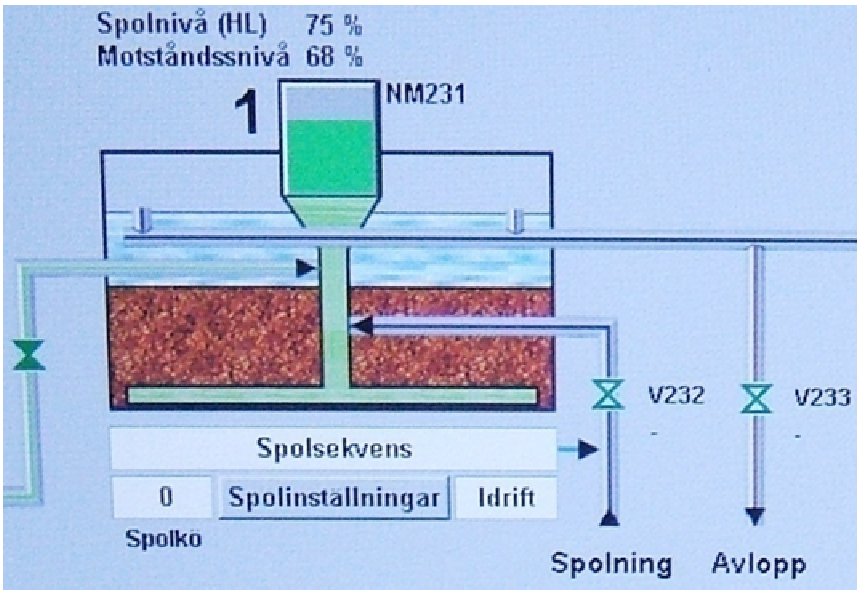
Rosfilter

Verification report

Coagulation and direct filtration for treatment of surface water



WATER • ENVIRONMENT • HEALTH

Ingenjörsfirma Ros AB
May 2010

Rosfilter

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CONTENTS

APPENDICES

1 INTRODUCTION

Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application, under defined conditions and quality assurance.

1.1 Name of product

Rosfilter is a combination of coagulation and direct filtration, used as part of a process chain for the production of drinking water from surface water.

1.2 Name and contact of vendor

Ingenjörsfirma Ros AB, Insjövägen 13, 79333 Leksand, Sweden.
Phone +46 247 64470

Contact: Lars Niklasson, email: lars@ros.se, phone +46 247 64470

Web site: www.ros.se

1.3 Name of centre/verification responsible

The Danish Centre for Verification of Climate and Environmental Technologies, (DANETV), DHI DANETV Water Center, DHI, Agern Allé 5, DK-2970 Hørsholm, Denmark.

Verification responsible: Mette Tjener Andersson, e-mail mta@dhigroup.com,
phone +45 4516 9148

Test responsible: Gerald Heinicke, e-mail ghe@dhigroup.com, phone +45 4516 9268.

1.4 Verification and test organization

The verification was conducted by the Danish Centre for Verification of Climate and Environmental Technologies, DANETV, which performs independent tests of technologies and products for the reduction of climate changes and pollution.

The verification is planned and conducted to satisfy the requirements of the ETV scheme currently being established by the European Union (EU ETV).

The day to day operations of the verification and tests were coordinated and supervised by DHI personnel, with the participation of the vendor, Ingenjörsfirma Ros. The testing was conducted at Lilla Edet water works, Lilla Edet, Sweden. The technical staff at Lilla Edet water works operated the Rosfilter pilot plant during the verification, supervised by DHI. Ingenjörsfirma Ros provided a containerised Rosfilter pilot plant, and installed it at the test site. Lilla Edet water works gave the Test centre access to their raw water and to their on-line measurements. Furthermore, Ingenjörsfirma Ros provided information on the product and operation instructions, and will participated in the development of protocol and plans with DHI.

An internal and an external expert were assigned to provide independent expert review of the planning, conducting and reporting of the verification and tests.

The organization chart in Figure 1-1 identifies the relationships of the organization associated with this verification and tests.

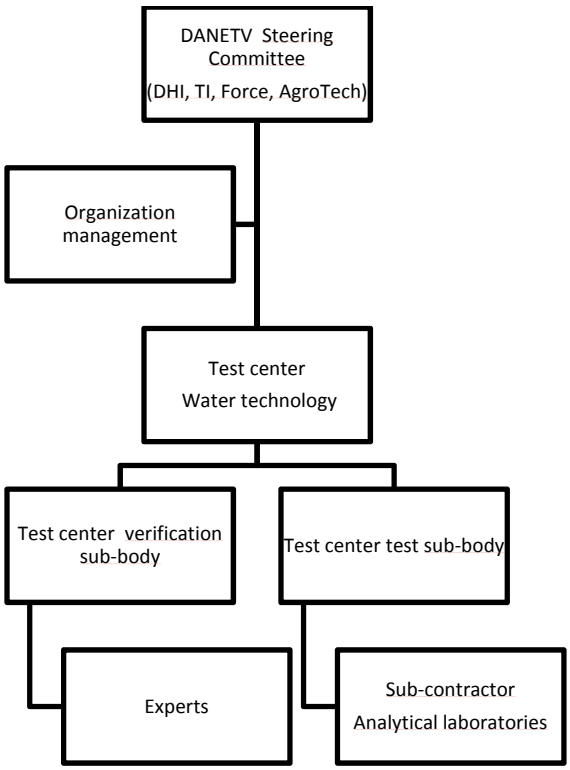

Figure 1-1 Organization of the verification and tests.

1.5 Technical experts

External technical expert to review the verification protocol and verification report, as well as the test plan and testreport:

Prof. John Tobiason, University of Massachusetts Amherst, e-mail: tobiason@ecs.umass.edu, phone +1 413 545 5397.

Internal technical expert was Morten Møller Klausen, Urban and Industry department, DHI, e-mail: mmk@dhigroup.com, phone +45 8620 5114.

1.6 Verification process

The principles of operation with the role of the verification and test documents and the different sub-bodies responsible are given in Figure 1-2. The Technical expert QA covers the review of planning and reporting documents. Audit was performed internally by DHI. Reference for the verification process is the Quality Manual for the ETV operations at DHI following the DANETV Centre Quality Manual – Water Technology /1/.

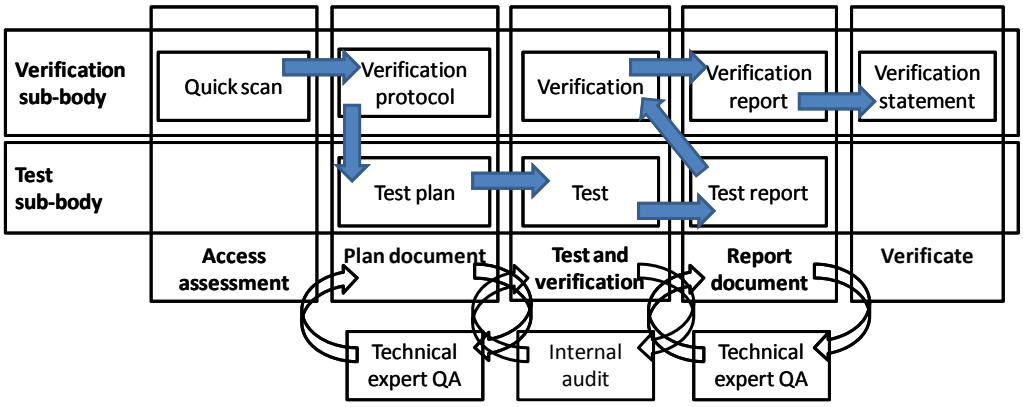

Figure 1-2 Principles of operation of the DANETV verification scheme

A verification statement will issued by DANETV after completion of the verification. The final verification report and the test report shall be seen as one consolidated verification description.

2 DESCRIPTION OF THE TECHNOLOGY

Rosfilter is a process combination of coagulation and direct filtration, developed and marketed by Ingenjörsfirma Ros, Leksand, Sweden. Coagulation neutralizes the repelling forces between particles and negatively charged organic molecules, thereby destabilizing them. Flocs are formed that subsequently can be removed by filtration. In coagulation/direct filtration, the water passes a media filter shortly after addition of the coagulant. Coagulation with direct filtration is generally chosen because of its smaller footprint compared to conventional treatment, which includes flocculation tanks and sedimentation or flotation tanks.

3 DESCRIPTION OF THE PRODUCT

3.1 Rosfilter

After addition of the coagulant, the water enters a contact tank, and then passes an up-flow filter loaded with a multi-media bed. The filter bed consists of coarse fractions in the bottom (1 m in height), and of 2.5 m fine sand. The filter is normally cleaned when a headloss set point is reached, alternatively after a fixed number of hours. As Rosfilter applies upflow filtration, the backwash is done by forward washing, *i.e.* with a flow in the same direction as the feed flow, at a rate high enough to expand (fluidize) the bed of fine sand. In the following, the cleaning procedure is nevertheless referred to as *back-wash*.

The filters normally consist of stainless steel columns in diameters from 1000 to 2500 mm, with a design production of 78 to 540 m^3 per day at 22 hours of operation per day (information from vendor, see appendix 9 in test plan /2/). Filters up to 2700 mm diameters are available on request. For larger flows, multiple filters are installed, and the feed water flow divided by a weir box.

Rosfilters use polyaluminium coagulants of different brands. Changes in the coagulant dosage is not automated, but taken by the operator when changes in raw water quality occur.

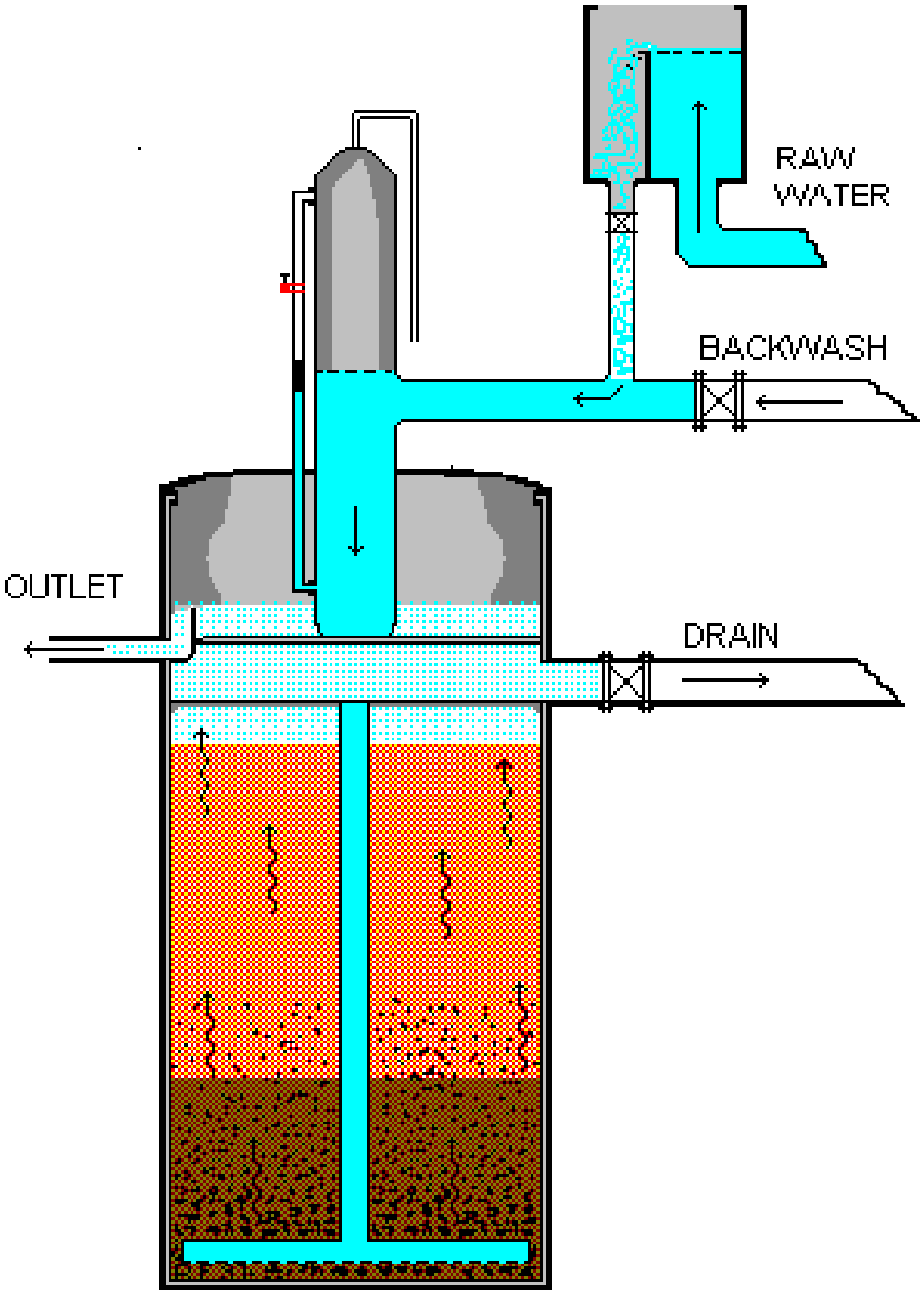

Figure 3-1 Schematic drawing of a Rosfilter (information from vendor, see appendix 7 in test plan /2/).

Rosfilters have been in full-scale operation since 1978 as an alternative to conventional treatment. They are installed in more than ten municipal water works in Sweden, with a design capacity of up to 6500 m^3/d. With each full-scale plant, a specific user manual is delivered.

4 APPLICATION AND PERFORMANCE PARAMETER DEFINITIONS

The application is defined as detailed in appendix 3 in terms of matrices, targets and effects.

4.1 Application definition

Rosfilter is a combination of coagulation and direct filtration, used as part of a process chain for the production of drinking water. They are predominantly used for the treatment of surface water. For this verification, the matrix was surface water from river Göta älv, as abstracted by the municipal water works at Lilla Edet, Sweden. Targets were the water quality parameters listed in Table 4-1.

Table 4-1 Target parameters.

Particles	NOM	Chemical parameters	Microbial parameters
Turbidity (NTU)	Colour	Aluminium	Coliforms
	TOC		Enterococci
	COD_{Mn}		HPC $_{3\text{-d, }22°C}$
	UV_{254}		

The main effect of the application evaluated was the water quality produced. The performance was also reported as removal of target parameters, as well as operational parameters. The vendor had no specific performance claim other than that Rosfilter fulfils (Swedish) drinking water standards and produces a water of low turbidity, with a particle removal comparable to conventional treatment.

4.2 Performance parameters for verification

Performance parameters were defined that describe the treated water quality, the removal of specific water quality parameters and the operational performance of Rosfilters (Table 4-2). A detailed description is found in Appendix 3.

Table 4-2 Performance parameters for coagulation and filtration processes for the production of drinking water. The criterion is related to the Swedish drinking water regulation /3, 4/.

Parameter	Unit	Definition	Criterion
Particles			
Turbidity from matured filter	NTU	Percentage of values in turbidity range <0.1, 0.11-0.2, 0.21-0.34, 0.35-0.5, >0.5	<0.5 Recommended <0.2 and lower, stated that <0.1 often is achievable.
Initial turbidity	NTU	Filtered turbidity at 20 minutes into run	No criterion. Indication of how long filter to drain is necessary.
Length of initial improvement period	minutes	Time to reach 0.5 NTU Time to reach 0.2 NTU Time to reach 0.1 NTU (if applicable)	No criterion. Indication of how long filter to drain is necessary.
Natural Organic Matter (NOM)			
Colour	mg Pt /l	Average in treated water Average removal (%) Percentage of samples not below 15 Percentage of samples not below 5	<15, recommended <5
TOC	mg/l	Average in treated water Average removal (%)	Alternative measurement to COD_{Mn}. No criterion. Removal is indication of treatment efficacy.
COD_{Mn}	mg/l	Average in treated water Average removal (%) Percentage of samples not below 4	<4
UV_{254}	1/m	Average in treated water Average removal (%)	No criterion. Removal is indication of treatment efficacy.
Chemical parameters			
Aluminium	mg/l	Average in treated water Percentage of samples not below 0.1	<0.1
Microbial parameters			
HPC $_{3\text{-d, }22°C}$	no./ ml	Average in treated water Average log_{10} removal Percentage of samples not below 100	< 10 at water works after disinfection, < 100 at consumer's tap Removal is indication of treatment efficacy.
Removal of coliform bacteria	no./100 ml	Percentage of detects Average log_{10} removal	<10 at works and at tap
Removal of enterococci	no./100 ml	Percentage of detects Average log_{10} removal	Not detected
Operational			
Backwash water loss	%	Ratio of feed water used for filter backwash	No criterion. Indication of operational performance
First filtrate water loss	%	Ratio of feed water used until <0.2 NTU.	No criterion. Indication of operational performance
Time to reach turbidity breakthrough	hours	Time to reach turbidity >0.50 NTU	No criterion. Indication of operational performance
Time to reach terminal head loss	hours	Time to reach vendor-specified head loss	No criterion. Indication of operational performance

4.3 Additional parameters

Additional parameters such as product costs, user manual, as well as occupational health and environmental impact were not included in the verification.

5 EXISTING DATA

5.1 Summary of existing data

The vendor has provided data from the recent operation of its pilot plant on raw water with high concentrations of particles and NOM (Table 5-1).

Table 5-1 Results of a pilot filter test run with raw water from River Lidån, Sweden. Sampling date 14 March 2007. The analysis was performed by an accredited laboratory.

Parameter	Method	Raw water	Filtrate
Turbidity (FNU)	former SS 028125-2	24.5	0.13
Colour at 405 nm	SS EN ISO 7887:3, modified	120	7
COD_{Mn} (mg/l)	former SS 028118-1, modified	16	4.3
Aluminium (mg/l)	ICP-AES	1.4	0.034

The vendor also provided data from an application of Rosfilters for the removal of low-level turbidity from groundwater.

There is also performance data from the water works that have full-scale Rosfilters installed. This data is not centrally collected. The water works are subject to a monitoring programme regulated by the Swedish drinking water directive /3/, and approved by the responsible local health authority. Furthermore, inspections are carried out by the Swedish national food authority, *Livsmedelsverket*. Data from full-scale waterworks with Rosfilters was not collected for this verification.

The pilot plant was set up late in 2009, before the activities had to be stopped due a fierce onset of winter. During the initial operation, the operator took samples for physical-chemical samples and sent them for analysis to ALcontrol laboratories Table 5-2. At that time, the raw water was affected by a storm event.

Table 5-2 Results of a sample taken during the initial operation on 9 December. 2009, at Lilla Edet.

Parameter	Method	Raw water	Filtrate
Turbidity (FNU)	SS-EN ISO 7027, edition 1	41	0.3
Colour at 405 nm	SS EN ISO 7887:3, modified	25	<5
COD_{Mn} (mg/l)	former SS 028118-1, modified	7.6	2.5
Aluminium (mg/l)	ICP-AES	1.1	<0.02

5.2 Quality of existing data

The test reported in 5.1 with raw water from River Lidan is relevant for this verification, *i.e.* surface water with high NOM and particle load, at low temperature (ice on the water, see photo on title page). The chemical analyses were performed by an accredited laboratory. The pilot test was not done by an independent organisation, and without formal QA.

The sampling occasion during initial operation at the Lilla Edet test site was done in a similar way as the sampling during verification testing. Full documentation of the operating conditions at that time is lacking. Only physical-chemical parameters were analysed in one grab sample of raw water and filtrate. The on-line measurements have not been logged at that time.

5.3 Accepted existing data

The existing data from the test with water from River Lidan cannot be accepted for verification, but was used in the preparation of the test plan.

The result of one grab sample during initial operation at the Lilla Edet test site is accepted as an indication of what filtrate quality the Rosfilter can achieve during periods of high turbidity in the raw water.

6 TEST PLAN REQUIREMENTS

Based upon the application and performance parameter identification section 5.4 the requirements for the test design have been set. The detailed test plan is prepared separately based upon the specification of the test requirements presented below.

6.1 Test design

The test design was partly based on the EPA/NSF ETV Equipment Verification Testing Plan - Coagulation and filtration for the removal of microbiological and particulate contaminants /5/.

The outline of the required tests is shown in Table 4-1Table 6-1. The principle behind the test design is that the following four overall tasks are carried out:

1. Characterization of the test site
2. Initial operational runs
3. Verification testing
4. Documentation

Table 6-1 Test design of the verification.

Characterization of test site 1	**Initial operation runs of pilot plant 2**	**Verification testing during 14 days 3**	**Documentation of verification 4**
• Acquisition and presentation of historical data on raw water quality. • Description of test site and description of the equipment tested.	• Operational conditions. • Backwash. • Maximum headloss allowed. • Setup of measurement and logging of data online.	Task 3a Verification testing runs. Task 3b Evaluation of water quality before and after treatment. On-line measurement and external analyses.	• Data management. • Data quality.

6.1.1 Task 1 Characterisation of the test site

Objectives
The objective of this task was to describe the test site and to obtain preliminary information about the feed water quality, relevant for the operation of the Rosfilter units.

Work plan
The initial characterization of the test site consisted of three tasks:

- Characterization based on historical data of raw water quality,
- Additional analysis (not necessary in this case),
- Description of the test site.

6.1.2 Task 2: Initial operation runs of the pilot plant

Objective
The objective of the initial runs is to find optimum operational conditions for the Rosfilter pilot plant, and to test both the pilot plant and the online measurement and data logging equipment, to avoid technical problems during the verification testing.

Work Plan
During the initial operation runs, the tasks comprise:

- Identification of optimum coagulant dose that minimises filtrate turbidity while keeping residual aluminium at an acceptable level[1].
- Adjustment of the backwash flow and backwash time.
- Identification of the maximum allowable headloss in the pilot plant to avoid backwash problems.
- Testing of the on-line measurements, of data logging and data communication.

6.1.3 Task 3: Verification testing of treatment performance regarding produced water and operational conditions

Objectives
The objective of this task was to evaluate the treatment performance as removal of naturally occurring particles, microorganisms and NOM. Also, operational parameters were monitored.

Work plan
The verification test was conducted over a 14-day period, including at least three full filter runs. A filter run was terminated either by reaching the maximum allowable head loss or the breakthrough of particles (turbidity).

The work plan comprised two sub-tasks tasks:

Task 3a: Verification testing runs
Task 3b: Analysis of feed water and finished water quality

Task 3a: Verification testing runs
The pilot plant was operated under pre-defined conditions so that the operational performance parameters could be determined and evaluated.

Task 3b Evaluation of finished water quality
In this task, grab samples were taken and sent for analysis, while data from on-line parameters were logged and transferred to a remote computer.

6.1.4 Task 4: Documentation of verification and operational conditions

Objectives
The objective was to establish the protocol for the management of all data produced during testing.

[1] The coagulant dose affects pH, which in turn affects the concentration of residual aluminium.

Work Plan
Deviations from the stated operation conditions (filtration rate, designated coagulant dosage, backwash conditions) were documented in the field log book. Only filter cycles were included in the evaluation if the operation conditions differed less than 10% during more than 70% of the filter run. Filter cycles during which there was temporary stop in coagulant dosing were excluded from the evaluation of filter cycle length.

6.2 Analytical methods

The analytical methods consisted of on-line measurements at the test site (Table 6-2), and of methods for the analysis of grab samples sent to the external analytical laboratories.

Table 6-2 Analytical methods.

On-line measurements	Grab samples
Flow	COD_{Mn}
Filter head loss	Colour
Turbidity	Alkalinity
pH	TOC
Conductivity	Coliforms
UV_{254}-absorption	Enterococci
Temperature	HPC $_{3\text{-d, }22°C}$
	Aluminium

6.3 Data management

Data storage, transfer and control were done in accordance with the requirements of Centre Quality Manual enabling full control and retrieval of documents and records. The filing and archiving requirements of the DHI Quality Manual will be followed (10 years archiving).

Data from the on-line measurements were stored in a data-logger and retrieved by the test personnel via GSM modem. The data was then transferred to Excel files and evaluated there.

6.4 Quality assurance

The quality assurance of the tests included control of the test system (here: Rosfilter pilot plant), the on-line measurement equipment, and control of the data quality and integrity. The test plan and the test report were subject to review by an internal and an external expert as part of the review of this verification protocol and the verification report.

6.5 Test report

The test report follows the principles of template of the Centre Quality Manual with data and records from the tests presented.

7 EVALUATION

The evaluation of the test results focused on the performance parameters. The efficacy of coagulation/filtration processes for particle and NOM removal depends, among other parameters, on coagulant dose and coagulation pH. These parameters are stated in the test report /2/.

7.1 Calculation of performance parameters

Calculations were done according to generally accepted statistical principles. For all-parameter (grab samples and on-line data), minimum, average and maximum values are stated. Turbidity results were stated as the ratio of values falling into a specific range. For parameters measured on-line, the dataset was first investigated for each filter run. , and averages calculated for raw water and filtrate. Data of on-line parameters was stated from all filter runs that fulfilled the criteria stated in section 6.1.4.

The removal of microbial indicators was presented as $\log_{10}$-removal[2]. In case of non-detects occurring, the removal were expressed as at least as much as achieving the detection limit. Furthermore, the data was presented as the ratio of samples in which the indicator was detected.

7.2 Performance parameter summary

In Table 7-1 the performance parameters for the verification of Rosfilters are stated as averages and should be presented in the verification statement.

Information on ranges, number of grab samples and filter runs included in the evaluation are stated in the test report /2/. Generally, the variation in filtrate quality was low. The span between average turbidity over a filter cycle was 0.07 to 0.10 NTU, while the span for UV-absorbance was 2.6 to 4.7 (1/m). For comparison, the highest one-minute turbidity value from a mature filter was 0.134 NTU. The concentration of bacteria varied in the raw water, but was below detection limit or at very low concentration in the filtrate.

Filtrate from the mature filter consistently fulfilled the criteria of the Swedish drinking water regulations /3/ for the parameters included in this verification, stated in Table 4-2. When judging performance, it should be noted that the test system was operated at its maximum filtration rate. Also the operational conditions should be included in the verification statement, from table 3-2 in the test report /2/.

During verification testing, the raw water had low turbidity, 1.7 to 3.7 NTU as average over a filter cycle. The result of one grab sample taken during the initial operation indicates that the pilot plant may fulfil the Swedish drinking water regulation's criteria for turbidity and COD_{Mn} also during periods of high raw water turbidity (Table 5-2).

[2] The reduction of microbial parameters over water treatment processes is often expressed in logarithmic terms. Regulations on microbial barriers often require high removals, which may appear abstract to the reader if expressed as per cent. Example: 4-$\log_{10}$ removal = 99.99% removal.

Table 7-1 Quantification of performance parameters (averages). n.d. = no data. No breakthrough was detected in any of the filter cycles.

Parameter	Unit	Definition	Value
Particles			
Turbidity from matured filter (NTU) Percentage of values in turbidity range.	%	0.10 NTU or lower 0.11-0.2 NTU 0.21-0.34 NTU 0.35-0.5 NTU >0.5 NTU	94.4 5.6 0 0 0
Initial turbidity	NTU	Filtrate turbidity 20 min into run	1.7
Length of initial improvement period	minutes	Time to reach 0.5 NTU Time to reach 0.2 NTU Time to reach 0.1 NTU	39 52 72
Natural Organic Matter (NOM)			
Colour	mg Pt /l	Average in treated water Average removal (%) Percentage of samples not below 15 Percentage of samples not below 5	<5 >76% 0% 0%
TOC	mg/l	Average in treated water Average removal (%)	2.8 44%
COD_{Mn}	mg/l	Average in treated water Average removal (%) Percentage of samples not below 4	1.3 69% 0%
UV_{254}	1/m	Average in treated water Average removal (%)	3.6 71%
Chemical parameters			
Aluminium	mg/l	Average in treated water Percentage of samples not below 0.1	0.016 0%
Microbial parameters			
HPC $_{3\text{-day, }22°C}$	no./ ml	Average in treated water Percentage of samples not below 100 Average log_{10} removal	<1 0% >2.3
Removal of coliform bacteria	no./100 ml	Percentage of detects Average log_{10} removal	0% >2.4
Removal of enterococci	no./100 ml	Percentage of detects Average log_{10} removal	0% >1.4
Operational			
Backwash water loss	%	Ratio of feed water used for filter backwash	8.1%
First filtrate water loss	%	Ratio of feed water used until <0.2 NTU.	5.3%
Time to reach turbidity breakthrough	hours	Time to reach turbidity >0.50 NTU	n.d.
Time to reach terminal head loss	hours	Time to reach vendor-specified head loss	17

7.3 Evaluation of test data quality

The information of the test report, the test system and data quality and integrity control were evaluated against the requirements set in this protocol and the objectives set in the test plan.

The spreadsheet used for the calculations was subject to control on a sample basis (spot validation of at least 5% of the data).

7.4 Compilation of additional parameters

Additional parameters were not included in the verification.

8 VERIFICATION SCHEDULE

The verification is planned for April 2010. The overall schedule is given in Table 8-1.

Table 8-1 Verification schedule.

Task	**Timing**
Verification protocol with test plan	November 2009 to January 2010
Test	2 weeks from 14/4 2010
Test reporting	April to May 2010
Verification	May 2010
Verification report	May 2010
Report document review	May 2010
Verification statement	May 2010

9 QUALITY ASSURANCE

The quality assurance of the verification was done by Table 9-1, and the quality assurance of the tests in the test plan.

Table 9-1 QA plan for the verification. MMK = Morten Møller Klausen; BZ = Bengt Zagerholm.

	DHI		**External expert**
Initials	**MMK**	**BZ**	**Prof. John Tobiason**
Tasks			
Plan document with application definition, verification protocol and test plan	Review		Review
Test system at test site		Audit	
Report document with test report and verification report	Review		Review

Reviews were prepared using the DANETV review report template.

A P P E N D I X 1

Terms and definitions used in the verification protocol

The abbreviations and definitions used in the verification protocol and the test plan are summarized below.

Word	**Meaning**
Application	The use of a product specified with respect to matrix, target, effect and limitations
Absorbance	The decrease in light intensity passing through a water sample
Coagulation and direct filtration	Combination of coagulation and media filtration, without flocculation and settling tanks. Swedish expression: *kontaktfiltrering*
Coagulation and filtration	Term that includes both Coagulation/direct filtration and Conventional treatment
COD	Chemical Oxygen Demand
COD_{Mn}	COD measured by oxidation of the sample with permanganate
Conventional treatment	Combination of coagulation, flocculation, settling and media filtration
DOC	Dissolved Organic Carbon. TOC measured on a filtered sample.
Effect	The way the target is affected
EN	European standard
Experts	Independent persons qualified on a technology in verification or on verification as a process
$HPC_{3\text{-day, }22°C}$	Heterotrophic plate count, for three days at 22°C. An indicator of water's general bacteriological quality
ISO	International Standardization Organization
Limit of detection LoD	Calculated from the standard deviation of replicate measurements at less than 5 times the detection limit evaluated. Corresponding to less than 5% risk of false blanks
Log_{10}-removal	The removal of a particulate or microbial contaminant expressed in logarithmic terms: $Log_{10}\text{-removal} = -\log_{10}(c_{filtrate} / c_{raw})$
Matrix	The type of material that the product is intended for
Method	Generic document that provides rules, guidelines or characteristics for tests or analysis
NOM	Natural Organic Matter
NTU	Nephelometric Turbidity
Performance claim	The effects foreseen by the vendor on the target (s) in the matrix of intended use
(Environmental) product	Ready to market or prototype stage product, process, system or service based upon an environmental technology
QA	Quality assurance
SS	Swedish Standard
Standard	Generic document established by consensus and approved by a recognized standardization body that provides rules, guidelines or characteristics for tests or analysis
Target	The property that is affected by the product
Test/testing	Determination of the performance of a product for parameters defined for the application
TOC	Total Organic Carbon
TVO	Thematic Verification Organisation
Vendor	The party delivering the product to the customer
Verification	Evaluation of product performance parameters for a specified application under defined conditions and adequate quality assurance

A P P E N D I X 2

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A P P E N D I X 3

Application and performance parameter definitions

This appendix defines the application and the relevant performance parameters application as input for verification and test of an environmental technology following the DANETV Programme.

1 Applications

The intended application of the product for verification is defined in terms of the matrix, the targets and the effects of the product.

Rosfilter is a combination of coagulation and direct filtration, used as part of a process chain for the production of drinking water.

1.1 Matrix/matrices

Rosfilters are predominantly used for the treatment of surface water. For this verification, the matrix is surface water from river Göta älv, as abstracted by the municipal water works at Lilla Edet, Sweden.

1.2 Target(s)

Coagulation followed by filtration removes suspended particles, colloids, natural organic matter and microorganisms from the raw water, and thus constitutes the main process for drinking water treatment in a water works that applies Rosfilters.

Particle removal is in this verification quantified by turbidity, measured as nephelometric turbidity units (NTU).

The removal of natural organic matter is in this verification quantified by the parameters Colour (mg/l Pt), total organic carbon (TOC, mg/l), chemical oxygen demand determined with permanganate oxidation (COD_{Mn}, mg/l), and absorption of UV light at 254 nm (UV_{254}, m^{-1}).

The coagulant residual is characterised by the total aluminium concentration in the treated water.

The general microbial water quality is characterised by the heterotrophic plate count, while the removal of indicator bacteria from the water is a quantitative measure of the microbial barrier against bacteria.

Appendix Table 1 Target parameters.

Particles	NOM	Chemical	Microbial parameters
Turbidity (NTU)	Colour	Aluminium	$HPC_{3\text{-}d,\ 22°C}$
	TOC		Coliforms
	COD_{Mn}		Enterococci
	UV_{254}		

1.3 Effects

The effects for the application are reported as removal of target parameters listed in Appendix Table 1.

The vendor has no specific performance claim other than that Rosfilter fulfils the stated drinking water standards in Sweden and the EU and produces a water of low turbidity and low organic matter concentration, comparable to conventional treatment.

1.4 Exclusions

This verification covers the performance of Rosfilters in a pilot plant at one site with raw water typical for Swedish surface waters.

Other raw waters such as ground waters, surface waters with very low or very high turbidity or surface waters during algae blooms are not covered by this verification.

The investigation of removal of microbial indicator organisms is limited to naturally occurring concentrations. No challenge tests were carried out.

The investigation of raw water variation from the given source is limited to the natural variation during the 2-week test period. No manipulation of the feed water quality was done during the test.

2 General performance requirements

In drinking water treatment, coagulation and filtration processes are used to chemically destabilize and physically remove particles and NOM from natural waters. In this context, microorganisms may be regarded particles.

For a water utility operating coagulation and filtration processes, it is essential that the process reliably produces water that fulfils the regulatory requirements. In most surface water works, coagulation and filtration are the only processes responsible for removal of particles and NOM, while the reduction of microbial concentration also is achieved by disinfection processes. However, if coagulation and filtration do not work optimally, also disinfection may be negatively affected.

2.1 Regulatory requirements

The formal performance requirements for the application are the drinking water standards issued by regulators. These are, for example, the EU drinking water directive and the member state's national drinking water regulations. The EU drinking water directive lists only a limited number of parameters, but demands that drinking water be "wholesome and clean". The World Health Organisation (WHO) also has published minimum requirements for drinking water quality.

The Swedish water quality standards for parameters relevant for this verification are summarized in Appendix Table 2.

Appendix Table 2 Selected parameters from the drinking water quality standards issued by the Swedish National Food Authority /3/.

Parameter	Limit	Sampling point	Type of limit
Turbidity (NTU)	0.5	at water works	Water above the limit is fit for consumption, but with remark[3]
Colour (mg/l Pt)	15	at water works	Water above the limit is fit for consumption, but with remark Recommended <5
COD_{Mn} (mg/l O_2)	4	at tap	Water above the limit is fit for consumption, but with remark
Al residual (mg/l)	0.1	at water works	Water above the limit is fit for consumption, but with remark
HPC $_{3\text{-d, }22°C}$ (per ml)	10 100	at water works, sampled after disinfection at tap	Water above the limit is fit for consumption, but with remark
Coliforms (in 100 ml)	10	at water works & at tap	Water above the limit is unfit for consumption
E. Coli (in 100 ml)	detected	at water works & at tap	Water above the limit is unfit for consumption
Enterococci (in 100 ml)	detected	at water works & at tap	Water above the limit is unfit for consumption

In the corresponding guidance document, it is recommended to keep turbidity in treated water as low as possible. The document claims that in most cases, it is possible to produce water with turbidity below 0.1. Turbidimeters for process monitoring should be able to detect changes of 0.1 NTU or less. Aluminium concentrations should be kept below 0.1 mg/l /4/.

As a general indicator of microbial water quality, the heterotrophic plate count (HPC) must be below 100 per ml. Indicator organisms for faecal contamination must be absent in 100 ml (*E. coli*, enterococci) or at very low concentration (coliforms) /4/.

The EU drinking water directive states parametric values for aluminium (0.2 mg/l) and oxygen demand (5 mg/l O_2), among others. Turbidity below 1 NTU is recommended in drinking water, measured at the water works /6/.

2.2 Application based needs

For water utilities operating coagulation/filtration processes, a number of characteristics are affecting the operational and economic feasibility of the process implemented. These are factors such as the amount of backwash water needed, the consumption of chemicals and electricity, the efficiency during adverse conditions such as low water temperature or algae blooms, the level of automatisation, general robustness, as well as the footprint for a given production capacity.

In practice, coagulation with direct filtration is an alternative to conventional treatment, achieving a smaller footprint through shorter retention times. In comparison to conventional treatment, lower removal efficiencies for particles and microorganisms have been reported /7/. In the US, direct filtration receives a lower cryptosporidium removal credit than conventional treatment /8/.

[3] It is expected that the water works investigate the cause of any remarks, and take the necessary measures to solve the underlying problem. In case of repeated remarks, the local health authority will demand a solution.

3 State of the art performance

Coagulation/filtration processes have been used worldwide for many decades, and have been extensively studied.

An USEPA/NSF ETV verification was done on coagulation and direct filtration for the production of drinking water /9/. The focus of the USEPA/NSF ETV verification protocol is the removal of particulate and microbial contaminants. There, also operational performance objectives for coagulation and filtration processed have been defined /3/. A selection of these is presented in Appendix Table 3.

The efficacy of coagulation/filtration processes for particle and NOM removal depends, among other parameters, on coagulant dose and coagulation pH. These issues should be included in the investigation.

Appendix Table 3 Selected examples of performance objectives stated in the EPA/NSF ETV Equipment verification testing plan /5/.

Characteristic	Definition	Criteria
Initial turbidity	Filtered turbidity at 15 minutes into run	0.5 NTU or less
Length of initial improvement period	Time to reach 0.2 NTU	0.5 hour or less.
Length of initial improvement period	Time to reach 0.1 NTU	1.0 hour or less
Operating turbidity	Turbidity from matured filter	0.10 NTU or less
All turbidity data	All data taken at equal, periodic time intervals from beginning to end of run	0.5 NTU or less in 95% of all turbidity samples analyzed or in all data from continuous turbidimeter at periodic time intervals
Time to reach turbidity break-through	Time to reach turbidity over 0.20 NTU	8 hours minimum
Time to reach terminal head loss	Time to reach 1.5 m increase in head loss	8 hours minimum

3.1 Removal of NOM

Coagulation and filtration is known to remove NOM by specific mechanisms. During charge neutralisation, negatively charged organic molecules form insoluble complexes with trivalent metal ions; a stoichiometric process that has been shown to take place at low aluminium or iron doses without hydroxide floc formation. At conventional coagulant doses, charge neutralisation is followed and superseded by sweep coagulation, resulting in the formation of hydroxide flocs to which organic molecules may adsorb, while colloids are entrapped during the process /10, 11/. Non-polar, *i.e.* uncharged and aromatic organic molecules are particularly prone to be removed by sweep coagulation, and thus make up the main part of the NOM removed by coagulation treatment /12/.

According to Edzwald *et al.* /13/, surface waters with a Specific UV absorption (SUVA) in the range of 2-4 l/(mg·m) are categorised as moderately humic *i.e*. contain a mixture of humic and non-humic NOM with varying hydrophobicity and molecular weight. Expected DOC removals by conventional treatment should then be in the range of 25-50% with aluminium sulphate coagulation.

The removal of NOM, measured as DOC, from nine Norwegian water works employing coagulation and filtration was 52% /14/.

3.2 Removal of particles and of indicator bacteria

The removal of turbidity by conventional treatment has been investigated in many studies. It is generally assumed that coagulation and filtration is able to achieve turbidities below 0.1 NTU /5, 13/.

The removal of microorganisms (indicators and pathogens) by coagulation and filtration was reviewed in the EU research program Microrisk. The range of bacteria removal by conventional treatment was 1.0 to 3.4 $\log_{10}$, with a median removal of 2.1 $\log_{10}$. For coagulation with direct filtration, the range was 0.8 to 3.3 $\log_{10}$, with a median removal of 1.5 $\log_{10}$ /7/.

4 Performance parameter definitions

The performance parameters (Appendix Table 4) shall be verified under pre-defined operational conditions stated in the test plan /2/ and it shall be documented during the verification that the product is operated according to the stated operational conditions. The choice of performance parameters is based on Swedish and EU drinking water regulations, the EPA/NSF ETV Equipment Verification Testing Plan, and application based needs.

Appendix Table 4 Performance parameters for coagulation and filtration processes.

Parameter	**Unit**	**Definition**
Particles		
Turbidity from matured filter	NTU	Percentage of values in turbidity range <0.1, 0.11-0.2, 0.21-0.34, 0.35-0.5, >0.5
Initial turbidity	NTU	Filtered turbidity at 15 minutes into run
Length of initial improvement period	minutes	Time to reach 0.5 NTU Time to reach 0.2 NTU Time to reach 0.1 NTU (if applicable)
Natural Organic Matter (NOM)		
Colour	mg Pt /l	Average in treated water Average removal (%) Percentage of samples not below 15 Percentage of samples not below 5
TOC	mg/l	Average in treated water Average removal (%)
COD_{Mn} (desired by vendor)	mg/l	Average in treated water Average removal (%) Percentage of samples not below 4
UV_{254}	1/m	Average in treated water Average removal (%)
Chemical parameters		
Aluminium	mg/l	Average in treated water Percentage of samples not below 0.1
Microbial parameters		
HPC $_{3\text{-d, }22°C}$	no./ ml	Average in treated water Average removal (%) Percentage of samples not below 100
Removal of coliform bacteria	no./100 ml	Percentage of detects Average log_{10} removal
Removal of enterococci	no./100 ml	Percentage of detects Average log_{10} removal
Operational		
Backwash water loss	%	Ratio of feed water used for filter backwash
First filtrate water loss	%	Ratio of feed water used until <0.2 NTU
Time to reach turbidity breakthrough	hours	Time to reach turbidity >0.50 NTU
Time to reach terminal head loss	hours	Time to reach vendor-specified head loss