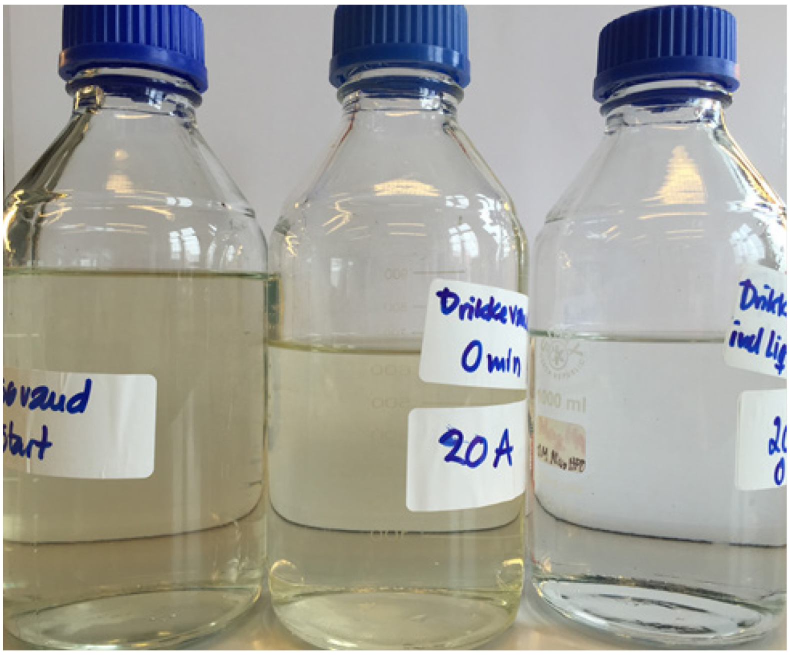


Figure 10.1 - Concentration of aerobic spores, coliform bacteria, *E. coli* and *Enterococcus* spp. in lake water, treated lake water and back-flush water. Water treatment included polymer filter, AO (Bac) and with/without LiqTech filter. The AO unit was running at 10 A or 20 A currents at different time intervals (min).



Lake water

Filter and Bac (5 min) 20 A

Filter, Bac and Liqtech (10 min) 20 A

Figure 10.13 - Visual illustration of lake water after different treatment steps. Filter is the BIO-AQUA A/S polymer thread filter, Bac is the AO unit and Liqtech is the secondary filter.

10.9.1 **Summary of results from Test 5**

- The bacterial concentrations in Emdrup lake water was rather low limiting the level of reduction that could be detected during treatment
- A maximum of 3 log-unit reduction was detected for total viable bacteria, coliform bacteria and aerobic spores while only a 1 log-unit reduction could be measured for *E. coli*, *Enterococcus* spp. and somatic coliphages
- A higher reduction in the concentration of bacteria was seen when the AO unit was operating at 20 A compared to 10 A
- •The polymer filter retained bacteria as shown by an increase in the concentration of bacteria in the back-flush water
- The LiqTech filter further reduced the concentration of bacteria
- After treatment by the AO unit, *E. coli*, *Enterococcus* spp. and somatic coliphages were not detectable
- As observed in test 3 and 4, runtime up to 120 min., did not affect the concentration of bacteria.

10.9.2 **Conclusions from Test 5**

- The AO unit is more efficient to reduce the concentration of bacteria when operating at higher current
- Concentration of bacteria is unaffected by runtime
- LiqTech filter reduced bacteria with 2 log-units.

10.10 Test 6

The final test was carried out with water obtained from a fish pond in Hanoi, Vietnam which resembles the water quality of flooding water. The configuration of the water cleaning unit was the same as for test 5. The test was carried out over 2 days. The AO unit was applied running at 18 A (4.9 V), and the flow generally was around 150 - 200 l/h. Fish pond water and treated water were analysed for total bacteria following cul-ture at 22°C and 37°C, *E. coli*, coliform bacteria, *Enterococcus* spp. and aerobic spores. Results of the test are given in figures below.

Figure 10.14 - Concentration of total viable bacteria cultured at 37°C and 22°C in lake water and following the different treatment steps in the water treatment unit. Samples were collected during two in Hanoi, Vietnam with back-flush water only being sampled and analyzed on day 2.

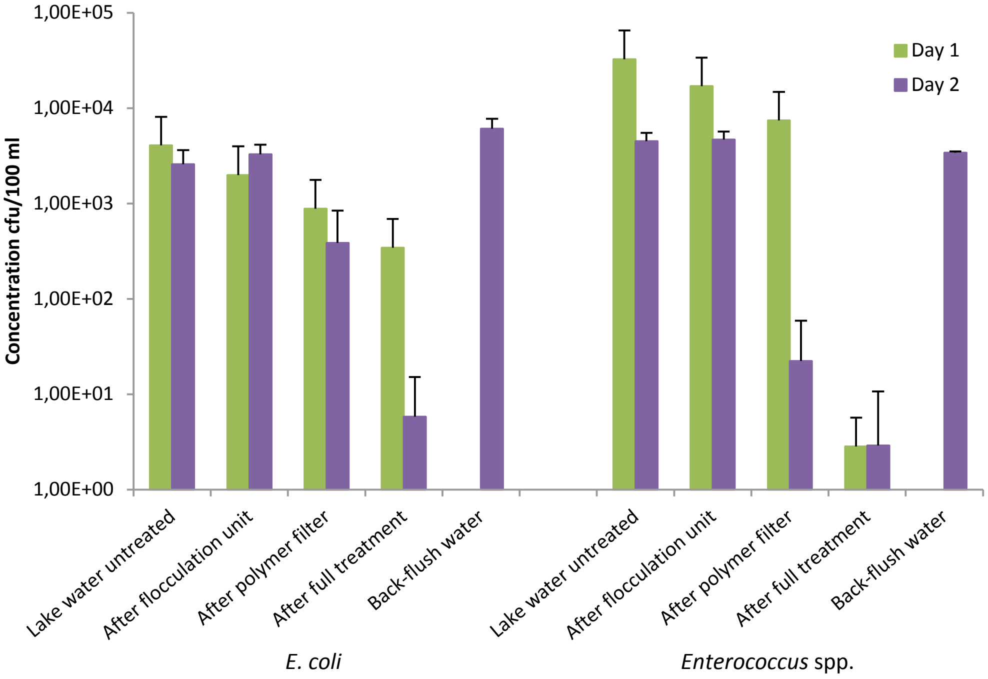


Figure 10.15 - Concentration of E. coli and Enterococcus spp. in lake water and after the different treatment steps in the water treatment unit. Samples were collected during two days in Hanoi, Vietnam with back-flush water only being sampled and analyzed on day 2.

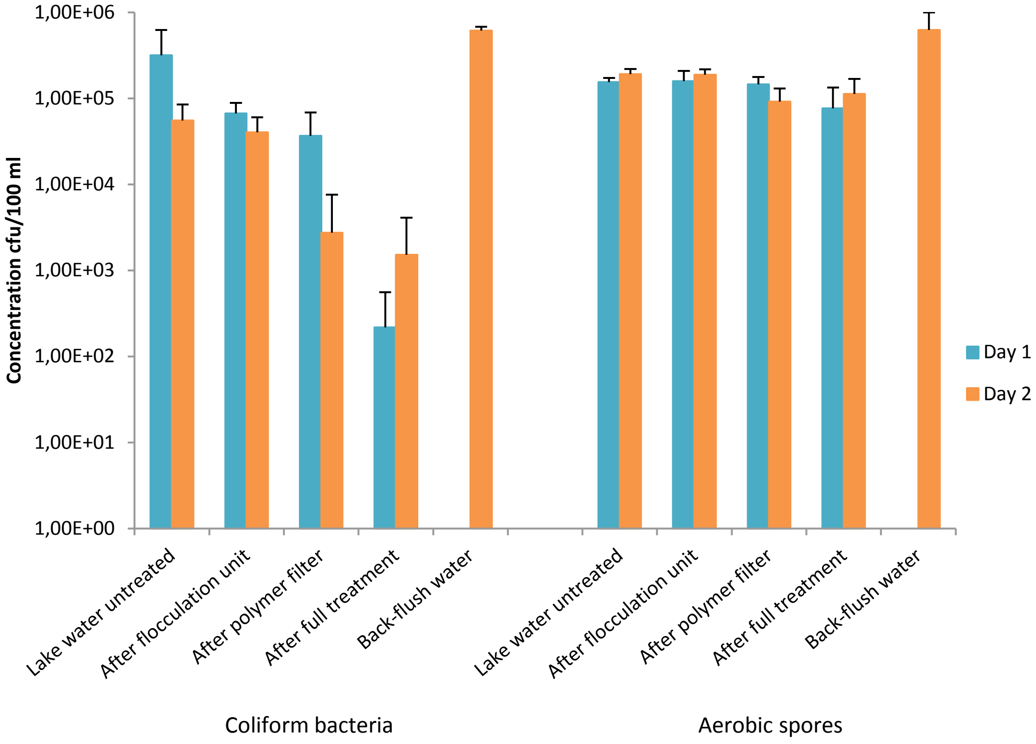


Figure 10.16 - Concentration of coliform bacteria and aerobic spores in lake water and after the different treatment steps in the water treatment unit. Samples were collected during two days in Hanoi, Vietnam with back-flush water only being sampled and analyzed on day 2.

10.10.1 **Summary of results from Test 6**

- The bacterial concentrations were reduced approximately 1 to 3 log-units after full treatment except for aerobic spores
- After the flocculation unit, the water contained almost similar bacterial concentrations as found in lake water
- The polymer filter retained bacteria and up-concentration of bacteria was detected in back-flush water
- The AO unit further reduced the concentration of bacteria in the water especially for faecal indicator bacteria, *E. coli* and *Enterococcus* spp.
- The concentrations of aerobic spores were unchanged after the different treatment steps of the wa-ter treatment unit
- For each sampling day, run time for up to five hours showed similar concentration of bacteria in the water
- A lower concentration of bacteria was found in lake water on the second day of sampling (day 2) probably a consequence of dilution caused by heavy rain between day 1 and day 2.

10.10.2 **Conclusions from Test 6**

- The water treatment unit reduced bacterial concentrations in the lake water except aerobic spores.
- The fully treated water could not be classified as drinking water according to the Danish drinking water regulation.

10.11 **Lab test: Effect of water composition on disinfection**

The purpose of the laboratory experiments was to evaluate how different water compositions affected the formation of chlorine and direct die-off as well as residual effect after storage on microorganisms. The electrochemical disinfection can be accomplished by two mechanisms.

One is the direct oxidation at the electrode surface and the other is indirect oxidation by reactive oxidants generated from the water electrol-ysis. The second mechanisms take place during storage for extended time.

A literature review was conducted initially to search for studies on survival of microorganisms treated with the advanced oxidation processes similar to the one developed by Adept Water Technologies A/S. The literature review showed that many studies had reported the die-off of bacterial and viral pathogens. These studies included the direct die-off and residual effect on e.g. *E. coli*, *V. cholerae*, *S. aureus* and *Legionella* spp., as well as bacteriophages and viruses. Limited studies were available on more complex microorganisms, e.g. bacterial spores and (oo)cyst of protozoan parasites. *Bacillus* spp. and *Clostridium* spp. spores show similar enhanced survival and resistance towards chlorine treatment. The cell wall of bacterial spores is structurally and chemically more complex than the vegetative cell and spores are therefore resistant to many chemicals, including most disinfectants (Russell, 1990).

Laboratory experiments were performed with a small AO unit cell used for laboratory testing. Spores of *Bacillus* cereus were included in the test of the electrochemical cell. A large number of experiments were conducted using demineralized water added sodium chloride, pH stabilising compound or hydroxyl radical scavenger. In addition, experiments were performed to document the effect of natural water composition on spore inactivation using untreated and filtrated lake water. All experiments were carried out in a setup where the influent was pumped through the electrolysis cell and the effluent were analysed immediately as well as after storage for up to one hour. Experimental conditions were based on the outcomes of initial studies during WP5 where the concentrations of active chlorine were determined as a function of flow and current density. In WP6, the effect of current density and storage time was further studied. The results are quite extensive and will be published as a paper in a scientific journal (in prep).

10.11.1 **Main results**

The electrolysis generated formation of active chlorine. The direct inactivation of *Bacillus* spores during the AO unit was less than 1 log-unit while storage up to one hour decreased the concentration of spores be-tween 1-6 log-units depending on the current and water composition. The main inactivation effect was indi-rect oxidation of spores during the experiments.

A higher current density was associated with a larger decrease in the survival ratio of spores. However, the current density was not directly proportional to the survival ratio. Very limited reduction was observed at current densities below 1 A (Fig. 10.17a). At the current 1.0 A to 2.5 A, the survival ratios of spore were quite similar after 60 min while no spores could be detected at 3 A.

Hypochlorous acid (HOCl) is the main disinfecting agent of microorganisms in the electrochemical disinfection, and this radical was produced at higher concentrations at pH values less than 7.4. At higher pH, the concentration of hypochlorous acid decreased. The pH increased significantly with the rise of current density and affected the inactivation of spores. Although the concentration of active chlorine produced at current density 2.5A was higher than at 1 A, the pH of the electrolysis solution was higher too, resulting in a similar inactivation of spores. Addition of phosphate buffer stabilized the pH during electrochemical treatment and enhanced the inactivation of spores while bicarbonate buffer was unable to stabilize the pH

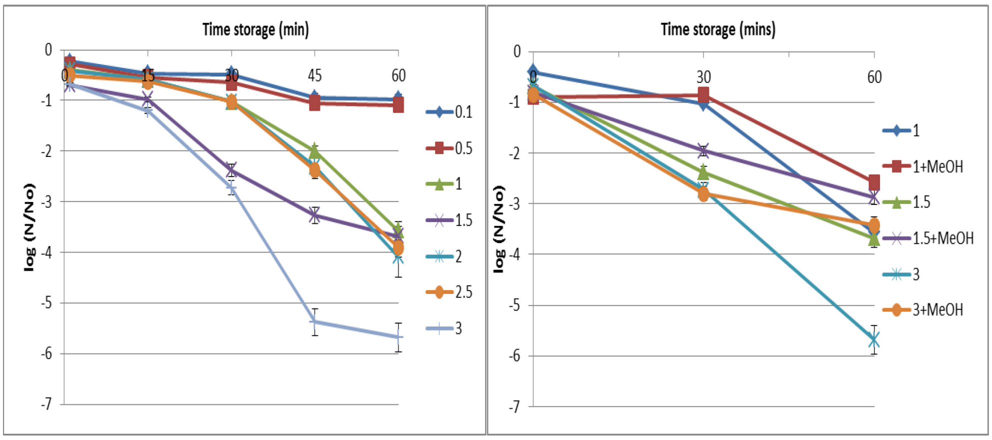


Figure 10.17 - Examples of data from experiments of oxidant species effect on Bacillus spore inactivation in the Adept Water Technologies A/S electrolysis cell. a) Effect of current density on spore inactivation during storage time (left) and b) addition of methanol (hydroxyl radical scavenger) on inactivation (right). The concentration of chloride in all experiments was 50 mg/L (NaCl). Concentration of spores added to water was 3.6 × 10^5 CFU/ml.

The electrolysis process did not only create active chlorine but did also produce other radical oxidation species like hydroxyl, ozone, and peroxide. These radicals were not detected in the chemical analysis. Addition of methanol, which is used as a hydroxyl radical scavenger, showed that spore inactivation and active chlorine concentration was reduced by the presence of excess methanol (Fig. 10.17b). This finding clearly shows that the hydroxyl radicals play a role in the inactivation of spores at high current densities. Diphenyl-1-pyrenylphosphine (DPPP) was used to investigate the target of hydroxyl radicals on inactivation of spores. DPPP reacts with lipid hydroperoxides stoichiometrically to yield fluorescent product DPPP oxide and was used as a fluorescent probe for lipid peroxidation in live cells. DPPP assay was carried out in order to determine cell membrane oxidation by electrochemical disinfection. Untreated cells did not produce fluorescence derived from lipid peroxidation (Fig. 10.18a). In contrast, the number of fluorescent spores increased with increasing current density of electrochemical treatment and time storage (Fig. 10.18b).

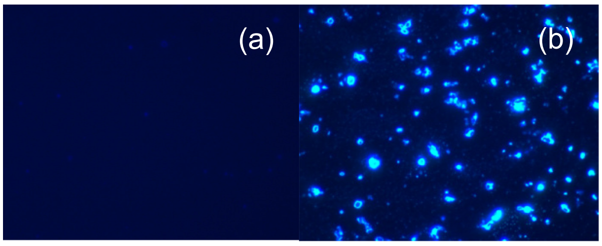


Figure 10.18 - Fluorescent microscopic images of DPPP-stained cells after 30 min of storage. a) untreated spores, b) spores treated electrochemically at 1A.

Lake water contains many substances including organic and inorganic compounds bound to biotic and abiotic particles. Water containing high number of particles and organic matter have a higher chlorine demand. The effect of removing particles on the production of active chlorine and inactivation of spores was investigated. Inactivation of spores was compared with natural lake water and lake water filtrated through 0.45 µm filter. These results indicate that the dose of active chlorine should be increased when disinfection with the AO unit are applied on lake water.

10.11.2 **Conclusion**

- The inactivation of *Bacillus* spores by electrochemical disinfection depends on the current density as well as the pH of the electrolysis solution
- Excess methanol, which was used as a hydroxyl radical scavenger, clearly showed that hydroxyl radi-cals are produced during the electrolysis and play a role in the inactivation of *Bacillus* spores
- There is a need to raise the active chlorine concentration when the AO unit is used to treat natural lake water. The lake water contains many compounds affecting the electrolysis and decreasing the concentration of active chlorine and thereby the inactivation of spores

10.12 Lab test: Direct disinfection and determination of capacity for selected pathogens

Cryptosporidium spp. is a protozoan parasite causing diarrhoea in humans and animals. During the past two decades, *Cryptosporidium* spp. has been involved in many water-borne disease outbreaks. *Cryptosporidium* spp. are excreted in faeces from humans and animals and can contaminate water sources. Water can be contaminated through sewage overflows, sewage systems that are not working properly, polluted storm water runoff, and agricultural runoff. Wells may be more vulnerable to such contamination after flooding, particularly if the wells are shallow, have been dug or bored, or have been submerged by floodwater for long periods of time. The parasite is protected by an outer shell that allows it to survive outside the body for long periods of time and makes it very resistant to chlorine-based disinfectants.

In the AO unit, active chlorine and hydroxyl radicals were produced and influenced the inactivation of *Bacillus cereus* spores (See 6.3). Laboratory experiments were performed with the AO cell in the laboratory to determine the effect of electrolysis on viability of *Cryptosporidium* oocyst. Experiments included viability of *Cryptosporidium* oocysts in lake water compared to demineralize water added sodium chloride (50 mg/L) and phosphate buffer (EC-water). Viability of oocysts was measured immediately after the AO unit and after retention time for up to four hours. Preliminary results showed that active chlorine was produced at a concentration of 14 mg/L in lake water at current density above 4 A. Even though high concentrations of active chlorine were measured, the viability of *Cryptosporidium* oocyst only decreased at a maximum of 10% after four hours of storage. In lake water, no decrease in viability was detectable at current densities below 4 A. Active chlorine concentration appeared to decline faster in lake water compared to EC-water during storage. At current density below 3 A, active chlorine was produced with a concentration of 4-6 mg/L but the viability of *Cryptosporidium* oocysts was unaffected by electrolysis treatment in EC-water.

Follow-up experiments are on-going and final results will be published as a journal paper (in prep).

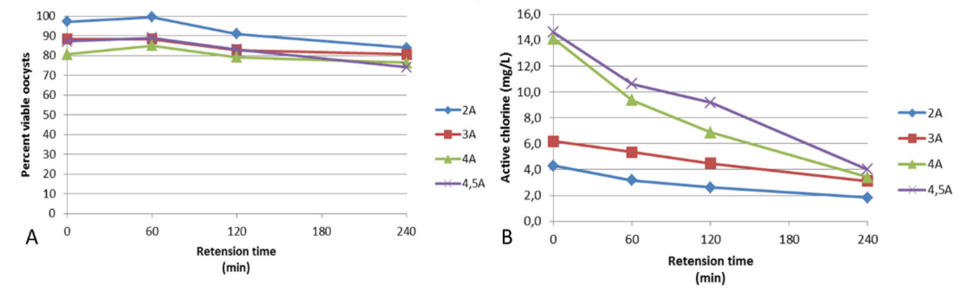


Figure 10.19 - Effect of storage time and current density on Cryptosporidium oocyst viability (a) and active chlorine production (b) in electrolyzed lake water.

10.13 Risk Assessment of the microbiological quality of the produced water

A full health risk assessment of the water cleaning unit cannot be carried out as we have limited quantitative data for such an assessment, however a qualitative health risk assessment can be made. When considering health risks associated with consumption of water, it is important to note that in emergency situation, e.g. flooding events, where existing drinking water supply networks are broken down or operating at reduced capacity, the main challenge is to provide adequate amounts of water rather than water that meet all drinking water standard requirements.

The results from Tests 3 and 4 shows that the water treatment unit was able to reduce the bacterial concentration with 5 to 8 log-units. Thus, after treatment, the faecal indicator bacteria *E. coli* and *Enterococcus* spp. as well as somatic coliphages were not detected while coliform bacteria were detected sporadically just above the detection limit. Low concentration of aerobic spores (1-100 cfu/100 ml) was detected after the AO unit. Thus, microbial water qualities obtained after treatment were acceptable or just above the international standards for drinking water (bacterial spores).

In water-borne outbreaks of gastro-intestinal diseases, bacterial pathogens, e.g. *Vibrio cholerae* O1, *Shigella* spp. and *Campylobacter* spp., are much more often implicated in such outbreaks as compared to viral pathogens. As the infectious dosage (number of pathogens needed to cause disease) of bacterial pathogens typically varies between 10^4 – 10^6 infectious cells, the high rate of removal of faecal bacterial indicators suggest that there is a very low risk for bacterial diseases associated with consumption of the treated water.

The reduction in concentration of bacterial spores was lower as compared to the test bacteria. The human health risks associated with exposure to spores through consumption of water is however uncertain as human disease caused by spore-forming bacterial pathogens, e.g. *Bacillus cereus* spores, typically are associated with food and not water intake. The removal of the somatic coliphages suggests a similar removal of viruses as such phages are often seen as indicators of viruses. On the other hand, the survival of some spores may indicate that some viruses may survive treatment. Although the infectious dosage of viruses is much lower than bacterial pathogens, pathogenic viruses are not commonly associated with waterborne disease outbreaks. Thus, the human health risks of viral disease following consumption of treated water are expected to be low.

The initial experiments with *Cryptosporidium* spp. oocysts showed limited effect of treatment on the oocyst viability. If the on-going follow-up studies confirm the initial findings, there could be real health risks for cryptosporidiosis following consumption of treated water

10.14 **Wp6 Conclusion**

Although the initial studies indicated that human pathogenic protozoan parasites, e.g. *Cryptosporidium* spp. oocysts, may survive treatment, field tests of the filtering and AO units documented a significant (5 to 8 log-units) removal of the faecal indicator bacteria *E. coli* and *Enterococcus* spp. as well as somatic coliphages. Thus, microbial water qualities obtained after treatment were acceptable and the human health risks associated with consumption of treated water is considered very low to low with regards to bacterial and viral diseases.

11. Conclusion

11.1 System – filter

The overall challenge of filtering water to a very fine degree, without implementing an advanced membrane system, was partly solved in the current project.

All results indicate that the combination of electroflocculation and flexible filters produces water with a very low turbidity, and, if combined with advanced oxidation technology, the water is suitable for drinking water. The main challenge is related to color removal of the water, a problem recognized in many regions of the world. With an improved flocculation, subsequent results obtained from additional testing (not part of this project) has shown that the color can be reduced. In order to achieve an efficient filtration with the flexible filters the selection of pump is crucial. In relation to the pilot testing, it can be concluded that it is very difficult to find pumps suitable for low flow applications. Low flow through the filters results in an insufficient compression of the filtration material and a very slow built up of filtration cake, resulting in reduced water quality. On the very positive side, the flexible filters have shown very good back-flushing behavior, it has been possible to regain the flow after fouling of the filters.

After the project, the filters have been applied for larger applications, with larger flows per filter, and the results of these experiments has shown significantly improved water quality.

The other filters applied (ceramic filters and dead-end filters) resulted in good water quality but suffered from rapid fouling and clogging. The fouling was particularly troublesome, as it was impossible to backflush.

11.2 System – advanced oxidation

The development of the BacTerminator® advanced oxidation AO system for this application has generally proven a success. The electrode fouling was much lower than expected, and the lifetime and performance of the system must be considered sufficient for any emergency situation. The mechanical strength of the system needs to be improved though, and the reliability of a core component, the polarity reversal relay, was problematic. In the meantime, several more reliable alternative components have become available, and a new generation of the system will not suffer from this. Similar, the control and power supply, which proved less than ideal for long time operation and operation by untrained personnel, would have much better performance and reliability in a new version.

11.3 System – general

As an experimental machine, the KOMBITEK has proved that a combination of these technologies offer water safe to drink, but not with a visually appetizing quality. When chosen, the filters offered several advantages, and were thus chosen for the KOMBITEK system instead of known, proven, technology. This is, after all, a development program.

As stated above, fine tuning of the technology (which has taken place separately by the companies involved) may offer significant improvement, should the system ever become available to the market.

11.4 System – costs

The costs of construction and marketing are too high to compete with the simpler alternatives currently available. Series production may, however, reduce the costs to a more competitive level, and while a sales price of 100.000 DKK may be impossible to reach, the extra cost will give extra benefits: Simplified logistics, no chemical handling and the long-lasting effect of chlorine in the water, allowing production for storage to a larger extend than other technologies.

11.5 Effect of AO on chemical contaminants

Field tests of the filtering and AO units document significant removal of phosphate, particulate material and TOC, and production of chlorine at > 1 mg/L even with water containing low chloride concentrations (10 mg/L). Laboratory tests show that organic contaminants such as pesticides can be oxidized and degraded by the AO unit; possible formation of chlorate in the AO unit should be further explored. Inclusion of a ceramic filter at end of treatment line strongly will improve the quality of the produced drinking water.

11.6 Effect of AO on pathogenic microorganisms

Field tests of the filtering and AO units document a significant (5 to 8 log-units) removal of the faecal indicator bacteria *E. coli* and *Enterococcus* spp. as well as somatic coliphages. Thus, microbial water qualities obtained after treatment were acceptable or just above the international standards for drinking water (bacterial spores). The human health risks associated with consumption of treated water is considered very low to low with regards to bacterial and viral diseases. Initial studies indicate that human pathogenic protozoan parasites, e.g. *Cryptosporidium* spp. oocysts, may survive treatment.

11.7 Summary

Through a combination of a electrocoaguation unit, a filtering unit, and an advanced oxidation unit, the KOMBITEK project resulted in a mobile and inexpensive water treatment plant which could produce drinking water with a residual antimicrobial effect. Although the treated surface water was not visually appealing without inclusion of a secondary membrane, the water was of sufficient quality to drink and the problems with flow through the tested silicium carbide membrane could be solved by increasing the size.

12. Appendix

12.1 KOMBITEK WP1 Analysis of existing treatment plants on the market

Extract of existing plants on the market (found by google search and selected on the basis of properties similar to the KOMBITEK proposed; keywords: (“package water treatment plants” and “compact potable water treatment plants”):

12.1.1 Tonka Water

Tonka has a complete line of surface water packaged treatment equipment for turbidity removal.

- The UTS (Unitized Treatment System) is a multi-stage gravity process with adjustable flocculation, tube or plate settling, and filtration for turbidity removal
- The Clari-Filt™ is a two-stage pressurized surface water treatment system. This modular design, when used along with the Simul-Wash™ system eliminates the need for fine slot media retaining nozzles and also conserves washwater
- The ClariFlote™ combines upflow flocculation and clarification with downflow filtration for treatment of moderately turbid waters (see brochure in appendix)

Groundwater Dualator® Series

The Dualator® meets Ten State Standards and is highly cost effect for many groundwater applications. It can also incorporate the Simul-Wash™ feature.

- The Dualator® I and Dualator® III are low profile rectangular multi-cell gravity filters
- The Dualator® VI is a taller profile circular unit also having multi-cells
- Tonka's Packaged Systems meet water treatment needs in a customizable manner. Tonka has packages systems for both groundwater and surface water. For groundwater applications, Tonka offers the Dualator™ series or UTS™. For surface water, Tonka offers UTS™, ClariFlote™ or Clari- Filt™. Each system is customizable to meet site specific application needs.
- The equipment incorporates gravity filters, which use multi-media for treatment of surface water applications with high turbidity levels. The staged process also provides adjustable flocculation as well as media clarification and filtration all in a compact, high performance system. Tonka also offers a wide variety of filter internals including Simul-Wash™ backwash system

Applications

- Surface water
- Groundwater
- Groundwater under the influence of surface water
- Steel, aluminum and concrete construction

Advantages

- Multiple processes in a single package
- Simul-Wash™ capable
- Modular design
- Single pumping
- Media rejection

Treatment

- Iron & Manganese
- Arsenic
- Radium
- Turbidity

- Algae

Packaged Water Treatment Reference Material:
- ClariFlote™ brochure
- Dualator®III groundwater treatment system brochure
- DTS™ Complete Water Treatment System

Packaged Water Treatment Project Profiles:
- Clari-Filt™ treating high turbidity and surface water in Calhoun, GA
- UTS™ treating high turbidity of the river water in Trinity Bay Conservation, TX
- Dualator®III system for iron and manganese removal in Prior Lake, MN
- Dualator®VI filter with ion exchange in Pomeroy, Ohio
- UTS™ treating phosphorous in Parker, CO
- UTS™ treating high turbidity in Kelleys Island, OH

12.1.2 **WesTech**

www.westech-inc.com

WesTech offers a holistic approach to surface water treatment for potable use. Depending upon the raw water quality, the flow rate, and operational preferences, WesTech can provide conventional flow, combina-tion treatment units, packaged systems, high-rate processes, or even customized solutions.

12.1.3 **Siemens**

www.water.siemens.com

Siemens provides solutions for drinking water, desalination, water reuse and plant automation. Especially to extend plant lifetime, minimize operating costs, and meet new requirements.

Municipalities and industries around the globe have come to rely on our innovative products and services designed for operational efficiencies and cost-effectiveness. From conventional to state-of-the-art membrane filtration and disinfection technologies, we offer water solutions that benefit industries and communities alike.

12.1.4 **MIOX**

www.miox.com

The MIOX P3 WTP (developed for USDA Forest Service campground) is designed to treat a surface water source or a ground water source under the direct influence of surface water to SWTR standards of potable water. It is not designed to treat brackish water or water with unacceptable levels of chemical or mineral contamination. The P3 WTP filters and disinfects water. It continually monitors influent and effluent water turbidity, treated water chlorine residual. The P3 WTP is a portable, skid mounted unit that weighs 280 pounds (110 kilograms). The skid has four handles for lifting and handling. It is 34-inches (.86 meters) wide by 54-inches (1.37 meters) long and it will fit in the bed of most pick-up trucks and through a 36-inch (.91 meters) doorway (figure 9). It is available in two models, depending on electricity source (solar or grid electricity). The P3 WTP was designed to operate unattended for up to 1 month, if treating less than 1,000 gallons per day. However, it should be checked weekly to ensure it is operating properly. Maintenance is required weekly or more often when the unit treats more than 1,000 gallons (3740 l) per day.
Routine operation and maintenance is very easy and usually takes 15 minutes to 1 hour.
Potable Water on-site purification

MIOX Corporation has extensive experience in treating municipal drinking water, ranging from rural communities to large cities. The improved safety offered by on-site chlorine generation often initiates interest in the MIOX technology. Water treatment plants are sometimes located in public areas, near schools or libraries, across from convenience stores, or even in the middle of residential neighbourhood's. The MIOX system uses only salt, water, and power to generate a dilute disinfectant on site. This on-site generation eliminates the need to store and transport hazardous chlorine gas or bulk hypochlorite (bleach), removing the potential for accidents and protecting not only the water plant operators but also neighbouring homes and businesses from exposure to hazardous chlorine.
In addition, the MIOX mixed-oxidant technology can also improve the quality of the drinking water, by eliminating bio growth within the pipelines, reducing the formation of disinfection by-products (DBPs), improving the durability of the protective disinfectant residual that prevents recontamination in the lines, and improving the taste and odour of the water. This is all accomplished with a system that operators report as being easy to maintain and costing less than traditional chlorine alternatives

Other side benefits of the MIOX technology in drinking water applications include:
- Microflocculation (reduction of both final turbidity and coagulant chemical doses)
- Iron bacteria control
- Oxidation of iron and manganese
- Oxidation of sulfides
- Breakpoint reaction at low chlorine to nitrogen ratios

12.1.5 **AP Baltic Technology and Trading**

http://www.ap-baltic.com/water.html

Mobile Water Treatment
The Water Turbidity>100-treatment plant is:

- A compact unit. No structure is needed
- Easy to operate
- Low operational cost
- The plant treating and purifying water for drinking purposes
- Source of row water can be river water or borehole water
- The plant does not treat salty water
- Disinfection by chlorination
- The plant can treat 15 m3 of water per hour equal to 360 m3 in 24 Hours. Diesel generator.

12.1.6 **DMB Mena Water**

www.dmb-menawater.com

Potable Water Treatment Plants (container size, produces also backpack sizes).
MENA Water is continuously developing its manufacturing designs and products for economical portable water treatment plants with all equipments necessary for process integrated in ISO standard containers. Our featured product in this field is the containerized Potable Drinking
Water Plant which is flexible as it is modular and easy to install and operate. It delivers a capacity of up to 15000 m3 drinking water per day and augment the needs of 30,000 to 75,000 people.

Specially for the requirement of the African and Middle East market we developed a system for advanced potable water treatment. The equipment will be supplied as package units (containerized) and mounted in short time with minimum civil works. At the site there is only need for piping and some cabling.

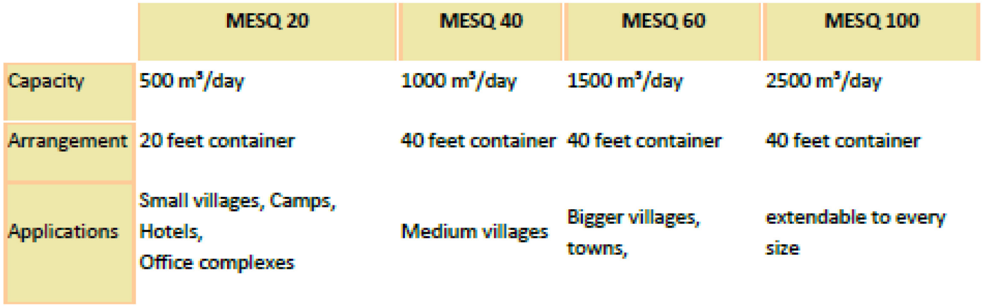
For town locations it is possible to give the treated drinking water to an existing network. In rural areas it is supposed to provide the water with potable water stations for quick realisation. Even in connection with a public sanitary station.

In future if a network is established, the water can be supplied using the same treatment plant. Also the plant is easy to extend with additional units or movable to new location.

The plant design is based on our experience as manufacturer and operator to match these conditions:

- low investment cost
- quick realization
- huge flexibility
- low running cost
- easy operation and maintenance
- long life time

Plant data:



	MESQ 20	MESQ 40	MESQ 60	MESQ 100
Capacity	500 m^3/day	1000 m^3/day	1500 m^3/day	2500 m^3/day
Arrangement	20 feet container	40 feet container	40 feet container	40 feet container
Applications	Small villages, Camps, Hotels, Office complexes	Medium villages	Bigger villages, towns,	extendable to every size

other sizes on request

12.1.7 **PACT**

www.pactchina.com

Package (Compact) Water Treatment Plant

PACT compact water treatment units are supplied to smaller communities and camps that have no access to a central water treatment facility. The units are normally installed along a surface water source (river or lake). The units are factory built in coated mild steel construction ready to install upon delivery to the site. The PACT water treatment units have been designed in the shape of standard ISO containers convenient for shipping and easy to install. Standard capacities range from 5-200 m3/h. Multiples of those units are normally used for larger installations.

The PACT Package Water Treatment Plants comprise of The Following Components

- Raw water intake pumps
- Chemical metering systems for disinfection and coagulation
- Flash mix and flocculation tank
- Clarifier (settling) tank
- Intermediate (filter feed) tank
- Filter feed (with Hydrophore pressure control system) and backwash pumps
- Blowers for sand filter air-scour
- Pressure type sand filters (manual or automatic backwash)
- RO unit (Skid mounted)
- Interconnecting piping, wiring and cables
- Stairs, walkways and hand-rails

- Motor control center

Advantages of the PACT Package Water Treatment Plant:
- Fast ex-works delivery, ideal for emergency water demand
- Coating and paint to suite installation location (marine-coating for seashore sites)
- Components are from internationally recognized manufacturers (fast access to spares)
- Rugged construction built for outdoor installation
- Comprehensive and easy-to-follow installation and operation instruction
- Installation supervision service is available for worldwide locations

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12.1.8 **Lenntech**

www.lentech.com

Water Treatment Plant Containerization.

Lenntech supplies any water treatment in a containerizable version with various available options based on:

Plant size, Accessibility requirements, Site temperature, ATEX zone requirements

Containerization of a water treatment plant does not only include the supply of a container, it includes the complete installation of the plant:

- Connected piping between equipment pumps, vessels, skids, tanks
- Cabling and wiring of pumps and instrumentation inside the container to main control cabinet. Ozone, UV and chloride dioxide as oxidizing biocide possible disinfection methods.

Read more: http://www.lenntech.com/container/container.htm#ixzz2Kyn13yvU

12.1.9 **Danpure**

www.danpure.dk

Reverse osmosis with UV disinfection – very compact units. Price up to 140.000 Dkr (incl. VAT) for the biggest plant; 44400 l/day

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12.1.10 **Best Water Technologies (BWT)**

www.bwt.dk (former HOH)

Beredsskabsstyrelsens plants are from HOH. Reverse osmosis with UV disinfection – very compact units, euro pallet size. Can also desalinate. Capacity: 100-1000 l/hour. Weight: 175-195 kg (can be transported by helicopter).

12.1.11 **Silhorko**

http://www.silhorko.dk/produkter/vandbehandling_i_container.aspx

Container has following units (among others): active carbon filter, pressure filter, softner, double pass reverse osmosis.

12.1.12 **Guldager**

www.guldager.com

Guldagers reverse osmosis (RO) units are intended for desalination of sea water for the reliable supply of potable and technical water for offshore and marine installations.

The water makers are plug and play skid based RO units and require little or no maintenance once installed. Available with all necessary pretreatment, filtration, chlorination and dechlorination before the RO membrane unit and post treatment with e.g. UV, chlorination, rehardening with dolomite, pH control, and distribution pump system.

Water quality according to WHO, national or company standards. Available in all capacities with optional redundancy.

12.1.13 **AEROMIX**

www.aeromix.com

AEROMIX COMPACT WATER TREATMENT Systems offer complete skid mounted or containerized solu-tions for the production of drinking or process water. Typical systems include coagulation and flocculation lamella plates settling, sand and activated carbon filtration, polishing 5 or 10 micro cartridge filters, followed by chlorination or UV. Treated water quality meets WHO (World Health Organization) standards. Totally automated plant operation is achieved with state-of-the-art control systems designed for outdoor installations. Standard systems available to supply drinking water for populations from 100 to 25,000 people. Meets WHO (World Health Organization) standards.

12.1.14 **Imagua Water Technologies**

http://en.imagua.es/pages/index/compact-water-treatment-plants

IMAGUA Water Technologies manufactures compact water treatment plants, designed in containerised treatment modules, easy to transport and install and with a very simple maintenance.

These equipments are a good solution for urgent water supply needs, for water supply to locations with different access or economic problems or for provisional works locations.

IWT manufactures standard models, offering a maximum quality and optimised cost, of the following capacities 5, 25, 50, 100, and 200 m3/ h.

Assuming a water daily consumption per day of 240l/person day, the following table indicates the technical characteristics of IWT compact water treatment plants:

Technical Characteristics	**WTP 5 m^3/h**	**WTP 25 m^3/h**	**WTP 50 m^3/h**	**WTP 100 m^3/h**	**WTP 200 m^3/h**
Population	500	2500	5000	10000	20000
Number of Containers	1	2	3	4	5

12.1.15 **Ciemsa**

http://www.ciemsa.com.uy/gxportal/archivos/IBC/+%20Brochure_%20EPAs_IBC.pdf

Meets WHO standards. Solar power an option.

12.1.16 **Hitachi**

http://www.hitachi-pt.com/products/es/water/cleanwater/package.html

These drinking water treatment devices are compact, use large-scale drinking water treatment systems (flocculation, sedimentation, sand filtration), and can easily supply drinking water through automatic operation.

12.1.17 **Degremont Technologies**

http://www.degremont-technologies.com

Chloride gas and UV disinfection.

12.1.18 **Meckow**

http://www.meckow-international.com/epa20.php

Utilizing conventional water treatment processes, the MECKOW EPA20 can produce up to 20,000 litres per hour of potable water, eliminating diseases and supplying clean, safe drinking water.
The unassembled MECKOW EPA20 and all of its components fit inside a 40ft container making shipment time short and efficient. Installation is quick and simple and as the unit requires no specialist technical knowledge, once installation and training are complete, the day to day running of the plant is passed over to the community thus encouraging local involvement.

Produces a constant supply of safe drinking water - sufficient for villages or small town. May be used to increase current supply. Compact in design, complete system is shipped in one 12 meter container and has a low requirement for electrical power. Can be easily transported, installed and maintained at low cost, requiring minimal training to operate and maintain. Withstands the extremes of the elements and successive relocation, by being strongly made from materials which ensure a satisfactory working life.

Typical Applications
- Villages and Small Towns
- To increase existing system Refugee Camps
- Construction Sites
- Military Deployments

Technology
Coagulation (Rapid mixing), Hydraulic flocculation, Sedimentation, Rapid filtration, Dosing system: Chemi-cals used in the treatment process are metallic coagulants (like aluminum sulphate, ferric chloride, etc), alkalinity regulators and disinfectants.

12.1.19 **Africa-Trade.ci**

http://www.africa-trade.ci/america/potable-water-treatment-plants/

Models	AS-10-A	AS-10-X	AS-20-A	AS-30-A	AS-50-A
Nominal flow (l/h)	2000	2000	4000	6000	10 000
Nominal depth to water (m)	30	30	30	30	30
Available pressure (kPa)	140-200	140-200	140-200	140-200	140-200
Alternative energy sources	-	Yes	-	-	-
Voltage	120 VAC 60 Hz	120 VAC 60 Hz	230 VAC 50/60 Hz	230 VAC 50/60 Hz	230 VAC 50/60 Hz
Power consumption (W)	1600	1600	3000	4300	6700
Shipping weight (kg)	300	400	525	640	800
Number of modules	1	1	2	2	2
Frame material	Aluminum*	Aluminum*	Aluminum*	Aluminum*	Aluminum*
Total floor area (m2)	2.41	2.41	4.72	5.24	7.10

*316 Stainless steel construction available on request Made in Canada

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AND SEVERAL OTHERS
http://www.alibaba.com/showroom/mobile-water-treatment-plant.html
list also with prices.

KOMBITEK

Limitations in drinking water resources is a major problem worldwide, particularly in arid areas. One solution for obtaining drinking water is to purify surface water to drinking water quality. The problem with current solutions for this purpose is that they either produce water in too small amounts, require bigger installations and secure infrastructure, are too expensive, or require considerable expertise to work optimally. This report describes the development of a water treatment system with a compact size and which only requirement is a power supply, making it ideal for emergency situations.
The water treatment plant consists of a flocculation tank, a filtering unit, and an advanced oxidation unit. Different secondary filtering units was also tested in the plant development, but it was found that they needed to be changed too often for field applications. In the flocculation unit, electrocoagulation was accomplished by using electrical current to generate free iron that reacts with the fine particulate material in the water. The process creates flocculates and helps to remove suspended solids to sub-micrometre levels, breaks emulsions such as oil and grease or latex, removes phosphate and lowers the particle concentration without the use of filters or the addition of separation chemicals. The filtering unit in the plant, developed by BIO-AQUA A/S, is based on flexible polymer threads, which allows for back-flushing. The advanced oxidation unit, developed by Adept Water Technologies, is based on electrolysis principles that uses naturally occurring chloride in the water, to produce a residual dis-infective effect.

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www.mst.dk