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Benchmarking of flue gas condensate cleaning technologies in waste-to-energy plants

Barbara Goldschmidt, Henrik Olsson, Helen Carlström

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VÄRMETEKNISK FORSKNING OCH UTVECKLING

Benchmarking of flue gas condensate cleaning technologies in waste-to-energy plants

Teknikval vid rening av rökgaskondensat i avfallsförbränningsanläggningar

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M08-835

VÄRMEFORSK Service AB
101 53 STOCKHOLM · Tel 08-677 25 80
Juni 2011
ISSN 1653-1248

Abstract

A benchmarking study on operational experience from six Swedish and Danish WtE plants, using different flue gas condensate cleaning technologies, is presented in the report. Alternative combinations of precipitation, filtration, membranes, ion-exchange, ammonia stripping, etc are discussed for the cleaning of waste waters and flue gas condensates from WtE plants with different types of flue gas treatment technologies. Yearly costs are presented for a number of flue gas condensate cleaning concepts. Recommendations are made for WtE plants with different waste water and flue gas condensate qualities.

Sammanfattning

Vid avfallsförbränningsanläggningar kan man idag välja mellan ett antal olika tekniker för att rena avloppsvatten från rökgasrenings- och kondenseringssteg. Förutom konventionell vattenreningsteknik med fällning, flockning, sedimentering och filtrering har man på senare tid också börjat använda membranteknik och tungmetallselektiva jonbytare. De senare är tekniker som har använts framgångsrikt vid rening av rökgaskondensat på biobränsleeldade anläggningar sedan ett tiotal år tillbaka.

I rapporten har erfarenheter sammanställts från ett antal avfallsförbränningsanläggningar där man använder olika typer av teknik för att rena rökgaskondensat. Erfarenheter från sex svenska och danska avfallsförbränningsanläggningar redovisas. Anläggningarna har valts ut för att täcka in ett brett spektrum av rökgaskvaliteter, med varierande tungmetallhalter (beroende på olika föroreningshalt i bränslet), ammoniakhalter (beroende på om SNCR eller SCR används för NO$_x$-reduktion) samt sulfat- och kloridhalter (beroende på om torr/våttorr eller våt svavelrening används). Hos två av anläggningarna recirkuleras det sura kondensatet från första skrubbersteget, medan detta kondensat renas hos de övriga fyra anläggningarna. Två av anläggningarna har vattenreningsteknik baserad på fällning, flockning, sedimentering och filtrering. Två anläggningar använder tungmetallselektiva jonbytare. Två anläggningar använder RO-membran.

I rapporten redovisas analyser av avloppsvatten från olika steg i vattenreningen hos de sex anläggningarna, tillsammans med drifterfarenheter från vattenreningsanläggningarna.
Dessutom diskuteras årskostnader för ett antal alternativa reningskoncept:

Rökgasreningstyp		**Avloppsvattenrening**
Rening av stoft och sura gaser	**NO$_x$-rening**	
*Elfilter *Våtskrubbning	Ingen eller SCR/SNCR med lågt ammoniakslip	*Fällning/filtrering av allt avloppsvatten
	SNCR med högt ammoniakslip	*Fällning/filtrering av allt avloppsvatten *Ammoniakstripping
*Elfilter *Våtskrubbning	Ingen eller SCR/SNCR med lågt ammoniakslip	*Fällning/filtrering av surskrubbervatten *Filtrering, jonbyte eller RO av kondensat
	SNCR med högt ammoniakslip	*Fällning/filtrering av surskrubbervatten *Filtrering, jonbyte eller RO av kondensat *Ammoniakstripping
*Slangfilter med kalkdosering *Våtskrubbning	Ingen eller SCR/SNCR med lågt ammoniakslip	*Fällning/filtrering av surskrubbervatten *Filtrering, jonbyte eller RO av kondensat
	SNCR med högt ammoniakslip	*Fällning/filtrering av surskrubbervatten *Filtrering, jonbyte eller RO av kondensat *Ammoniakstripping
*Slangfilter med kalkdosering *Våtskrubbning	Ingen, SCR/SNCR med lågt ammoniakslip eller SNCR med högt ammoniakslip	*Recirkulering av surskrubbervatten *Filtrering, jonbyte eller RO av kondensat

Nyckelord: Avfallsförbränning, avloppsvatten, rökgaskondensat, rening

Summary

In this report the results of a benchmarking study on flue gas condensate cleaning technologies in waste-to-energy (WtE) plants are presented. Alternative combinations of precipitation, filtration, membranes, ion-exchange, gas stripping, etc are discussed for the cleaning of flue gas condensates from plants with different types of flue gas treatment technologies. As a result, recommendations are made for different types of plants with different flue gas condensate qualities.

Six Swedish and Danish WtE plants were visited. The plants were chosen to represent a broad variety of flue gas condensate qualities, with different heavy metal concentrations (based on combustion of different waste fuels), different ammonium concentrations (based on the use of SNCR or SCR for NO_x reduction), different concentrations of sulphates and chlorides (based on the use of dry/semi-dry or wet flue gas treatment systems, with/without separate recycling of the acidic water from the first stage).

Operational experience of the plants is presented in the report, together with analyses of waste water from flue gas cleaning and flue gas condensation.

Yearly costs are presented for a number of flue gas condensate cleaning concepts.

The discussed waste water cleaning concepts are summarized in the table below.

Type of flue gas cleaning		**Concepts for waste water cleaning**
Dust and acid gas removal	**NO_x removal**	
*ESP *Wet scrubbing	None or SCR/SNCR with low ammonia slip	*Precipitation/filtration of all waste water
	SNCR with high ammonia slip	*Precipitation/filtration of all waste water *Ammonia stripping
*ESP *Wet scrubbing	None or SCR/SNCR with low ammonia slip	*Precipitation/filtration of HCl stage water *Filtration, ion-exch or RO of condensate
	SNCR with high ammonia slip	*Precipitation/filtration of HCl stage water *Filtration, ion-exch or RO of condensate *Ammonia stripping
*Fabric filter with lime injection *Wet scrubbing	None or SCR/SNCR with low ammonia slip	*Precipitation/filtration of HCl stage water *Filtration, ion-exch or RO of condensate
	SNCR with high ammonia slip	*Precipitation/filtration of HCl stage water *Filtration, ion-exch or RO of condensate *Ammonia stripping
*Fabric filter with lime injection *Wet scrubbing	None, SCR/SNCR with low ammonia slip or SNCR with high ammonia slip	*Recycling of HCl stage water *Filtration, ion-exch or RO of condensate

Key words: WtE, waste water, condensate, cleaning

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Appendices

A ANALYSES

1 Introduction

1.1 Background

A number of reports on technology for the cleaning of flue gas condensate from biomass fired plants (including biomass and industrial waste fired co-combustion plants) have been published by Värmeforsk.[1]

Several of these reports have been focusing on “new” technology, especially membrane based technology, and on possibilities to recycle waste water to the feed water production plant. Today membrane based technology, UF[2] and RO[3], is used for flue gas condensate cleaning at 20-30 Swedish biomass and co-combustion plants and is working satisfactorily in most plants. For biomass fired plants membrane technology may therefore be considered a mature technology.

Waste water from wet flue gas treatment systems and condensing scrubbers in WtE[4] plants (household waste fired plants as well as plants where household waste is co-incinerated with other types of waste) is normally treated by neutralisation, flocculation, precipitation and dewatering. Sand filters, and in some cases activated carbon filters, are used as polishing filters before the cleaned water is discharged.

Also ion-exchange filtration may be used, either as a polishing step or as the main cleaning step for flue gas condensate in plants where the waste water from the first (acidic) stage of a wet scrubber is recycled, e g to the boiler, without cleaning.

Thus, the choice of waste water cleaning technology today is not as straightforward as it has been traditionally. Neutralisation, flocculation, precipitation and dewatering is still the dominant technology for WtE plants. However, ion-exchange and membrane based technologies are gaining ground as alternatives to the traditional precipitation based technologies.

With an increasing number of optional technologies available today the choice becomes more complicated. Therefore, a guideline to help plant owners to choose among the available waste water cleaning technologies would be of interest for plant operators and equipment suppliers. This report was initiated by Alstom Power and supported by Värmeforsk to meet the interest in this area.

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[1] Reports no 568 ”Nyttiggörande av kondensat från rökgaskondensering”, 643 ”Avsaltning av varmt rökgaskondensat med membranteknik”, 895 ”Avancerad rening av rökgaskondensat” and 1089 ”Utvärdering av erfarenheter av membranteknik för rening av rökgaskondensat”

[2] Ultra Filtration

[3] Reverse Osmosis

[4] Waste-to-Energy

1.2 Objectives

The aim of this report was to create a guideline, which will help plant owners to choose the best technology for the cleaning of waste water from wet flue gas treatment systems and condensing scrubbers in WtE plants.

Alternative combinations of precipitation, filtration, membranes, ion-exchange, ammonia stripping, etc are discussed for the cleaning of flue gas condensates from plants with different types of flue gas treatment technologies. The alternatives are compared regarding complexity, efficiency, emission limits and cost. As a result, recommendations are made for different types of plants with different flue gas condensate qualities.

1.3 Methods

Six Swedish and Danish WtE plants were visited. The plants were chosen to represent a broad variety of flue gas condensate qualities, with different heavy metal concentrations (based on combustion of different waste fuels), different ammonium concentrations (based on the use of SNCR[5] or SCR[6] for NO_x reduction), different concentrations of sulphates and chlorides (based on the use of dry/semi-dry or wet flue gas treatment systems, with/without separate recycling of the acidic water from the first stage).

Representatives of each plant were interviewed. The questions below were discussed:

- Basic plant data (type of boiler, flue gas treatment and flue gas condensation)
- Treatment of all waste waters from wet flue gas treatment systems and condensing scrubbers (which waste waters are recycled and which are treated, equipment used for waste water cleaning)
- Requirements on treated waste water (emission limits)
- Reduction rates (separation of suspended solids, heavy metals, sulphates, chlorides, ammonium)
- Operational experience (availability, staff requirements, maintenance)
- Handling of chemicals
- Handling of waste products (sludge etc)

From each plant a number of samples were taken from the different steps of the waste water and flue gas condensate cleaning system.

The samples were analysed for the following parameters:

- Suspended solids
- Conductivity, pH, alkalinity
- Sulphate, chloride, ammonium
- Mercury (Hg), cadmium (Cd), cobalt (Co), thallium (Tl), arsenic (As), lead (Pb), chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn)

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[5] Selective Non-Catalytic Reduction

[6] Selective Catalytic Reduction

Suppliers of flue gas treatment and flue gas condensate cleaning systems were asked for investment and operating costs.

1.4 Acknowledgement

The authors would like to express their gratitude to all the representatives of visited plants and equipment suppliers, who have contributed with information to this report!

For contact information see the references chapter.

2 Technology options

This chapter acts as an introduction to the waste water treatment technologies investigated in the study.

A short description of flue gas cleaning technologies and of the waste waters produced in the flue gas cleaning and heat recovery is found in 2.1 and 2.2.

A short summary of a previous Värmeforsk report on experience with membrane technology for flue gas condensate cleaning in biomass fired plants is found in 2.4. For descriptions of waste water cleaning technologies, (e g RO, UF and other particle filters, ammonium removal) the reader is referred to this report.

A short discussion of the investigated waste water cleaning options for WtE plants is found in 2.5 and 2.6.

2.1 Flue gas cleaning in WtE plants

2.1.1 Dust removal and NO_x reduction

The flue gas from biomass fired boilers normally needs dust removal. This is often made in fabric filters. NO_x reduction is also often installed in biomass fired plants. NO_x reduction is commonly achieved the SNCR method, i e by ammonia injection into the furnace or flue gas duct, without the need for catalysts.

WtE plants utilise electrostatic precipitators or fabric filters for dust removal.

Figure 1. Electrostatic precipitator for dust removal (courtesy of Alstom)

Figur 1. Elfilter (källa:Alstom))

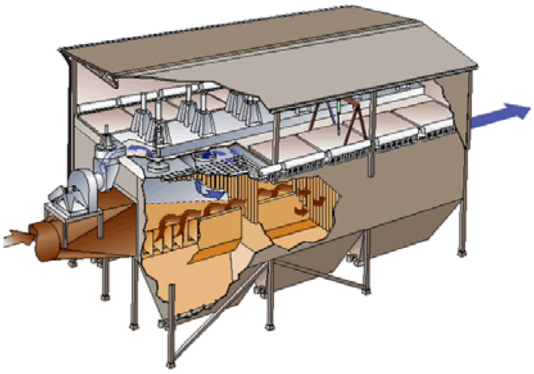

Figure 2. Fabric filter for dust removal (courtesy of Alstom)

Figur 2. Slangfilter (källa:Alstom)

Fabric filters are used in plants with dry or semi-dry acid gas removal, where acid gas is captured by e g lime or sodium bicarbonate which is injected into the flue gas and then removed in the fabric filter.

For NO_x reduction both SNCR and SCR is commonly used. SCR systems in WtE plants are installed after all other flue gas cleaning steps, in tail-end position, to minimize the risk for catalyst clogging and poisoning.

2.1.2 Removal of acid gases in dry and semi-dry flue gas cleaning systems

Since the waste which is combusted in WtE plants contains more contaminants than biomass, the flue gas from WtE plants needs additional cleaning to remove SO_x (mainly SO_2), gaseous halogens (chlorides and fluorides) and heavy metals.

In dry systems SO_2 and halogens are removed by injection of an alkaline reagent, e g lime, into the flue gas. SO_2 and halogens are absorbed on the reagent and the reaction product is removed in a fabric filter.

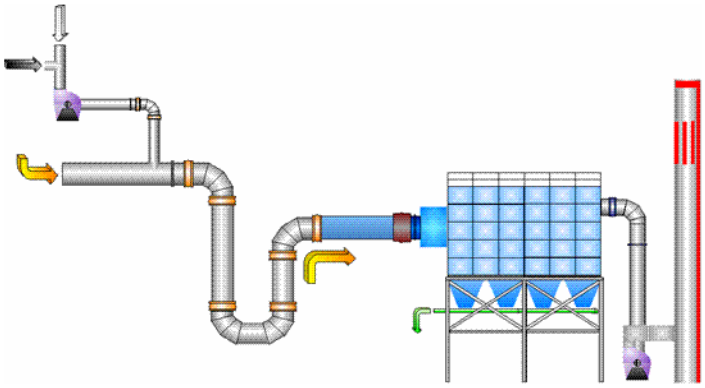

Figure 3. Dry flue gas treatment with downstream fabric filter (BREF waste incineration)

Figur 3. Torr rökgasrening med efterföljande slangfilter (BREF avfallsförbränning)

In semi-dry (also called semi-wet) systems the reagent is injected as a suspension or solution in water. The injected water is evaporated by the heat in the flue gas. The acid gases in the flue gas are absorbed on the reagent, which is then removed in a fabric filter as a dry product just as in the dry system.

In another type of semi-dry system, a humidified mixture of lime and recycled ash forms a free-flowing powder that is injected into the flue gas. The flue gas is cooled by the water evaporation and the acid gases are absorbed on the reagent and removed as a dry product in the fabric filter.

The reagent consumption, and the amount of solid residue produced, is lowered by the recycling. A stoichiometric ratio of reagent of 1,5-2 can be achieved with recycling.

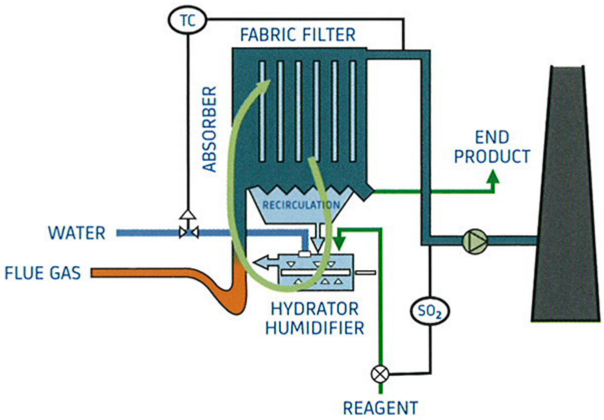

Figure 4. Semi-dry flue gas treatment with recirculation (courtesy of Alstom)

Figur 4. Våttorr rökgasrening med recirkulering av rökgasreningsprodukt (källa: Alstom)

2.1.3 Removal of acid gases and heavy metals in wet flue gas cleaning systems

In wet systems the flue gas is scrubbed with water in several stages, so that the acidic gases (SO_2, chlorides, etc) are absorbed in water together with dust and heavy metals and ammonia. The scrubber section is installed after dust removal in either electrostatic precipitator or fabric filter.

In the first scrubber stage only water is injected. This stage, called the acidic stage or HCl stage, typically has a pH of 0-1 since HCl is absorbed here. Also a major part of the heavy metals and ammonia in the flue gas are absorbed in the HCl stage. The absorption of SO_2 is low in this stage.

SO_2 is absorbed in the next scrubber stage, called the neutral or SO_2 stage. This stage is kept at pH 6-7 via injection of lime or sodium hydroxide (NaOH).

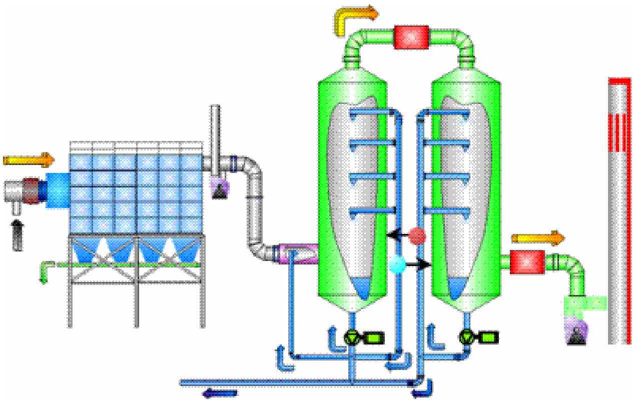

Figure 5. Wet flue gas treatment with upstream fabric filter (BREF waste incineration)

Figur 5. Våt rökgasrening efter slangfilter (BREF avfallsförbränning)

2.1.4 Heat recovery by flue gas condensation

In WtE plants where heat recovery by flue gas condensation is installed, the flue gas condenser is normally placed as a separate scrubber with heat exchanger after the acidic and neutral stages.

Due to the condensation of water vapour from the flue gas, the condensation stage has the largest waste water flow. The flue gas condensate, i e the waste water from the condensation stage, is less polluted than the waste water from the previous stages.

2.2 Flue gas cleaning in biomass fired plants and co-combustion plants

Biomass fired plants and co-combustion plants, which have less polluted flue gas than WtE plants, normally do not need wet scrubbers for flue gas cleaning. However, they are often equipped with flue gas condensation for heat recovery. The condensate from the flue gas condenser may need treatment before it can be discharged.

2.3 Waste water and condensate cleaning in biomass fired plants and co-combustion plants

The flue gas condensate may be treated by filtration in sand filters, sometimes together with precipitation, flocculation and sedimentation, to remove dust and heavy metals. Also ammonium removal may be necessary, in plants equipped with SNCR and ammonia injection for NO_x reduction.

In recent years many biomass fired and co-combustion plants have been equipped with membranes for condensate cleaning.

2.4 Membrane technology in flue gas condensate treatment applications in biomass fired plants and co-combustion plants

Experience from plants with membranes for flue gas condensate treatment was discussed in a previous Värmeforsk study[7]. In the study ten Swedish plants, using membranes for flue gas condensate treatment, were visited in 2008 and their experiences were discussed. The plants were either biomass fired plants or co-combustion plants using a mixture of biomass and industrial waste. Chapter 2.4 is a short summary of this study.

2.4.1 RO membranes

All of the plants were equipped with RO membranes. The RO membranes were installed with the intention of recycling clean condensate and using it as feed water.

In six of the plants RO permeate was used as boiler feed water, after polishing with EDI[8] or a mixed bed ion-exchange filter or after additional cleaning in a separate demineralisation plant. In one plant the RO permeate was used as feed water to the district heating net.

The RO concentrate was recycled in two of these six plants. One of the plants had a flue gas condenser with a preceding quench, to which the RO concentrate was recycled. In one plant the RO concentrate was used for lime slaking. RO concentrate from the remaining four plants was discharged to recipient or to municipal sewage treatment.

In two of the plants the RO permeate was discharged to recipient. The concentrate was recycled to the boiler. In these two plants the RO was used mainly as an ammonia removal step.

2.4.2 UF membranes

In the two plants, where the RO concentrate was recycled, the RO step was preceded by particle removal in a sand filter plus an activated carbon filter.

In the other plants particles were removed before the RO step by vibrating screen filters followed by hollow-fibre UF membranes. In one plant a sand filter was used in addition to the screen filter and UF.

2.4.3 Ammonia removal

Seven of the plants were equipped with ammonia removal. Ammonia, was removed either by membranes, by strippers or in the humidifier of the flue gas condenser. In three plants ammonia was removed by air stripping. Two of the plants used ammonia membrane contactors, installed after the UF unit. In two plants ammonia was transferred to combustion air in the humidifier of the flue gas condenser, so that the removed ammonia was subsequently destroyed when the air entered the boiler.

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[7] Report no 1089 ”Utvärdering av erfarenheter av membranteknik för rening av rökgaskondensat”

[8] Electrodeionisation

At the two plants, where the RO concentrate was recycled to the boiler, ammonia was not removed. Since most of the ammonia was found in the recycled RO concentrate, there was no discharge of ammonia/ammonium to the recipient.

2.4.4 Carbon dioxide removal

Seven of the plants had carbon dioxide removal, either by membranes or by strippers. At four of the plants carbon dioxide was removed directly after the flue gas condenser. At two plants carbon dioxide was removed from the RO inlet or the RO permeate.

Carbon dioxide removal was installed for a number of reasons, for example to minimize the consumption of alkali for pH adjustment of the condensate before ammonia removal, to minimize precipitation of carbonates, or to lower the residual conductivity of RO permeate.

2.4.5 Operational experience

Generally the procurement of the flue gas condensate treatment equipment went well. At half of the plants pilot tests with condensate treatment were performed before procurement. Several of the installations took considerably longer time to complete than originally planned. Half of the plants had had more than six months delay in their projects. At three plants the delay was more than two years. The reasons for this vary, but a general impression is that the membrane based flue gas condensate treatment technology had not quite reached maturity when the projects were started.

Almost all visited plants had high availability at the time of the visit. However, it had often taken several years to reach this goal. Reconstructions and completions with additional equipment had been made to the original installations. One plant had an availability of only 50% after 18 months operation, and had still not been approved for trial operation.

Membrane based flue condensate treatment plants are often said to be fully automatic, with a minimum requirement of staff for operation and maintenance. In reality, the need for staff was quite considerable at the visited plants. As an average, 12 hours per week of maintenance was required for the visited flue gas condensate treatment plants.

2.5 Conventional technology for treatment of waste waters from wet flue gas cleaning and condensation in WtE plants

As mentioned above, unlike the biomass fired plants and co-combustion plants which have only one condensation stage, WtE plants usually have several scrubber stages for flue gas cleaning and condensation. The waste waters and condensates from the different stages are sometimes treated separately, since they are of very different qualities.

Normally the waste water is cleaned in a physico-chemical treatment unit by neutralisation, flocculation, precipitation, sedimentation and dewatering. Sand filters, and in some cases activated carbon filters, are used as polishing filters.

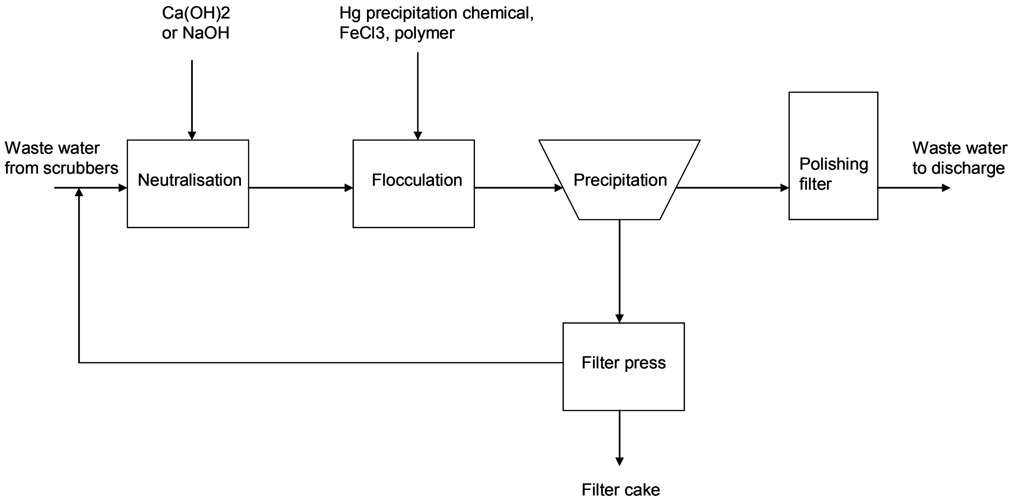


Figure 6. Conventional physico-chemical waste water treatment (BREF waste incineration)

Figur 6. Konventionell vattenrening med fällning och filtrering (BREF avfallsförbränning)

At Sysav 4 all waste water is treated by precipitation, flocculation and sedimentation, followed by polishing in sand and carbon filters. At Gärstaverket only the waste water from the first (HCl) scrubber stage, which is the most heavily contaminated, is treated by precipitation, flocculation and sedimentation, followed by ammonia stripping and polishing in sand and carbon filters. The waste water from the condensation stage is led directly to the polishing step.

2.6 Membrane technology and ion-exchange technology for flue gas condensate cleaning in WtE plants

Ion-exchange filtration may be used, either as a polishing step or as the main cleaning step for flue gas condensate in plants where the waste water from the first (acidic) stage of a wet scrubber is recycled, e g to the boiler, without cleaning. This alternative has been chosen at two Swedish plants so far, Sysav 1+2 and Värmekällan.

In Sweden no WtE plant has been equipped with membrane based flue gas condensate treatment, as yet. The first Swedish WtE plant with membrane based condensate cleaning is under construction at the moment.

One Danish WtE plant, Måbjergvaerket, is equipped with condensate treatment using membrane technology. Waste water from the condensation stage is cleaned by activated carbon filtration followed by RO membrane filtration. Waste waters from the acidic stages are cleaned by conventional precipitation technology. The same approach has been used at another Danish plant, Sönderborg Kraftvarmevaerk, where waste water from the condensation stage is cleaned by both UF and RO membrane filtration.

3 Experience from existing plants

Six Swedish and Danish WtE plants were visited.

Two of the plants (Sysav combustion line 4 in Malmö and Gärstadverket in Linköping) are equipped with wet flue gas cleaning. However, all of the waste water is treated by precipitation and filtration at Sysav, whereas only the waste water from the first (acidic) stage is precipitated and settled at Gärstadverket. The condensate is led directly to sand and activated carbon filters, which are also used for polishing the acidic water after the precipitation step.

At two of the plants (Sysav combustion line 1&2 in Malmö and Värmekällan in Skövde) the water from the acidic stage is recycled. Only waste water from the last stage, which is the condensation stage, is treated. Heavy metal specific ion-exchangers are used for this.

The waste water from the condensation stage of the wet flue gas cleaning in the two Danish plants (Måbjergvaerket in Holstebro and Sönderborg Kraftvarmevaerk in Sönderborg) is cleaned by RO membranes. The water from the acidic stages is cleaned by conventional precipitation and filtration.

The waste water treatment philosophies are summarized in the table below.

Table 1. Treatment of waste waters from flue gas cleaning at the visited plants
Tabell 1. Rening av avloppsvatten från rökgasrening hos de besökta anläggningarna

	Acidic stage	**SO_2 stage**	**Condensate**
Absorbed flue gas components	**HCl, SO_3, NH_3, heavy metals**	**SO_2**	**Mainly heat recovery**
Sysav 4	Precipitation of waste water from all stages, No NH_3 removal required, SCR and NH_3 injection downstream		
Gärstadverket	Precipitation, NH_3 stripping	Recycled to ash	Polishing in sand and carbon filter
Sysav 1&2	Recycled to boiler, including NH_3	Ion-exchanger	
Värmekällan	Recycled to boiler, including NH_3	Carbon filter and ion-exchanger	
Måbjergvaerket	Precipitation, low NH_3 levels	Sent away to external treatment	Carbon filter + RO
Sönderborg	Precipitation, low NH_3 levels	Precipitation	UF + RO

Experience from the six visited plants is discussed in this chapter. For complete analyses of the waste water samples taken during visits to the plants see the appendices.

The sampling point numbers, shown in the schematic diagrams of the plants, are used in the diagrams in chapters 3, 4 and 5.

3.1 Sysav combustion line 4

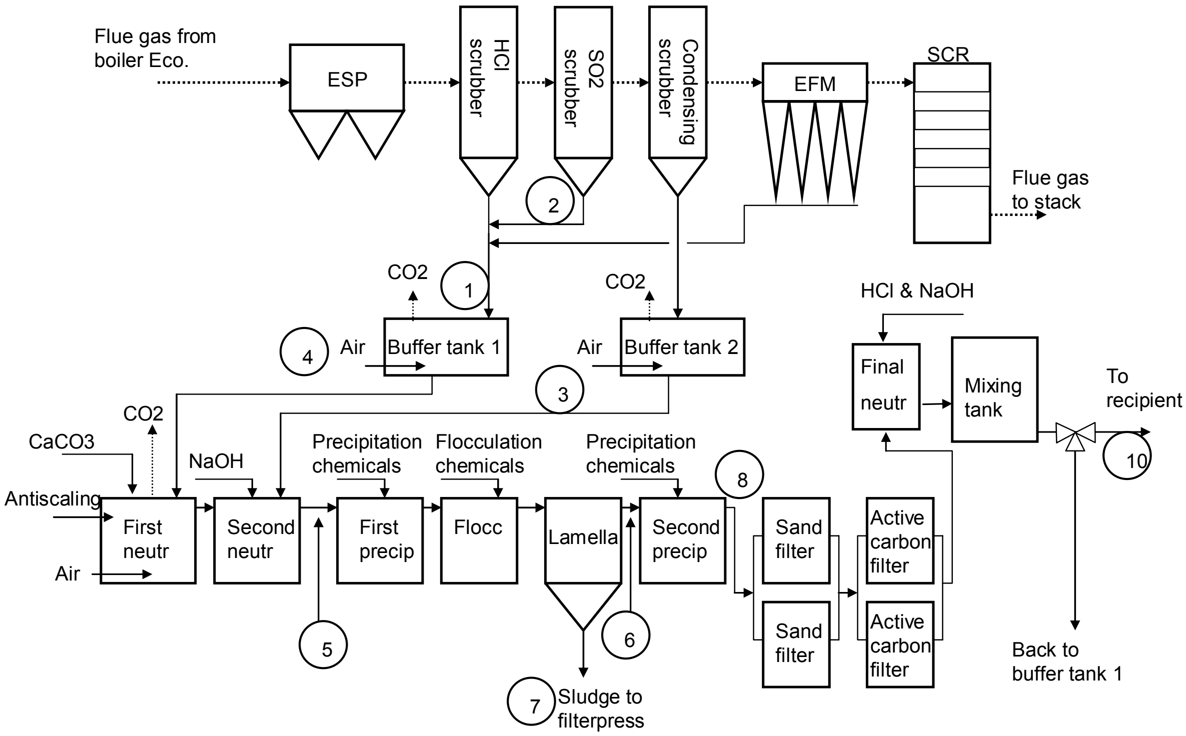


Figure 7. The waste water treatment of combustion line 4 at Sysav in Malmö (sampling points marked)

Figur 7. Processavloppsvattenreningen vid Sysav linje 4 i Malmö (provtagningspunkter markerade)

3.1.1 Technology and operational experience

Contact person	Rasmus Beckman, rasmus.beckman@sysav.se
Boiler	Grate fired steam boiler (Martin GmbH) commissioned 2008. 87 MW (19-29 t/h waste) producing steam 40 bar, 400 °C
Fuel	Domestic/industrial waste (50/50)
Operation hours	7600 h/year. Depends on needs in the district heating system
Flue gas treatment	Lab SA 2008
Dust removal	Electrostatic precipitator (ESP) with 2 fields before wet flue gas treatment removes dust to < 20 mg/Nm^3 Electro filtering module (EFM) after scrubbers removes fine dust particles to < 1 mg/ Nm^3
NO$_x$ reduction	Tail-end SCR after wet flue gas treatment with 3 layers of catalyst.
Acid gas reduction	Removal of HCl and heavy metals in the first open scrubber tower and increase of pH to 1,5 by addition of limestone ($CaCO_3$). Removal of SO_2 in the second scrubber tower by scrubbing with limestone at pH 5,5. Additional removal of SO_2 in the packed bed condensation scrubber by dosing NaOH at pH 6,5.
Flue gas condensation	Two compressor heat pumps producing 2 x 9 MW of district heating. Condensation scrubber with packing. Condensate is primarily recycled within the plant.
Treatment of waste water from flue gas cleaning and flue gas condensation	Techfina 2008 (max 21 m^3/h water throughput)
Waste water from HCl and SO2 scrubbers and EFM	Appr 4 m^3/h of the water from the HCl and SO_2 scrubbers and the EFM is discharged to the waste water treatment. The water at pH 1,5 is treated by addition of limestone, NaOH, Hg precipitation chemical, $FeCl_3$ and polymer, sedimentation in lamella clarifier and filtration in sand filters and carbon filters before discharge to recipient.
Waste water from SO_2 scrubber	Excess water from the SO_2 scrubber bleeds to the HCl scrubber. Gypsum is extracted via a hydro cyclone to a vacuum band filter.
Flue gas condensate	Appr 12 m^3/h of condensate from the condensation scrubber is discharged to the waste water treatment and mixed with the water from HCl and SO_2 scrubbers in the second neutralisation tank. The mixed water is then treated according to the steps described above.

The flue gas leaving the boiler economiser passes through a 2-stage electrostatic precipitator (ESP) for removal of dust to < 20 mg/Nm^3. The gas coming from the ESP first passes through a gas/gas heat exchanger to lower the temperature before it enters the HCl scrubber. The first part of this scrubber consists of a horizontal quench where the flue gas flows through a water curtain which quenches and saturates the gas with water vapour, cooling it down to wet bulb temperature, i e appr 60°C. In the scrubber substances as chlorides, fluorides and heavy metals are removed from the flue gas. The pH in the scrubber water is increased to 1,5 by addition of limestone slurry, in order to make it less corrosive. Before the flue gas is directed to the SO_2 scrubber it passes through a droplet separator, which catches most of the water drops. In the SO_2 scrubber limestone slurry is added to reach pH 5,5 for removal of SO_2 in the flue gas. The limestone reacts with the sulphur dioxide to form gypsum. The gypsum is discharged from the scrubber water via hydro cyclone to a vacuum band filter, where it is dewatered and put into a container. The flue gas passes thorough another droplet separator before it enters the condensation scrubber. In the condensation scrubber the flue gas is further cleaned from SO_2 by adding NaOH and increasing pH to 6,5. The main purpose of the condensing scrubber is to recover heat from the flue gas and transfer it to the district heating network. The scrubber contains tower packing material doped with activated carbon in order to acquire a large contact surface between flue gas and process water and to capture some of the dioxins. Two compressor heat pumps are used to extract the maximum amount of heat from the condensed water. The next step in the flue gas treatment process is the electro filtering module (EFM). The EFM works in almost the same way as the electrostatic precipitator but in a wet condition. In the EFM fine dust particles are captured and the dust level is reduced to < 1 mg/Nm^3. The final step of the flue gas treatment is the SCR. In the SCR the NO_x is reduced by approx 90 % and most of the dioxins are destroyed.

The excess water (approx 4 m^3/h) from the HCl scrubber, SO_2 scrubber and EFM is discharged to buffer tank 1 before it enters the waste water treatment. In the buffer tank air is injected in the bottom part to prevent sedimentation and accomplish some CO_2 degassing and SO_2 oxidation. When the heavily polluted water enters the first neutralisation tank it has a pH around 1,5. In this step limestone milk is injected to reach pH 3 and air is injected in the bottom to degas most of the CO_2. Anti scaling chemical is added to avoid deposits of carbonates and gypsum in the following treatment steps. In the second neutralisation tank pH is adjusted to around 9 with NaOH to precipitate the heavy metals as hydroxides. The cleaning capacity of the waste water treatment is appr 21 m^3/h of water throughput.

Condensate from the condensation scrubber is primarily reused in the flue gas treatment as process water to feed the quench, droplet separators etc. Excess condensate (appr 12 m^3/h) is discharged to buffer tank 2 where air is injected to prevent sedimentation and accomplish some CO_2 degassing. The pH of the condensate is approx 6,5-8 when it enters the waste water treatment in the second neutralisation tank and mixes with the other water. The maximum cleaning capacity of the waste water treatment is appr 21 m^3/h of water throughput. The mixed water has a pH around 9 when it enters the next step, the first precipitation tank. In this step a precipitation chemical and $FeCl_3$ is dosed in order to precipitate the remaining heavy metals as sulphides and to coagulate them. In next step, the flocculation tank, a polymeric flocculent is dosed by means of a dosing pump in order to flocculate the precipitated complex under slow agitation. Leaving the chemical treatment, the waste water is transferred to the lamella separator. The sludge is collected in the bottom and discharged to filter press where it is dewatered and put into a container. The overflow (clear water) from the lamella separator flows by gravitation to a second precipitation tank in order to increase the performance by precipitating metals which were not precipitated earlier.

In the final steps the water is pumped through two sand filters and two activated carbon filters. The purpose of the sand filter is to achieve a complete removal of the fine particles by blocking heavy metals compounds that did not settle in the decanter or that were formed in the second precipitation tank. The filters are automatically cleaned by back flushing with water and air when the pressure drop across the filters becomes excessive. The purpose of the coal filter is to adsorb all organic compounds as well as dioxins. The filters are cleaned similarly as the sand filters. From time to time, the filters can be soaked by a mixture of water and hydrochloric acid (HCl) to remove the gypsum and carbonates which could cause clogging. Cleaning water from the filters goes back to buffer tank 1. Before sending the water to the recipient Öresund, pH is adjusted to 6,5-8 with HCl.

The waste water treatment was installed in 2008. The commissioning went fine except for some control problems with the sludge filter press. The overall performance of the waste water treatment was approved and the plant was taken over. The operator experience from the waste water treatment is positive. In average 20 h/week is required for cleaning, calibration and maintenance. Dosing of anti scaling chemical in the first neutralisation tank reduces problems with carbonate and gypsum deposits in the coming tanks, filters and on pH meters. The difference is obvious compared to the waste water treatment in Sysav line 3, where no anti scaling is added. Automatic acid cleaning and back flushing of sand and carbon also helps decrease plugging problems caused by deposits. The sludge handling system, and in particular the filter press, is quite problematic and requires attention of the operators. Sand and carbon in the sand and carbon filters are exchanged every third year and the filters in the filter press are exchanged every second year. Consumption of chemicals is on of the largest costs concerning the water treatment. In particular pH adjustment with NaOH in the second neutralisation tank and dosing of precipitation chemical are costly. In average 95 ml of precipitation agent is used for every m^3 of waste water. It adds up to a yearly cost of appr 0,4 MSEK. According to Sysav the waste water treatment requires a lot of cleaning and maintenance during revision.

3.1.2 Sampling and sampling points

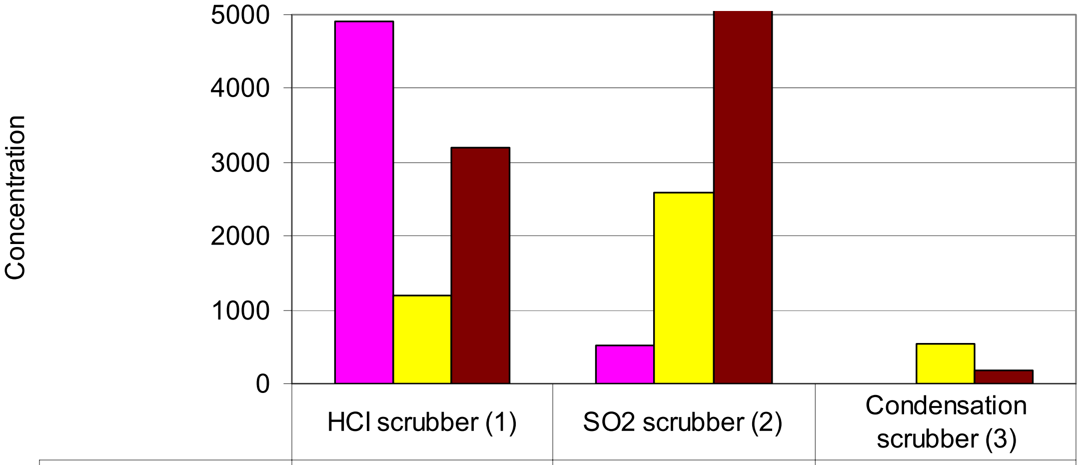
At Sysav, combustion line 4, samples were collected at four different times during appr four hours. For each sample the temperature, pH and conductivity were noticed. The four different samples, 250 ml each, were collected in a one litre bottle for each sampling point. Each one litre bottle was then analysed individually.

The samples were taken 2010-10-22 at full load operation of the plant. The sampling points can be seen in Figure 7. Sample (1) was taken on the circulation water in the HCl scrubber and sample (2) was taken on the circulation water in the SO_2 scrubber. Sample (3) was taken on the bleed water from the condensation stage after buffer tank 2.

Sample (4) was taken after buffer tank 1, on the mixed bleed water from the HCl scrubber, EFM and the SO_2 scrubber. Sample (5) was taken after neutralisation tank 2 on the common water from all scrubbers. Sample (6) was taken on the clean overflow water from the lamella separator and sample (7) on the sludge in the bottom of the lamella separator. Sample (8) was taken after the second precipitation tank and sample (10) on the cleaned water going to recipient.

3.1.3 Concentrations of pollutants and cleaning efficiency

The concentrations of chlorides, sulphates and suspended solids in waste water and condensate from the different stages of the flue gas treatment and heat recovery system at Sysav line 4 are shown below.



	HCl scrubber (1)	SO2 scrubber (2)	Condensation scrubber (3)
🟪 Chlorides [mg/l]	4900	510	
🟨 Sulphates [mg/l]	1200	2600	540
🟥 Susp solids [mg/l]	3200	13000	180

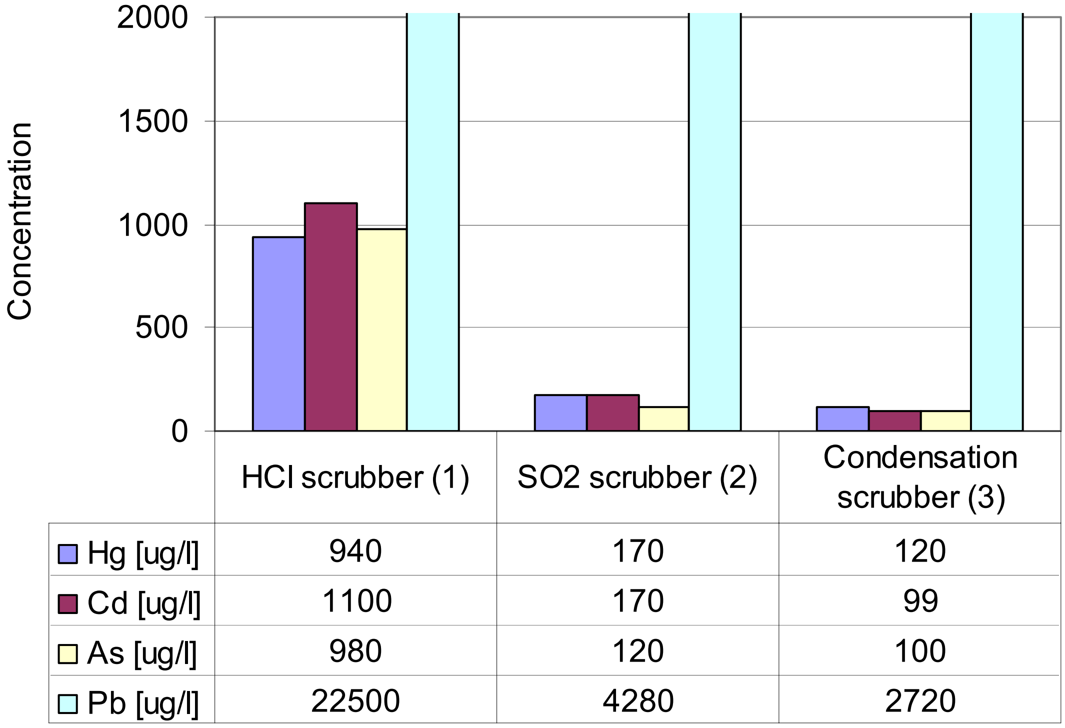
Figure 8. Chlorides, sulphates and suspended solids in untreated waste water from scrubbers in combustion line 4 at Sysav in Malmö

Figur 8. Klorid, sulfat och suspenderat material i orenat vatten från skrubbrar i linje 4 på Sysav i Malmö

The diagrams above show that the flue gas treatment is functional. Most of the HCl in the flue gas is absorbed in the HCl scrubber (1) and the SO_2 in the SO_2 scrubber (2) as expected. The chloride concentration in the HCl scrubber was remarkably low at the day of measurements. This probably depends on low chloride content in the waste. The normal concentration is expected to be appr 35 000 mg/l. The laboratory did not manage to measure chlorides in the condensation scrubber, but looking at previous measurements the expected chloride concentration is around 100 mg/l. The sulphate concentration in the HCl scrubber was quite high since the SO_2 scrubber excess water goes there. Outlet emission values from the stack of HCl and SO_2 were close to zero, which proves that the flue gas treatment is efficient.

The circulation water in the HCl scrubber (1) had a suspended solids concentration of 3200 mg/l, in contrast to the circulation water in the SO_2 scrubber (2) where the suspended solids concentration was 13 000 mg/l. This very high concentration can be explained by efficient SO_2 absorption in the SO_2 scrubber by addition of limestone and formation of gypsum. The gypsum gives a very high concentration of suspended solids in the waste water from the SO_2 scrubber. The concentration of suspended solids in excess water from the condensation scrubber (3) was also quite high, 180 mg/l. This can be explained by accumulation of suspended solids in the buffer tank 2.

The concentrations of heavy metals in waste water and condensate from the different stages are shown below.



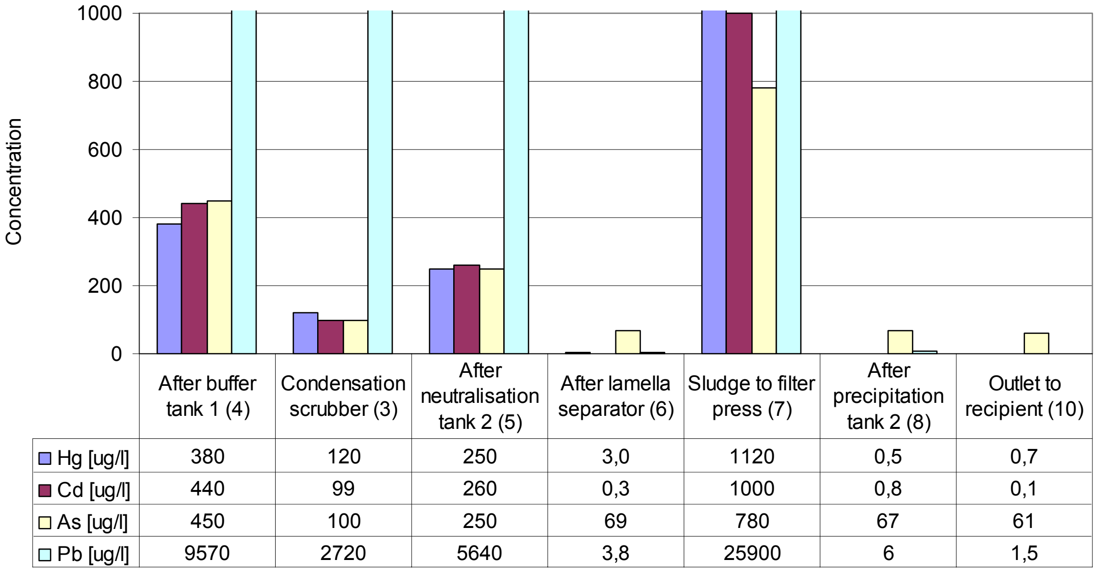
	HCl scrubber (1)	SO2 scrubber (2)	Condensation scrubber (3)
□ Hg [ug/l]	940	170	120
■ Cd [ug/l]	1100	170	99
□ As [ug/l]	980	120	100
□ Pb [ug/l]	22500	4280	2720

Figure 9. Heavy metals in untreated waste water from scrubbers in combustion line 4 at Sysav in Malmö

Figur 9. Tungmetaller i orenat vatten från skrubbrar i linje 4 på Sysav i Malmö

Figure 9 shows that the HCl scrubber is efficient for removal of heavy metals from the flue gas.

The concentrations of heavy metals in different steps of the waste water treatment are shown below.



	After buffer tank 1 (4)	Condensation scrubber (3)	After neutralisation tank 2 (5)	After lamella separator (6)	Sludge to filter press (7)	After precipitation tank 2 (8)	Outlet to recipient (10)
☐ Hg [ug/l]	380	120	250	3,0	1120	0,5	0,7
■ Cd [ug/l]	440	99	260	0,3	1000	0,8	0,1
☐ As [ug/l]	450	100	250	69	780	67	61
☐ Pb [ug/l]	9570	2720	5640	3,8	25900	6	1,5

Figure 10. Performance of the waste water treatment in combustion line 4 at Sysav, Malmö

Figur 10. Prestanda i vattenreningen tillhörande förbränningslinje 4 på Sysav i Malmö

Figure 10 shows that the excess water from the condensation scrubber (3) is clean compared to the heavy polluted mixed waste water from the HCl scrubber and SO_2 scrubber collected after buffer tank 1 (4). In neutralisation tank 2 (5) all waters are mixed and the concentration of heavy metals in the water from buffer tank 1 is lowered by dilution with cleaner condensate.

The precipitation, flocculation and sedimentation process is very efficient. The total concentration of heavy metals in the waste water was reduced by 99,5% between neutralisation tank 2 (5) and the overflow of the lamella separator (6). Hg , Cd and Pb was reduced by > 99,8% while As was reduced by only 75%. Most heavy metals were captured in the sludge (7) as expected. After precipitation tank 2 (8) the concentration of Hg was reduced by another 83% from 3 mg/l to 0,5 mg/l, but most of the other metals were slightly increased. After the second neutralization stage the water passes through sand filters and carbon filters. Most heavy metal concentrations are decreased after the filters on the outlet (10) but Hg is an exception. The increased concentration of Hg in the outlet water (10) may depend on previous accumulation of Hg in the filters which leak continuously.

3.2 Gärstadverket combustion line 4

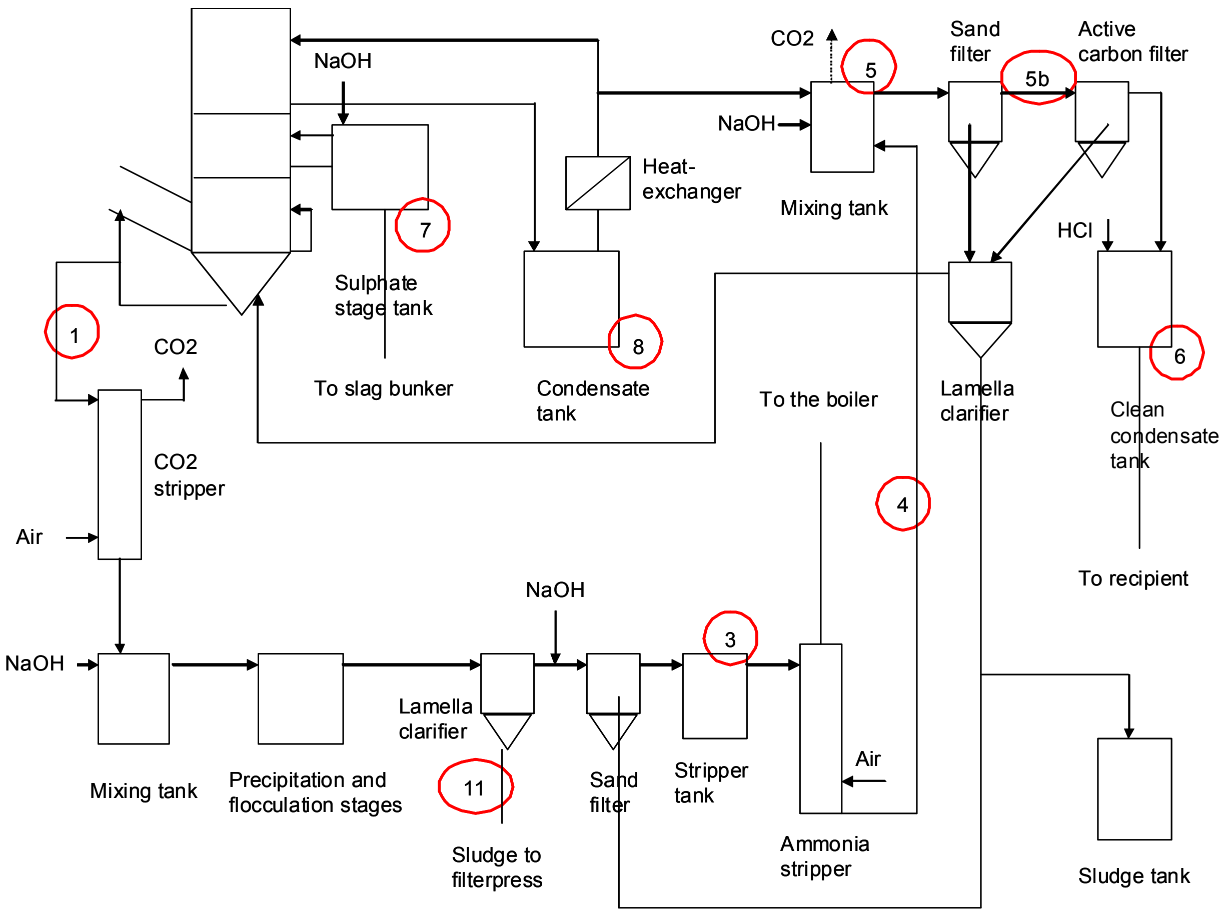


Figure 11. Waste water treatment of combustion line 4 at Gärstadverket in Linköping (sampling points marked)

Figur 11. Processavloppsvattenreningen vid Gärstadverket linje 4 i Linköping (provtagningspunkter markerade)

3.2.1 Technology and operational experience

Contact person	Henrik Andersson, henrik.andersson@tekniskaverken.se
Boiler	68 MW (Völund 2005)
Fuel	Approx 40 % industrial waste and 60 % domestic waste
Operation hours	All year
Flue gas treatment	
Combined dust removal and acid gas reduction	Lime feed, activated carbon feed and fabric filters (Simatek)
NO_x reduction	SNCR with urea
Acid gas reduction (scrubbing)	Lower part of scrubber system
Flue gas condensation	15 MW heat recovery scrubber (Pronea)
Treatment of waste water from flue gas cleaning and flue gas condensation	Pronea 2005
Waste water from HCl stages	CO_2 removal (by aeration in tank), precipitation, sedimentation, sand filter, NH_3 stripper
Waste water from SO_2 and dioxin stages	To bunker and then landfill
Flue gas condensate	CO_2 removal (by aeration in tank), sand filter, activated carbon filter

The flue gas is cleaned in a dry system developed by Simatek. Activated carbon and lime are fed into the flue gas before it passes through a bag filter. Then the flue gas enters the quench which is a part of the scrubber system. Water is sprayed into the quench and the waste water from this stage, called the HCl stage, is pumped into the HCl stage water treatment that consists of CO_2 removal in a stripper column, precipitation including addition of $FeCl_3$ and a Hg precipitation chemical, lamella sedimentation, sand filtration and removal of ammonia. After this treatment the water is fed into the condensate treatment system, where it is cleaned further together with the condensate.

The water from the SO_2 stage is recycled and/or pumped on for mixing with bottom ash. Thereafter the mixture is transported to the local landfill.

The condensate from the flue gas condensation stage passes through heat exchangers for heat recovery. Thereafter the CO_2 content in the condensate is reduced in a stripper column. Then the condensate passes through a sand filter and an activated carbon filter. The pH of the clean condensate is adjusted before discharge to the lake Roxen.

The HCl stage water treatment capacity is appr 6 m^3/h. The capacity of the sand filter and the activated carbon filter is 25 m^3/h. The volume of the activated carbon filters is 6 m^3 each and two of them are installed. The activated carbon is exchanged every second year. The personnel have the impression that substances are gathered on the surface of the carbon, not actually absorbed. The HCl stage water and condensate treatment is handled mainly by the process monitor system and does not require a lot of manual handling except for calibration.

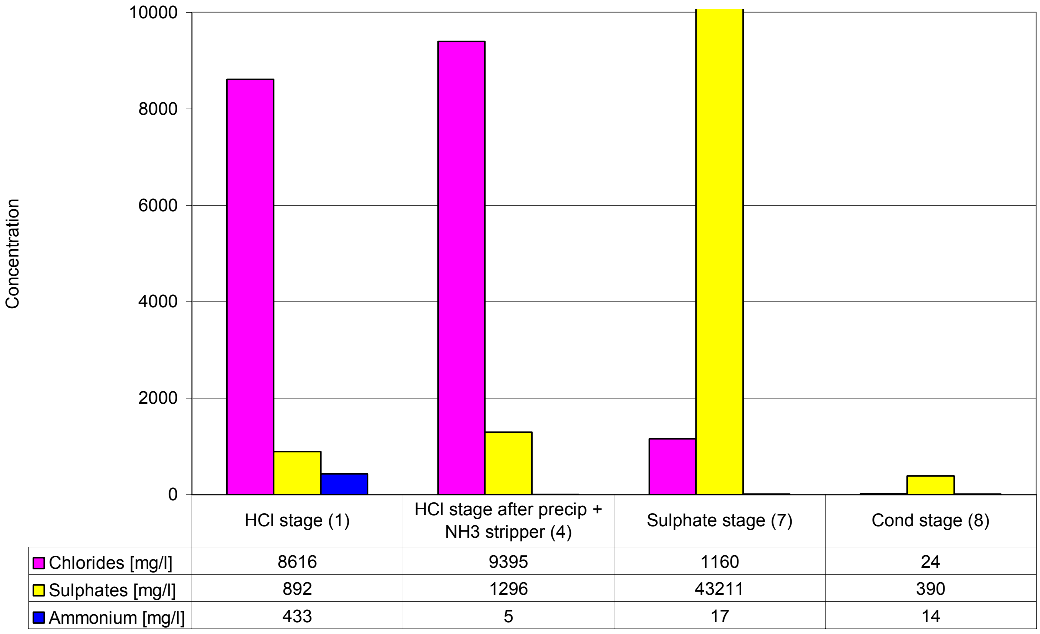
3.2.2 Sampling and sampling points

Samples have been taken at various points in the treatment plant (see Figure 11). Unfortunately, the samples taken at the visit 2010-10-26 seemed to have not been analysed reliably (confusing Cl data). The data discussed in this report are, therefore, data from 2008 which were supplied by Gärstadverket.

3.2.3 Concentrations of pollutants and cleaning efficiency

Typical concentrations of pollutants in waste water and condensate from the different stages of the flue gas cleaning and heat recovery system at Gärstadverket are shown below. (Data from 2008.)

The chlorides and the ammonia in the flue gas are absorbed mainly in the acidic (HCl) stage. The SO_2 is absorbed (as sulphite and sulphate) mainly in the neutral SO_2 stage. The absorbed ammonia, from the SNCR type NO_x reduction in the boiler, is almost completely removed in the ammonia stripper.



	HCl stage (1)	HCl stage after precip + NH3 stripper (4)	Sulphate stage (7)	Cond stage (8)
🟪 Chlorides [mg/l]	8616	9395	1160	24
🟨 Sulphates [mg/l]	892	1296	43211	390
🟦 Ammonium [mg/l]	433	5	17	14

Figure 12. Chlorides, sulphates and ammonium in untreated waste water from flue gas cleaning and condensation stages at Gärstadverket 4

Figur 12. Klorid, sulfat och ammonium i orenat avloppsvatten från rökgasrening och *kondensering på Gärstadverket 4*

The waste water from the acidic stage is treated by flocculation, precipitation and filtration, followed by ammonia stripping, and then is mixed with the condensate and cleaned further by sand and activated carbon filtration. The precipitation stage reduces the heavy metal content by 50-100%. In the first diagram below the concentration of a number of heavy metals can be seen before and after precipitation. (The concentrations are mean values of concentrations analysed during 2008.)

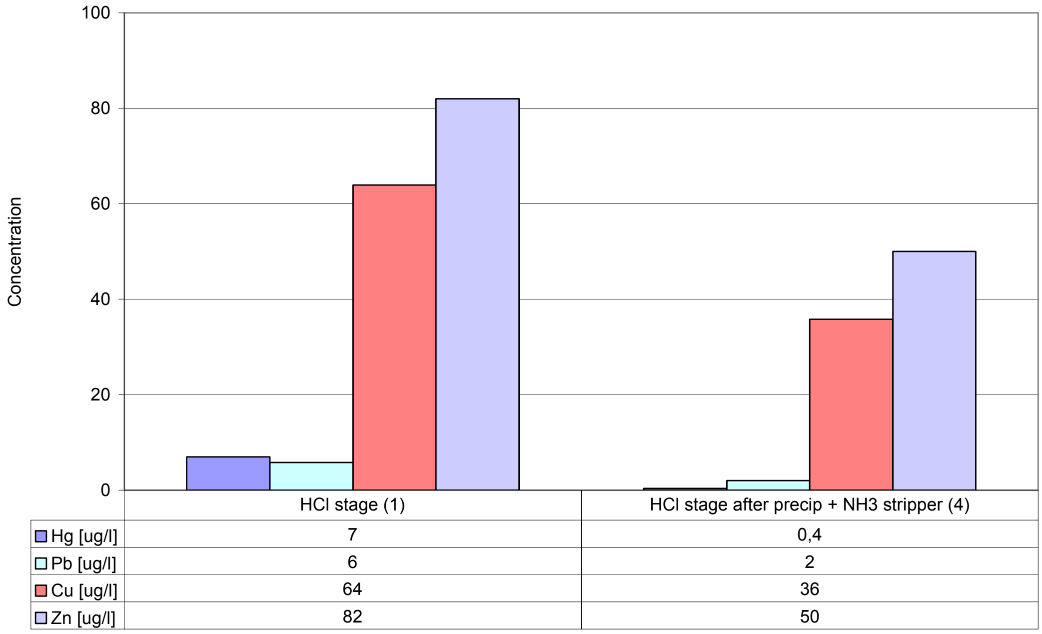
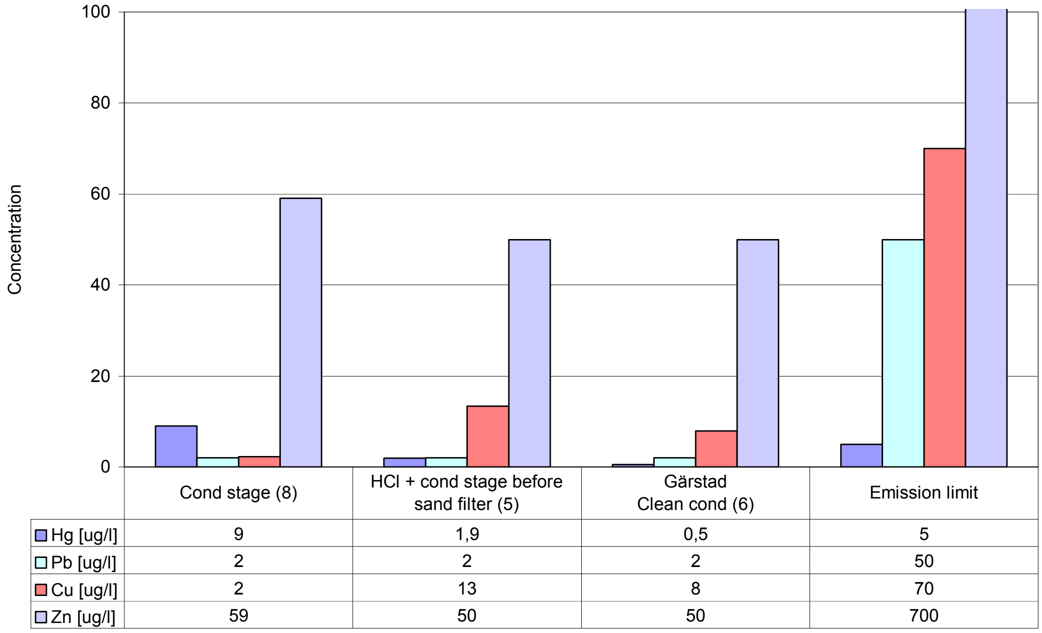


Figure 13. Heavy metal concentrations in the acidic water treatment

Figur 13. Tungmetallhalter i survattenreningen



	Cond stage (8)	HCl + cond stage before sand filter (5)	Gärstad Clean cond (6)	Emission limit
Hg [ug/l]	9	1,9	0,5	5
Pb [ug/l]	2	2	2	50
Cu [ug/l]	2	13	8	70
Zn [ug/l]	59	50	50	700

Figure 14. Heavy metal concentrations in the condensate water treatment

Figur 14. Tungmetallhalter i kondensatreningen

The heavy metal concentrations in the waste water from the condensation stage (sampling point 8 in the second diagram above) are in the same range as the concentrations in the acidic waste water after the precipitation (sampling point 4 in the first diagram above). However, the annual average Hg concentration in the untreated condensate is higher than the annual average in the untreated acidic water. After the sand and activated carbon filter (sampling point 6) the Hg concentration, as well as all other heavy metal concentrations, is below the emission limit.

3.3 Sysav combustion line 1&2

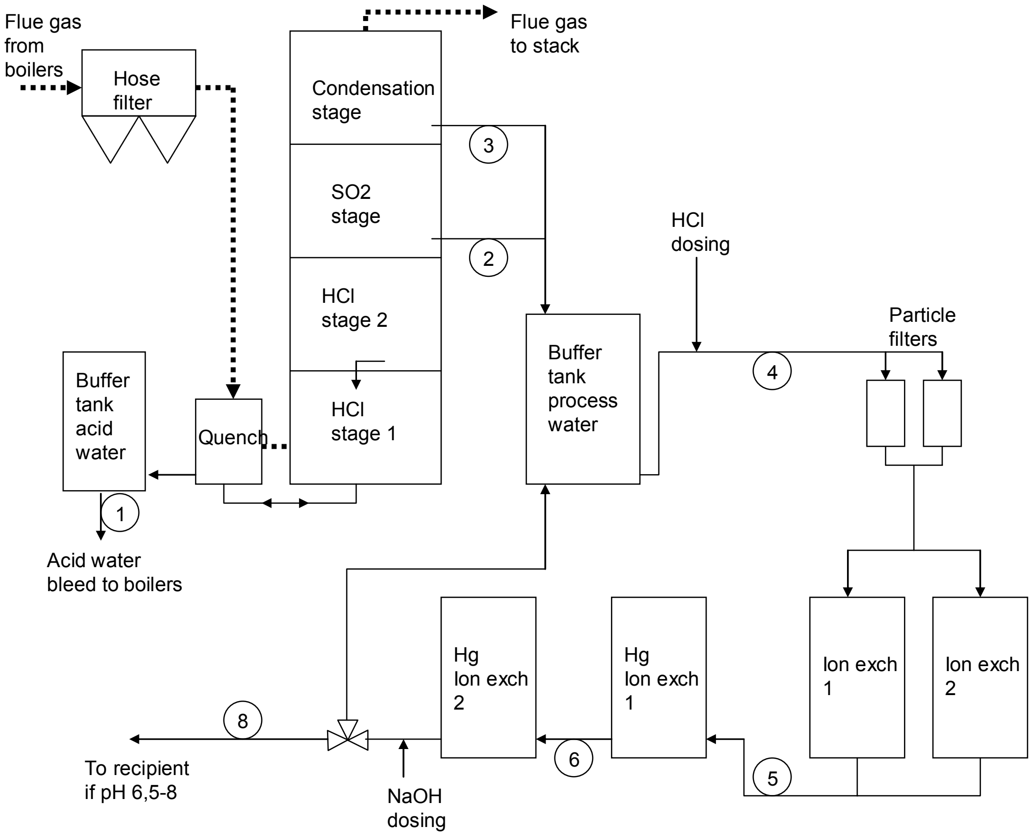


Figure 15. The waste water treatment of combustion line 1 and 2 at Sysav in Malmö (sampling points marked)

Figur 15. Processavloppsvattenreningen vid Sysav linje 1 och 2 i Malmö (provtagningspunkter markerade)

3.3.1 Technology and operational experience

Contact person	Rasmus Beckman, rasmus.beckman@sysav.se
Boilers	Two grate fired steam boilers (Martin GmbH) commissioned 1973. 2 x 30 MW
Fuel	Domestic/industrial waste (50/50)
Operation hours	6000 h/year. Depends on district heating needs.
Flue gas treatment	Fabric filter (Alstom 1981) and wet FGT (GMAB 2005)
Combined dust removal and acid gas reduction	Fabric filter with 6 chambers before wet flue gas treatment removes dust to < 5 mg/Nm^3
NO_x reduction	SNCR system with ammonia injection (Petro Miljö)
Acid gas reduction	Fabric filter with lime injection, quench and scrubber tower in four stages. Two HCl stages, one SO_2 stage and one condensation stage.
Flue gas condensation	Direct condensation connected to district heating system producing appr 6 MW depending on return temperature
Treatment of waste water from flue gas cleaning and flue gas condensation	GMAB by Eurowater 2005
Waste water from HCl stages	Appr 0,5 m^3/h of the water from the quench and HCl stages is pumped back to the boiler for destruction.
Waste water from SO_2 and condensation stages	Water from the SO_2 stage and condensation stage is discharged to a buffer tank and mixed before the waste water treatment. The water treatment consists of two particle filters, two ion-exchangers and two Hg ion-exchangers.

The flue gas coming from boiler 1&2 passes through a fabric filter with lime injection, where most of the pollutants are separated. The fabric filter consists of 6 chambers and reduces the dust level to < 5mg/Nm^3. The flue gas coming from the fabric filter first passes through a quench where it flows through a water curtain which quenches and saturates the gas with water vapour, cooling it down to wet bulb temperature, i e appr 60°C. The scrubber tower consists of four cleaning stages, two HCl stages, one SO_2 stage and one condensation stage. The quench and the HCl stages are communicating vessels. In the HCl stages substances like HCl, HF, ammonia and most of the heavy metals are separated from the flue gas. The pH in the HCl stages is kept < 2 to ensure an effective removal of ammonia slip from the SNCR system. In some cases HCl is dosed to keep the pH < 2. In the third cleaning stage SO_2 is separated from the flue gas by increasing the pH to 5,5 with NaOH dosing. The fourth stage is a condensation stage where heat is recovered from the flue gas and directly transferred to the district heating network with a plate heat exchanger. The condensation stage also separates remaining SO_2 from the flue gas by dosing of NaOH.

Heavily polluted excess water from the quench and the HCl stages is discharged, pH regulated and pumped to the boiler for destruction. The flow varies in the range of 0,3-0,5 m^3/h depending on the conductivity. Excess water from the SO_2 stage is discharged to a buffer tank for process water with an average flow of 1,7 m^3/h. The flow is regulated with a conductivity meter which is really a measure of the sulphate concentration in the water. Sulphate concentration varies depending on the SO_2 level in the inlet flue gas and is maximum 30 g/l. Condensate from the condensation stage is primarily reused in the flue gas treatment as process water to feed the quench, droplet separators etc. Excess condensate, appr 4 m^3/h, is discharged and mixed with the SO_2 stage water. The temperature of the mixed water is if needed lowered to 45 °C in a heat exchanger before it reaches the process water buffer tank, in order to protect the ion-exchangers in the water treatment.

The water treatment is designed for a maximum flow of 9 m^3/h. The average flow is 4-6 m^3/h. It consists of two particle filters, two heavy metal ion-exchangers and two mercury (Hg) selective ion-exchangers. Before the water reaches the water treatment, the pH is lowered with HCl from 6,5 to 4,5 to prevent absorption of calcium ions in the ion-exchangers. In the first step particles are removed in the particle filters. Pressure drop is continuously monitored over the filters and operators will get an alarm in the control room when it is too high. The next step is ion-exchangers where most of the dissolved metals are absorbed. The ion-exchangers are redundant, parallelly connected, and regenerate automatically with HCl after a certain amount of time. The regeneration process takes about 2 hours per column and happens appr 4 times per year. Regeneration water is sent back to the scrubber. The ion-exchangers also have an automatic back flushing function which starts on high pressure drop. In the two following steps Hg ions are removed from the water by two columns, connected in series, containing a special ion-exchange resin for Hg ion absorption. The Hg ion-exchangers can not be regenerated so the resin has to be exchanged with 3-5 year intervals. Before the cleaned water is pumped to the recipient (Öresund) the pH is regulated to 6,5-8 with NaOH.

The waste water treatment was commissioned in 2005. The commissioning went fine and the performance was satisfying except for the Hg levels. For this reason the originally installed activated carbon in the final column was exchanged for Hg ion-exchange resin. The problem remained and it was explained by that Hg ions formed a complex with cyanide which could not be captured in the ion-exchangers. The cause of the problem was the urea used in the SNCR system. When Sysav decided to change urea for ammonia in the SNCR system the problem was solved. The operators are very satisfied with the waste water treatment because it requires very little maintenance and handling of chemicals. They spend appr 3 hours per week for calibration, cleaning and changing of particle filters. The particle filters are changed twice a week and the resin in the ion-exchangers every third or fourth year. Some HCl and NaOH is consumed for pH regulation but it is not a large cost.

The system for pumping water from the HCl stages back to the boilers has been problematic. Originally the water was injected with nozzles directly into the boilers but the nozzles were constantly plugged because of the hot environment and required a lot of maintenance. After that Sysav tried to spray the water over the hoppers and mix it with the waste before incineration, but this led to ammonia smelling problems in the bunker area and corrosion problems in the hoppers. Sysav is currently trying out a new technique for injecting the acid water in the boiler, which has to be evaluated later.

3.3.2 Sampling and sampling points

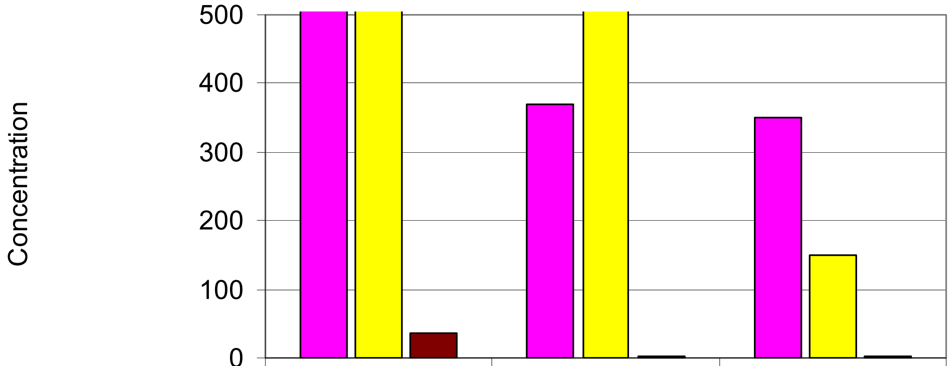
Waste water samples were taken 2010-11-30 with only one boiler in operation. The sampling points can be seen in Figure 15.

Samples were collected at two different times during appr four hours. For each sample the temperature, pH and conductivity were noticed. The two different samples, 500 ml each, were collected in a one litre bottle for each sampling point. Each one litre bottle was then analysed individually.

Sample 1 was taken directly after the quench on the bleed water going to the boiler for destruction. Sample 2 was taken on the bleed water from the SO_2 stage and sample 3 on the bleed water from the condensation stage. Sample 4 was taken on the mixed water just before the waste water treatment. Sample 5 was taken after particle filters and ion-exchangers. Sample 6 was taken after the first Hg ion-exchanger. Sample 7 was taken after the second Hg ion-exchanger on the outlet to recipient.

3.3.3 Concentrations of pollutants and cleaning efficiency

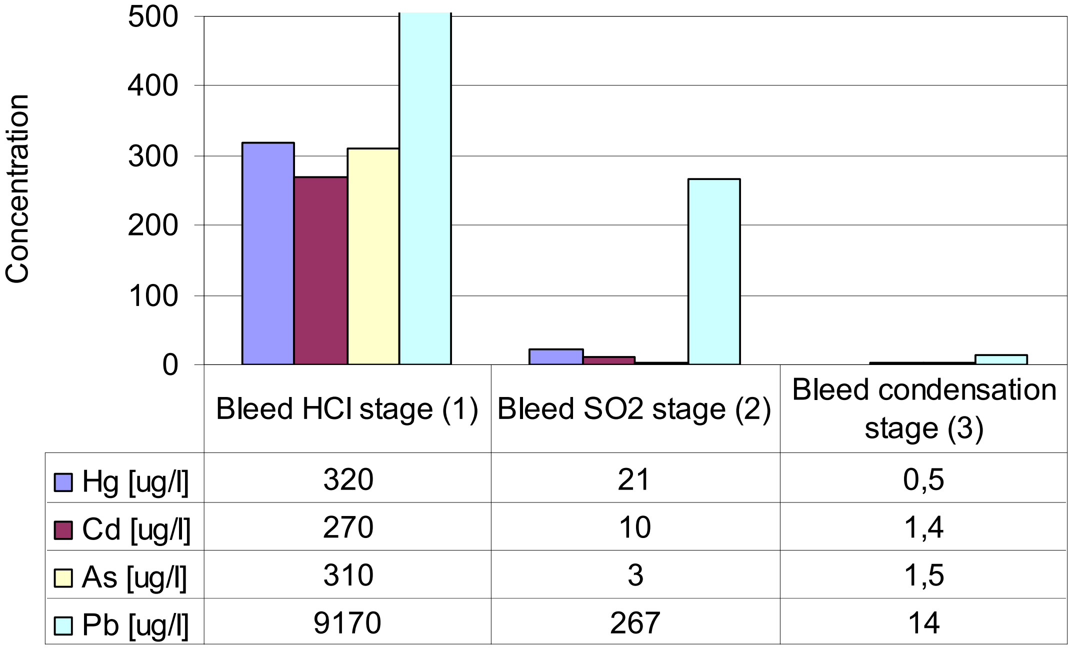
The concentrations of pollutants in waste water and condensate from the different stages of the flue gas cleaning and heat recovery system at Sysav line 1&2 are shown below.



	Bleed HCl stage (1)	Bleed SO2 stage (2)	Bleed condensation
Chlorides [mg/l]	82000	370	350
Sulphates [mg/l]	16000	20000	150
Susp solids [mg/l]	36	2	2

Figure 16. Chlorides, sulphates and suspended solids in untreated waste water at Sysav 1&2

Figur 16. Klorid, sulfat och suspenderat material i orenat vatten från skrubbrar på Sysav 1&2



	Bleed HCl stage (1)	Bleed SO2 stage (2)	Bleed condensation stage (3)
■ Hg [ug/l]	320	21	0,5
■ Cd [ug/l]	270	10	1,4
□ As [ug/l]	310	3	1,5
□ Pb [ug/l]	9170	267	14

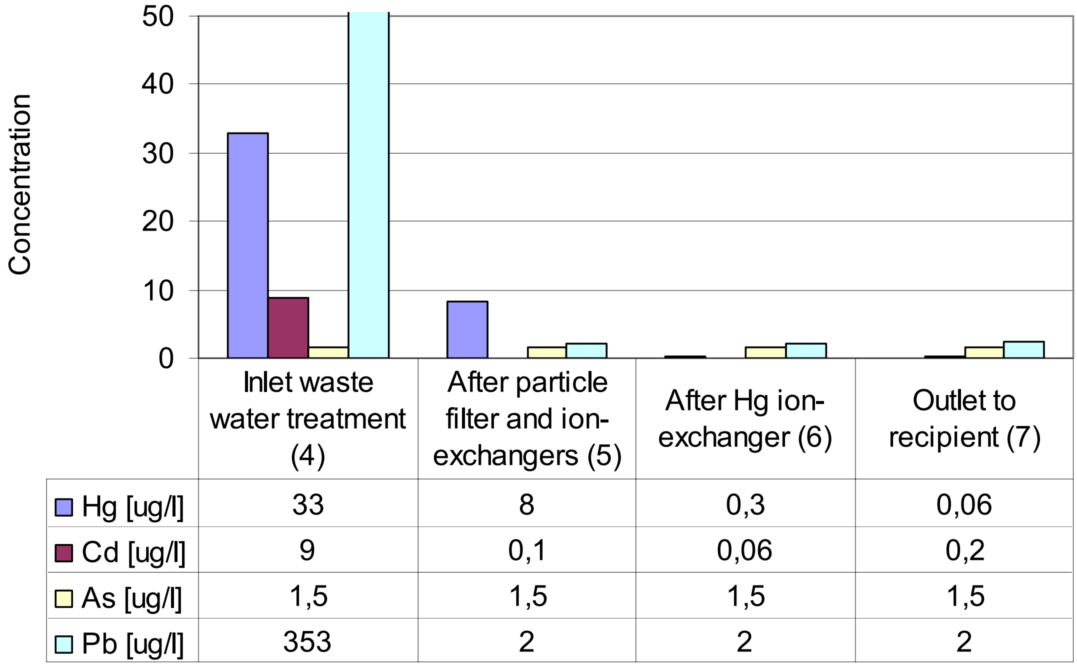
Figure 17. Heavy metals in untreated waste water at Sysav 1&2 in Malmö

Figur 17. Tungmetaller i orenat vatten från skrubbrar på Sysav 1&2 i Malmö

From the analysis data in the diagrams above it is clear that the flue gas cleaning system is functioning well. The waste water from the HCl stages (1) contains 99% of the absorbed chlorides. It is remarkable that a substantial part of the SO_2 is absorbed in the HCl stages where the pH is < 1. The main SO_2 absorption still takes place in the SO_2 stage (2) as expected. (Although the sulphate concentration is almost as high in the HCl stage as in the SO_2 stage, the waste water flow of the SO_2 stage is 3-5 times the flow in the HCl stage.) Outlet emission values from the stack were < 1 mg/Nm^3 for both HCl and SO_2.

The waste water from the HCl stages (1) had a suspended solids concentration of 36 mg/l, in contrast to the other waste waters where the suspended solids concentration was near or at the detection limit of 2 mg/l.

The absorption of heavy metals also mainly takes place in the quench and HCl stages. Most heavy metals were found in sample (1) from the quench and HCl stages (see Figure 17). This water is pumped back to the boiler and incinerated. Water from the SO_2 stage and condensation stage is treated in the water treatment plant.



	Inlet waste water treatment (4)	After particle filter and ion-exchangers (5)	After Hg ion-exchanger (6)	Outlet to recipient (7)
🟦 Hg [ug/l]	33	8	0,3	0,06
🟥 Cd [ug/l]	9	0,1	0,06	0,2
🟨 As [ug/l]	1,5	1,5	1,5	1,5
□ Pb [ug/l]	353	2	2	2

Figure 18. Performance of the waste water treatment in combustion line 1&2 at Sysav

Figur 18. Prestanda i vattenreningen tillhörande förbränningslinje 1&2 på Sysav

The bleed water from SO_2 stage and condensation stage, going to the waste water treatment, is relatively clean water with low levels of suspended solids and metals compared to bleed water from HCl stages. As shown in Figure 18 above, most heavy metals were absorbed in the first cleaning steps of the waste water treatment, which consists of particle filters and ion-exchangers. The total concentration of metals was reduced by 91% between the inlet of the water treatment (4) and the outlet of the ion-exchangers (5). For Cd and Pb the reduction was > 99 % and for Hg 75 %. Required outlet values were already reached for Pb and Cd but not for Hg. The inlet value of As (4) was under the detection limit 1,5 µg/l, so it is impossible to know the cleaning performance. In the following steps mainly Hg is absorbed in the Hg ion-exchangers. In Hg ion-exchanger 1, between (5) and (6), the Hg concentration is reduced by an additional 96% and in Hg ion-exchanger 2, between (6) and (7), the remaining Hg is reduced by 80%. The Hg ion-exchangers are very efficient, which gives outlet emission below < 0,1 µg/l Hg. For Cd and Pb there was a slight increase over the Hg ion-exchangers, probably caused by measurement error. In total 93% of the incoming metals are absorbed in the waste water treatment.

3.4 Värmekällan in Skövde

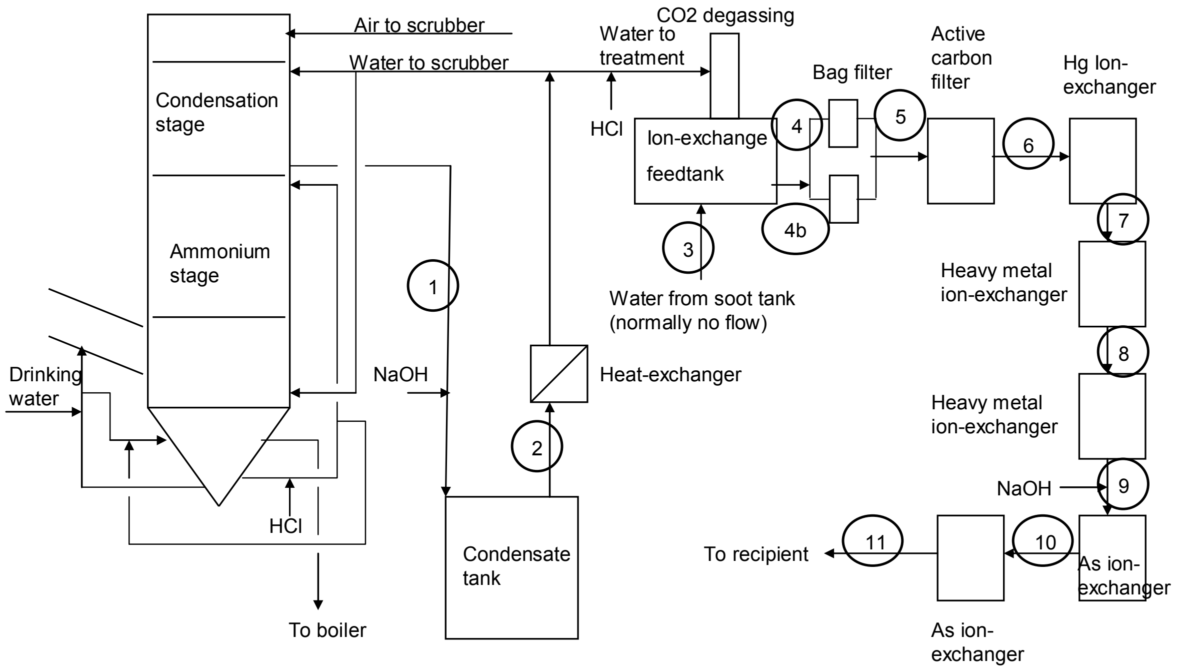


Figure 19. Waste water cleaning at Värmekällan in Skövde (sampling points marked)

Figur 19. Kondensatreningen vid Värmekällan i Skövde (provtagningspunkter markerade)

3.4.1 Technology and operational experience

Contact person	Håkan Johansson, hakan.r.johansson@skovde.se
Boiler	20 MW, grate fired oven and boiler from 2007
Fuel	Domestic waste 60 %, industrial waste
Operation hours	All year
Flue gas treatment	
Combined dust removal and acid gas reduction	Injection of lime, activated carbon and recycled fly ash before dust removal in fabric filters (Alstom's NID system)
NO_x reduction	SNCR with NH_3
Acid gas and NH_3 reduction	Wet scrubbing with NaOH in the lower part of the scrubber
NH_3 reduction	Wet scrubbing in the lower middle part of the scrubber
Flue gas condensation	Ca 3,4 MW scrubber (Pilum 2007). Water is recycled from the bottom part of the scrubber to the quench part.
Treatment of waste water from flue gas cleaning and flue gas condensation	Pilum
Waste water from ammonia stages	Recycled back into scrubber
Flue gas condensate	CO_2 removal (by aeration in tank), bag filters, activated carbon filter, Hg selective ion-exchange resin, heavy metals selective ion-exchange resin, As selective ion-exchange resin
Recipient	Municipal waste water plant

An essential part of the design in Skövde is a high degree of flue gas cleaning before the flue gas enters the flue gas condensation. The flue gas is cleaned by the NID[9] system, which is based on the reaction between acid gases and $Ca(OH)_2$ in humid conditions. The humidified mixture of hydrated lime and activated carbon and recycled fly ash is re-injected into the system and cools the inlet flue gas by evaporation.

The cooled flue gas then flows to the dust collector, in this case a fabric filter, where the particles in the flue gas are removed and recycled.

The quench is a part of the flue gas condensation. Here the incoming flue gas is cooled down by recycled water from the bottom part of the scrubber. After the quench, the flue gas first enters the acidic stage and then the ammonia stage of the scrubber where metals, chlorides and ammonia are removed. After this stage the flue gas enters the

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[9] Semi-dry system

condensation stage. The ammonia stage and the condensation stage are separated by plates.

Waste water from the ammonia stage, is recycled to the quench, but some of it is also pumped to the boiler for destruction. The pH in the acidic gas and ammonia scrubber tank shall be 2 for optimal removal of ammonia but also to minimize the absorption of CO_2. The pH is regulated by addition of HCl. After the ammonia stage, NaOH is added to the condensate before it enters the condensate tank of the condensation stage.

The water treatment mainly consists of CO_2 degassing, bag filters, activated carbon filter, one ion-exchanger selective for Hg, two ion-exchangers selective for heavy metals and two ion-exchangers selective for As. In order to minimize the carbonate scaling and minimize the NaOH consumption, the condensate is degassed before treatment. The pH is lowered to 4,8 before the bag filters and then raised to 7,7 again before the As selective ion-exchanger. (Due to large pumps, the pH control is not very accurate and the pH varies within a rather wide range, between 7 and 9.)

The condensate flow rate is appr 3,5 m^3/h. The activated carbon filter and the five ion-exchanger columns have a volume of appr 500 l each. The columns are designed for an exchange of ion-exchange resins every second year. The two heavy metal selective ion-exchanger column fillings have been replaced once, due to Cd breakthrough. The breakthrough occurred after appr two years of operation, first in the first column and soon after also in the second column. The cost was 130 000 SEK. Besides the time required for resin renewal the water treatment requires very little work, just pH meter calibration every second week. The average time required for this is less than one hour per week.

The pH before the water enters the first ion-exchange columns varied between 7 and 10 during the sampling period due to regulation difficulties. The pumps have an over-capacity and the system is therefore hard to keep steady. The plant has had some problems with the flue gas cleaning during the last couple of weeks due to problems with the fabric filters or the dust measurement. The fabric filters will be replaced. This problem might have affected the content of substances in the samples taken during the visit.

At Värmekällan, the acidic water in the quench, appr 100 l/h, is recycled back into the boiler. The water treated in the water treatment is therefore quite unpolluted. The impurities in the acidic water will be captured in the fabric filter instead of in the water treatment due to the recycling of acidic water. The acidic water is recycled without prior neutralisation. The recycling has been rebuilt several times. At first the acidic water was recycled to the convection part of the boiler. This resulted in hard deposits on the tubes of the convection part. Tests were then made to recycle the acidic water to the bottom ash discharge system of the boiler. This method was abandoned due to problems with ammonia smelling bottom ash. Now the acidic water is injected into the incineration chamber a few meters above the grate. According to plant representatives this seems to be a good solution and no corrosion problems have been detected yet during the annual corrosion measurements of the boiler.

3.4.2 Sampling and sampling points

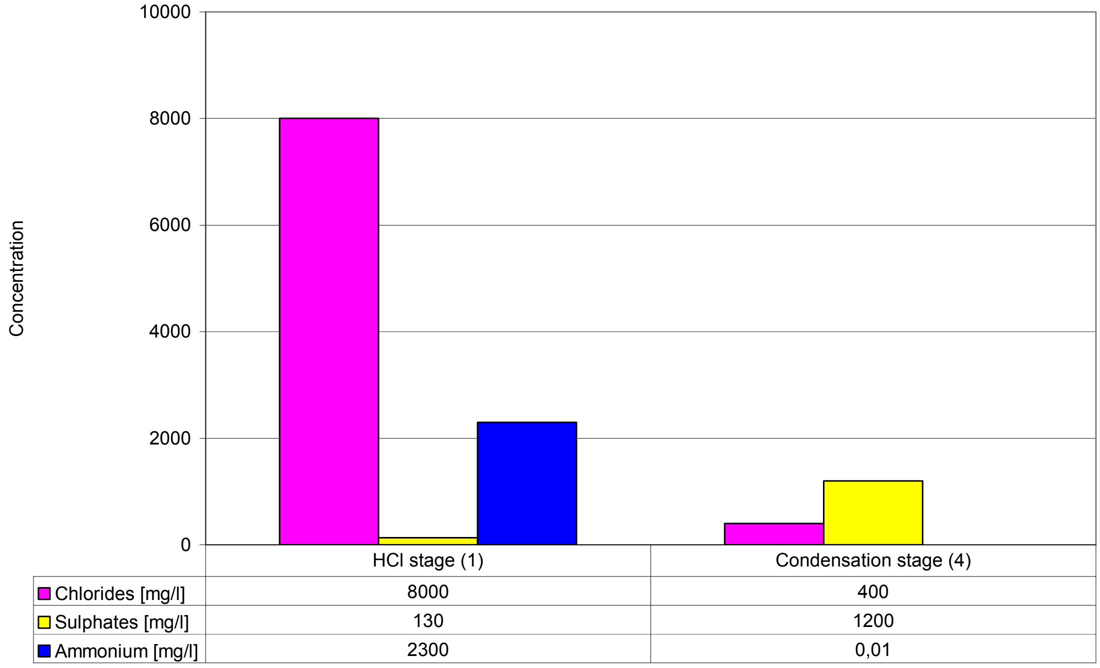
Samples have been taken at various points in the treatment plant (see Figure 19). The samples were taken 2010-11-04.

3.4.3 Concentrations of pollutants and cleaning efficiency

The concentrations of pollutants in waste water and condensate from the different stages of the flue gas cleaning and heat recovery system at Värmekällan in Skövde are shown below. (Data for the HCl stage are typical plant data. No sample was taken here when the plant was visited.)

The chlorides in the flue gas are absorbed mainly in the acidic (HCl) stage, and the SO_2 is absorbed (as sulphate) mainly in the neutral condensation stage.

Ammonia, from the SNCR type NO_x reduction, is almost completely absorbed in the acidic stage.



	HCl stage (1)	Condensation stage (4)
🟪 Chlorides [mg/l]	8000	400
🟨 Sulphates [mg/l]	130	1200
🟦 Ammonium [mg/l]	2300	0,01

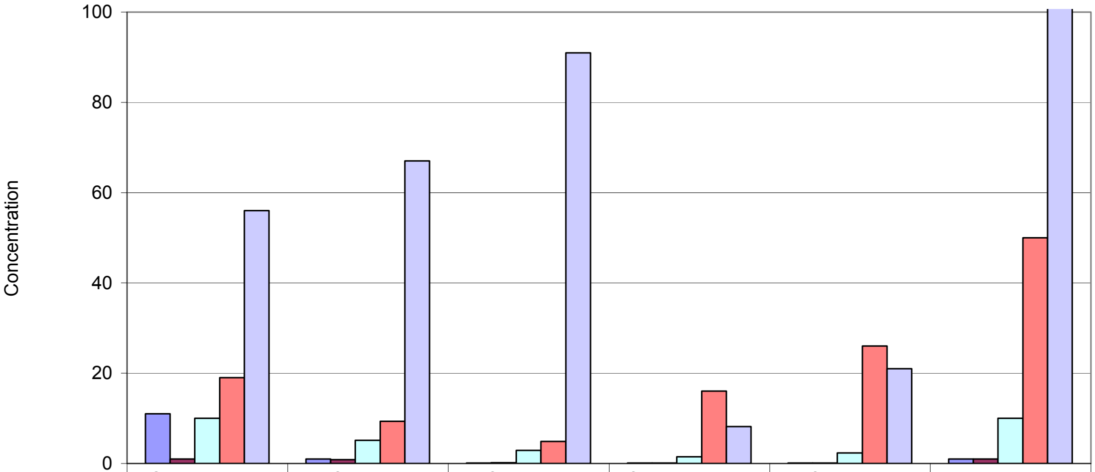
Figure 20. Chlorides, sulphates and ammonium in untreated waste water at Värmekällan

Figur 20. Klorid, sulfat och ammonium i orenat avloppsvatten på Värmekällan

The metal concentrations in the waste water from the condensation stage are low, and near or below the detection limits of many metals. All metal concentrations in the untreated condensate, except for Hg, are already below the emission limits of the plant.

90% of the Hg is removed in the carbon filter, which is actually sufficient to meet the required emission levels. Another 90% of the remaining Hg, as well as 80% of the remaining Cd, is removed in the Hg selective ion-exchanger. The two heavy metal ion-exchangers remove mainly Zn. See diagram below.

The activity of the two As selective filters is impossible to evaluate, due to the low levels already before the filters. (The As concentrations of all samples were below the detection limits.)



	Condensation stage (4)	After active carbon filter (6)	After Hg ion-exchanger (7)	After heavy metal ion-exchanger (9)	After As ion-exchanger (11)	Emission limit
□ Hg [ug/l]	11	1	0,05	0,05	0,05	1
■ Cd [ug/l]	1,00	0,84	0,18	0,05	0,05	1
□ Pb [ug/l]	10	5,1	2,9	1,5	2,3	10
■ Cu [ug/l]	19	9,3	4,9	16	26	50
□ Zn [ug/l]	56	67	91	8,2	21	500

Figure 21. Heavy metals in untreated waste water at Värmekällan in Skövde

Figur 21. Tungmetaller i orenat avloppsvatten på Värmekällan i Skövde

3.5 Måbjergvaerket

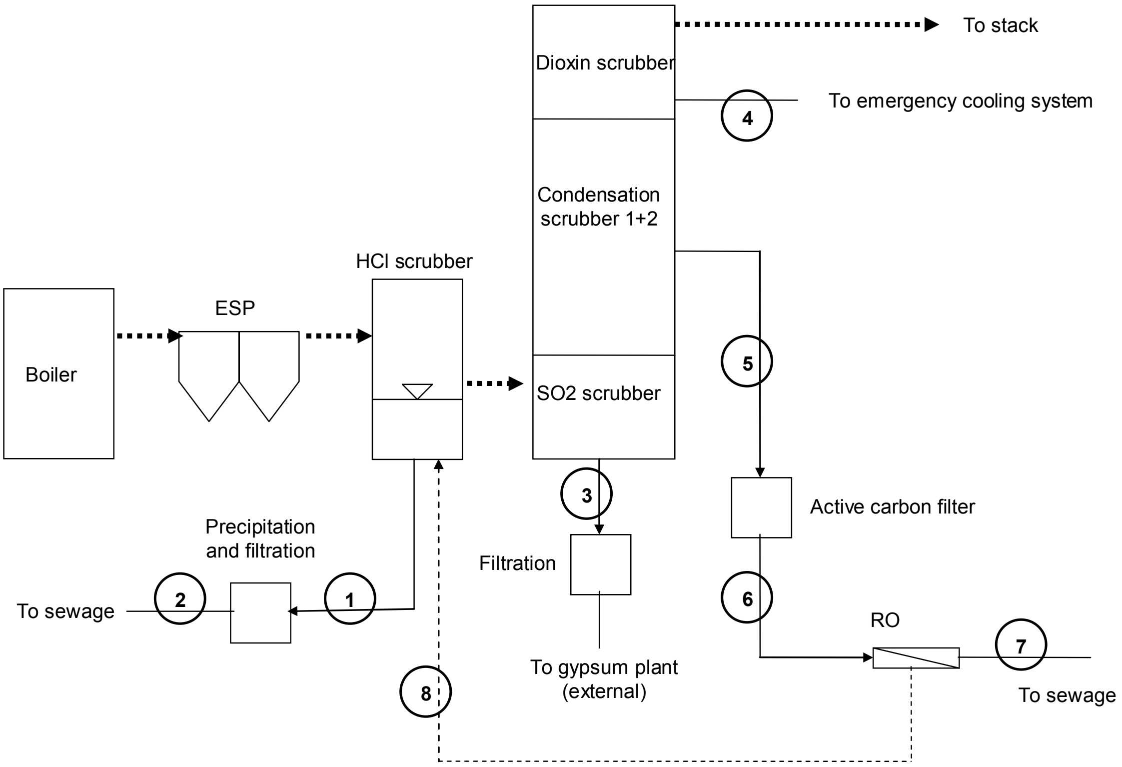


Figure 22. Flue gas treatment, condensation and waste water cleaning at Måbjergvaerket in Holstebro (sampling points marked)

Figur 22. Rökgasrening, kondensering och kondensatrening på Måbjergvaerket i Holstebro (provtagningspunkter markerade)

3.5.1 Technology and operational experience

Contact person	Mogens Tind Kristensen, mogtk@dongenergy.dk
Boiler	2*30 MW (10 ton waste/h) grate fired ovens and Eckrohr boilers (Völund 1992)
Fuel	Domestic/industrial waste (50/50), sewage sludge
Operation hours	Boiler at full load all year, flue gas condensation in operation during winter
Flue gas treatment	
Dust removal	ESP with 2 fields (1992)
NO_x reduction	SNCR (ammonia injection)
Acid gas reduction	Wet scrubbing with limestone (ABB Flakt 1992)
	Rebuilding of wet scrubber to packed tower and addition of new packed tower with NaOH scrubbing in SO_2 stage, condensation stage and dioxin stage (Götaverken Miljö 2004)
Flue gas condensation	9 MW energy recovery in the flue gas condensation stage (Götaverken Miljö 2004)
Treatment of waste water from flue gas cleaning and flue gas condensation	
Waste water from HCl stage	Appr 5 m^3/h of HCl scrubber water (in total from both boiler lines) is removed and treated by addition of slaked lime, $FeCl_3$, NaOH, MP7 and polymer, sedimentation in lamella clarifier and filtration in activated carbon filter before discharge to sewage.
Waste water from SO_2, condensation and dioxin stages	0,7 m^3/h of SO_2 scrubber water (in total from both boiler lines) is removed, filtrated in bag filter and sent to external gypsum plant.
Flue gas condensate	The condensate, appr 16 m^3/h (in total from both boiler lines), is cleaned in bag filters and activated carbon filters, cooled and cleaned further in bag filter and RO (HOH 2005). RO concentrate (or untreated flue gas condensate from before RO) is used as feed water in the HCl scrubbers. RO permeate is discharged to sewage.
Handling of untreated waste waters and sludge	
Activated carbon from waste water treatment	Incinerated in the ovens
Concentrate from RO	Recycled to acidic scrubbers
Sludge from lamella	Dewatered in filter press and sent to disposal

Originally the two WtE boilers were equipped with 2-field electrostatic precipitators and HCl scrubbers. The waste water from the scrubber was, and still is, cleaned in a conventional waste water treatment plant by addition of limestone, CO_2 removal (in the pipe from the first buffer tank to the neutralisation tank placed 3 m below), neutralisation with slaked lime and NaOH, precipitation and sedimentation and finally activated carbon filtration.

In 2004 additional stages for SO_2 and dioxin removal, as well as for energy recovery, were installed. All scrubber stages, including the HCl stage, were equipped with tower packing material doped with activated carbon.

Waste water from the SO_2 stage is filtrated and sent to a neighbouring gypsum plant.

Waste water from the flue gas condensation and energy recovery stage was originally cleaned by filtration in bag filter and activated carbon filter. The cleaned condensate was used as feed water for the HCl scrubber or discharged to sewage.

In 2005 an RO plant was installed to clean the condensate further. Before the RO the condensate is cooled and bag filtered. The RO concentrate is discharged to sewage. The RO permeate was originally used as feed water in the RO/mixed-bed demineralisation plant at the site. After a period of straw firing in the WtE plant, the flue gas condensate treatment experienced some operation problems. The pre-filter before the RO as well as the RO membranes were contaminated. After cleaning of the RO, and renewal of the activated carbon filter, problems with the operation of the mixed-bed filter remained. The mixed-bed ion-exchanger of the demineralisation plant is normally regenerated externally. However, after the contamination problems the running time of the mixed-bed filter between regenerations was decreased. At present, therefore, the RO permeate is discharged to sewage.

Experience from the waste water treatment is positive. Appr 8 h/week are spent on maintenance, mainly on the waste water treatment of the acidic scrubbers which is cleaned from calcium deposits during one day every second week. The RO membranes are cleaned once a year. The activated carbon filters are renewed every second year. In addition to this dedicated maintenance, general maintenance on pumps and instruments etc is necessary.

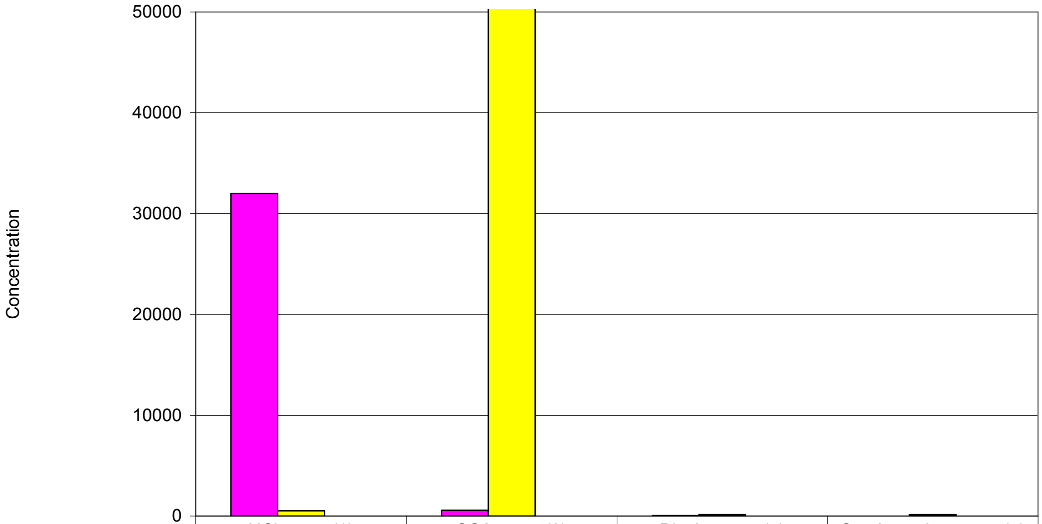
3.5.2 Sampling and sampling points

Waste water samples were taken 2010-11-18 at full load operation of the plant. The sampling points can be seen in Figure 22.

Samples 3-5 were taken directly after the SO_2 stage, condensation stage and dioxin stage of boiler line 2. The other samples are from sampling points in the waste water cleaning located after buffer tanks and mixing of water from both lines, and therefore contain a mixture of waste water from line 1 and line 2.

3.5.3 Concentrations of pollutants and cleaning efficiency

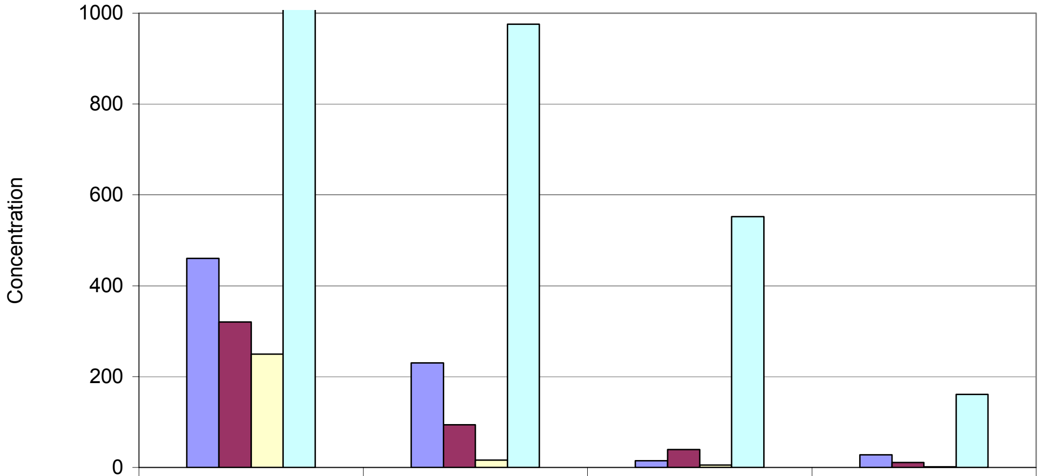
The concentrations of pollutants in waste water and condensate from the different stages of the flue gas cleaning and heat recovery system at Måbjergvaerket are shown below.



	HCl stage (1)	SO2 stage (3)	Dioxin stage (4)	Condensation stage (5)
■ Chlorides [mg/l]	32000	560	23	6
■ Sulphates [mg/l]	520	57000	150	150
■ Susp solids [mg/l]	14	3	2	2

Figure 23. Chlorides, sulphates and suspended solids in untreated waste water from flue gas cleaning and condensation stages at Måbjergvaerket

Figur 23. Klorid, sulfat och suspenderat material i orenat avloppsvatten från rökgasrening och kondensering på Måbjergvaerket



	HCl stage (1)	SO2 stage (3)	Dioxin stage (4)	Condensation stage (5)
■ Hg [ug/l]	460	230	15	28
■ Cd [ug/l]	320	94	40	11
□ As [ug/l]	250	16	5	1,9
□ Pb [ug/l]	6480	976	552	161

Figure 24. Heavy metals in untreated waste water at Måbjergvaerket

Figur 24. Tungmetaller i orenat avloppsvatten på Måbjergvaerket

From the analysis data in the diagrams above it is clear that the flue gas cleaning system is functioning well. The chlorides are absorbed almost exclusively in the acidic (HCl) stage. The water of the following stages contains less than 1% of the absorbed chlorides. Instead, appr 90% of the SO_x absorption takes place in the neutral (SO_2) stage, and only appr 5% in the HCl stage (where SO_3 is absorbed) and 5% in the dioxin stage.

The waste water from the HCl stage had a suspended solids concentration of 14 mg/l, in contrast to the other waste waters where the suspended solids concentration was near or at the detection limit of 2 mg/l.

The absorption of heavy metals also mainly takes place in the HCl stage. 70-100% of the total amount of heavy metals in the waste waters was found in sample (1) from the HCl stage.

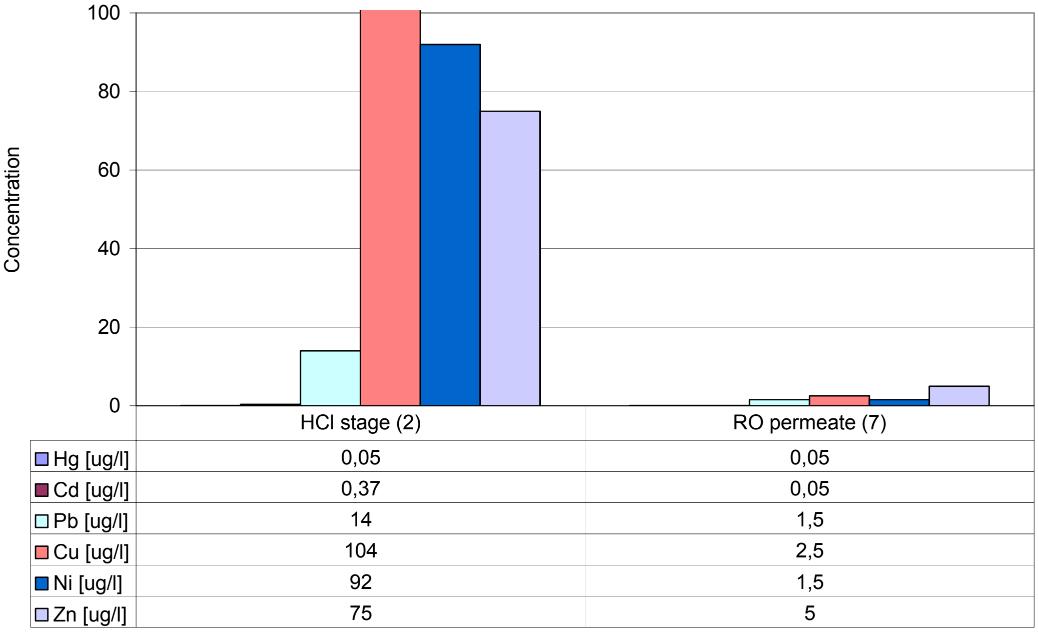
The remaining heavy metals were found in the other waste waters. Among these waters, samples (3) and (4) from the SO_2 and dioxin stages had higher heavy metal concentrations than sample (5) from the condensation stage. However, due to the larger volume of the condensate which has a flow rate of appr 16 m/h in total for lines 1&2, much of the heavy metals is found in the condensate. 15% of the Hg and 10% of the Cd was found in the condensate, even though the concentration of Hg and Cd in condensate sample (5) was only 3-6% of the concentration found in the HCl stage water sample (1).

The waste water treatment of the HCl stage must cope with the most heavily contaminated water. In this conventional neutralisation, precipitation, sedimentation and filtration based waste water cleaning plant almost 100% of the Hg, Cd and Pb is removed. From sample (1) to sample (2) the concentration of many metals was reduced by more than 90%. An exception was As, but this was ascribed to poor analysis accuracy.

The activated carbon filter in the condensate cleaning system is efficient in removing Hg. From sample (5) before cleaning to sample (6) after cleaning the Hg concentration is reduced by more than 90%. Pb and Cu are reduced by appr 40%, whereas Zn is not reduced at all.

An evaluation of the cleaning efficiency of the RO, which is used for additional condensate cleaning after the activated carbon filter, is not possible to make for the pollutants whose concentration are near the detection limit. However, Hg, Cd, Pb and Zn are reduced by 97-100% from sample (6) before RO to sample (7) after RO.

The heavy metal concentrations in clean waste water are shown below.



	HCl stage (2)	RO permeate (7)
■ Hg [ug/l]	0,05	0,05
■ Cd [ug/l]	0,37	0,05
□ Pb [ug/l]	14	1,5
■ Cu [ug/l]	104	2,5
■ Ni [ug/l]	92	1,5
□ Zn [ug/l]	75	5

Figure 25. Heavy metals in treated waste water at Måbjergvaerket

Figur 25. Tungmetaller i renat avloppsvatten på Måbjergvaerket

3.6 Sönderborg Kraftvarmevaerk

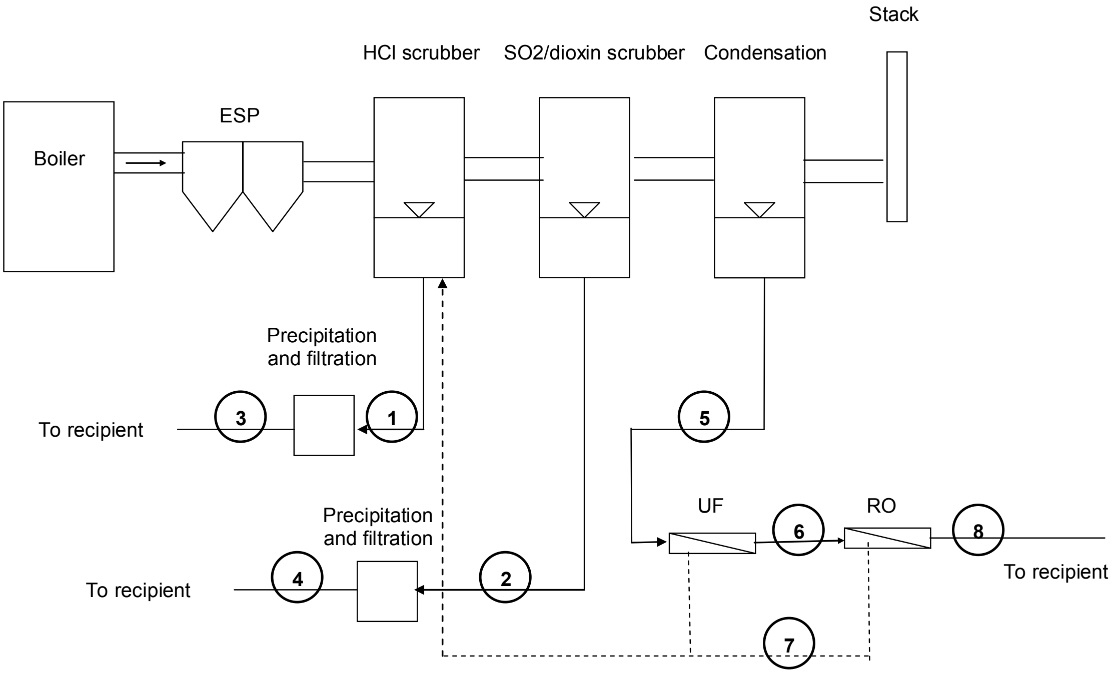


Figure 26. Flue gas treatment, condensation and waste water cleaning at Sönderborg Kraftvarmevaerk (sampling points marked)

Figur 26. Rökgasrening, kondensering och kondensatrening på Sönderborg Kraftvarmevaerk (provtagningspunkter markerade)

3.6.1 Technology and operational experience

Contact person	Tue Geil Christensen, tgc@skvv.dk Peter Mouritsen, pm@skvv.dk
Boiler	23 MW (8 ton/h) grate fired oven (Krüger, now Völund) and boiler (Burmeister & Wain Energy 1996)
Fuel	Domestic waste, industrial waste
Operation hours	8000 h/year, part load during summer
Flue gas treatment	
Dust removal	ESP with 2 fields, 190°C (ABB, now Alstom 1996)
NO_x reduction	No
Acid gas reduction	HCl stage: Wet scrubbing with water in 2 stages, 63-64°C (Alstom 1996) SO_2 and dioxin stage: Wet scrubbing with NaOH and activated carbon in 2 stages, the first of which is a packed tower (LAB 2004)
Flue gas condensation	4,5 MW energy recovery by flue gas condensation in a packed tower, 48°C (Götaverken Miljö 2008)
Treatment of waste water from flue gas cleaning and flue gas condensation	
Waste water from HCl stage	Appr 2 m^3/h of the scrubber water, pH 0, is removed and treated by addition of lime, NaOH, Hg precipitation chemical, $FeCl_3$ and polymer, sedimentation in lamella clarifier and filtration in sand filter before discharge to recipient (Alstom 1996)
Waste water from SO_2/dioxin stage	Appr 1,5 m^3/h of the scrubber water, pH 4,5-6, is removed and treated by addition of NaOH, Hg precipitation chemical, $FeCl_3$ and polymer, sedimentation in lamella clarifier and filtration in sand filter before discharge to recipient (LAB 2008)
Flue gas condensate	The condensate, appr 3 m^3/h pH 6, is used as feed water in the HCl and SO_2 scrubbers. Excess condensate is cooled to 35°C and cleaned in bag filter, UF, bag filter and RO before discharge to recipient. (Götaverken Miljö/Mercatus 2008)
Handling of untreated waste waters and sludge	
Activated carbon from SO_2/dioxin stage	Incinerated in the oven
Concentrate from RO	Recycled to acidic scrubbers
Sludge from lamella	Sent to landfill in old salt mine

Originally the plant was equipped with a 2-field ESP and a 2-stage acidic (HCl) scrubber. The waste water from the acidic scrubber was cleaned, and still is cleaned, in a conventional waste water treatment plant by neutralisation with lime and NaOH, precipitation and sedimentation and finally sand filtration.

In 2004 the flue gas cleaning was improved by installation of a 2-stage neutral scrubber with activated carbon injection for dioxin removal. The waste water from this SO_2 and dioxin scrubber stage is cleaned in a separate waste water treatment plant. This waste water treatment is similar to the old waste water treatment plant above, with neutralisation, sedimentation and sand filtration. However, only NaOH is used for neutralisation, as the waste water from the SO_2 and dioxin scrubber is less acidic than the waste water from the HCl scrubber.

In 2008 an energy recovery stage was installed. Here the flue gas is condensed in a tower packed with tower packing doped with activated carbon for dioxin removal. (Since dioxin removal is already taken care of in the SO_2 scrubber stage, the neutral scrubber acts as a police filter for dioxin removal.)

Waste water from the flue gas condensation stage is cleaned by UF and RO membrane filtration. Particles are removed in a bag filter before the UF and a second bag filter before the RO. The RO concentrate is used as feed water for the acidic scrubber. The RO permeate is discharged to the sea.

Experience from the waste water treatment is positive. Appr 6 h/week are spent on maintenance of the waste water treatment plants. Most of the time is spent on the waste water treatment of the acidic scrubber, which needs to be cleaned from calcium deposits. The sand filter of the acidic scrubber is washed with acidic scrubber liquid once per month. The bag filter before the UF has been exchanged once, because it was discoloured. However, experience shows that the UF may be unnecessary as a pre-filter before the RO, since the condensate is very free from particles. The RO membranes are cleaned twice per year. This is considered to be adequate, since less frequent cleaning during the first year of operation had resulted in some loss of flow capacity in the RO.

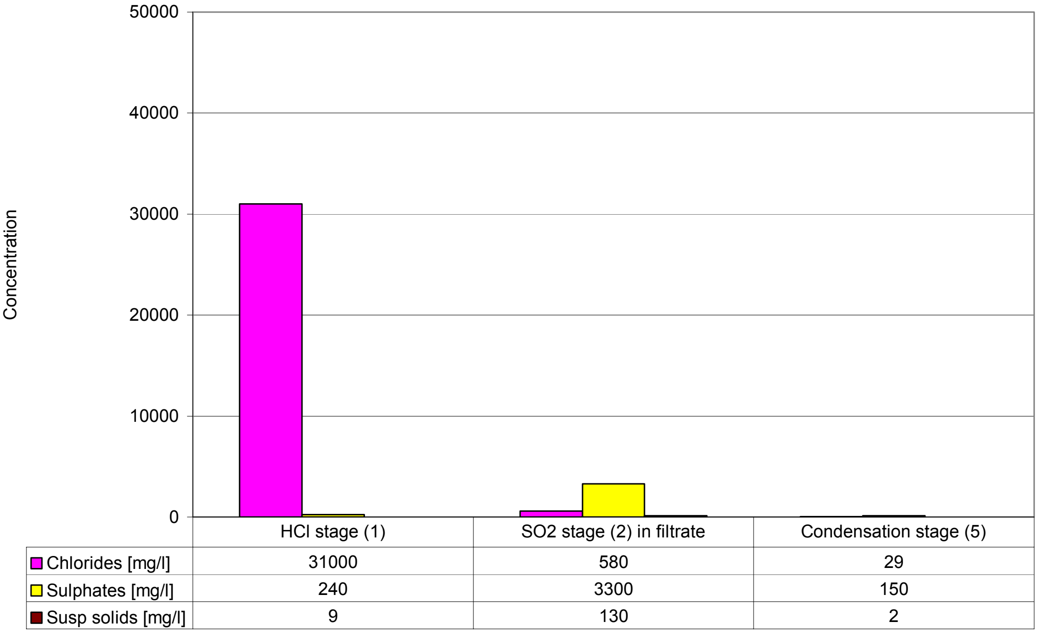
The quality of the RO permeate is similar to the quality of a typical permeate from an RO operating on municipal water. The conductivity is below 1 mS/m. In future the permeate will be used as a substitute for municipal water in the boiler feed water production plant. Tests will be made to lead the RO permeate directly to the EDI of the RO/EDI type demineralisation plant at the site.

3.6.2 Sampling and sampling points

Waste water samples were taken 2010-11-11 at full load operation of the plant. The sampling points can be seen in Figure 26.

3.6.3 Concentrations of pollutants and cleaning efficiency

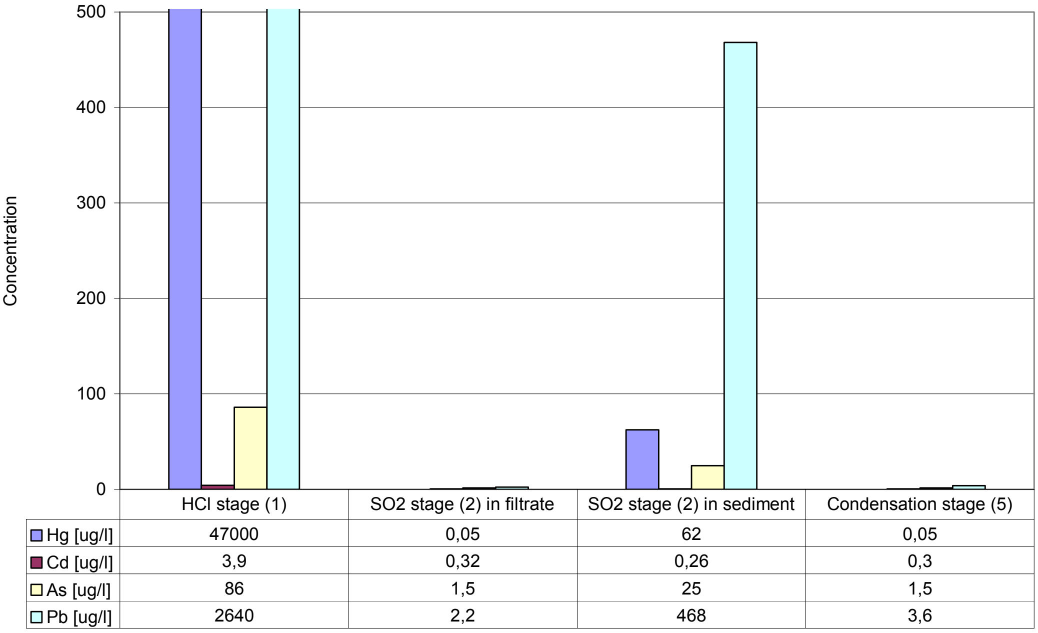
The concentrations of pollutants in waste water and condensate from the different stages of the flue gas cleaning and heat recovery system at Sönderborg Kraftvarmevaerk are shown below.



	HCl stage (1)	SO2 stage (2) in filtrate	Condensation stage (5)
■ Chlorides [mg/l]	31000	580	29
□ Sulphates [mg/l]	240	3300	150
■ Susp solids [mg/l]	9	130	2

Figure 27. Chlorides, sulphates and suspended solids in untreated waste water from flue gas cleaning and condensation stages at Sönderborg Kraftvarmevaerk

Figur 27. Klorid, sulfat och suspenderat material i orenat avloppsvatten från rökgasrening och kondensering på Sönderborg Kraftvarmevaerk



	HCl stage (1)	SO2 stage (2) in filtrate	SO2 stage (2) in sediment	Condensation stage (5)
□ Hg [ug/l]	47000	0,05	62	0,05
■ Cd [ug/l]	3,9	0,32	0,26	0,3
□ As [ug/l]	86	1,5	25	1,5
□ Pb [ug/l]	2640	2,2	468	3,6

Figure 28. Heavy metals in untreated waste water at Sönderborg Kraftvarmevaerk

Figur 28. Tungmetaller i orenat avloppsvatten på Sönderborg Kraftvarmevaerk

As for Måbjergvaerket, also at Sönderborg Kraftvarmevaerk the chlorides are absorbed almost exclusively in the acidic (HCl) stage. Almost 99% of the absorbed chlorides were found here. Instead, almost 85% of the absorbed SO_x was found in waste water from the neutral (SO_2) stage, and only appr 8% in the HCl stage (where SO_3 is absorbed) and 8% in the condensation stage.

The waste water from the HCl stage had a suspended solids concentration of 9 mg/l, in contrast to the condensate where the suspended solids concentration was at the detection limit of 2 mg/l.

In sample (2) from the SO_2 stage, the suspended solids concentration was 130 mg/l. This was clearly due to contamination with activated carbon which is used in the SO_2 scrubber. The activated carbon seems to be very efficient in absorbing heavy metals, especially Hg and Cd. Centrifugation of the sample indicated that 100% of the Hg and Pb, and more than 90% of the Cd and As in the waste water from the SO_2 stage was absorbed on the activated carbon.

However, as for Måbjergvaerket, the majority of the heavy metals were found in the waste water from the HCl stage. 75-100% of the total amount of heavy metals in the waste waters was found in sample (1) from the HCl stage.

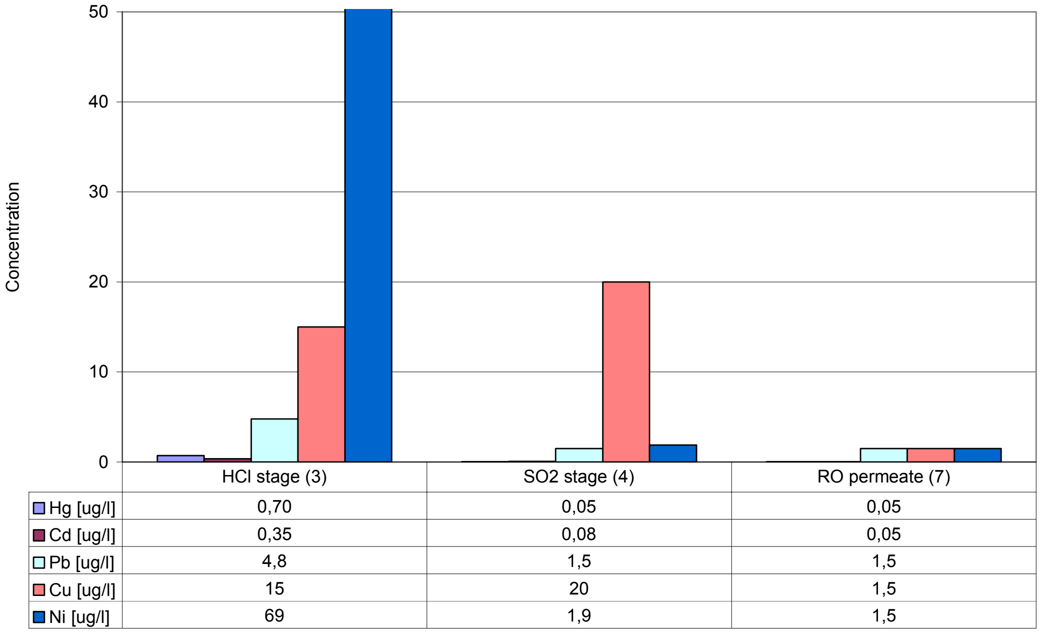
The remaining heavy metals were found in the waste waters from the SO_2 stage and the condensation stage. In Figure 28 the concentration of Hg, Cd, As and Pb in samples (1), (2) and (3), from the HCl, SO_2 and condensation stage respectively, are shown. The concentration in sample (2) is shown for metals in solution and activated carbon bound

metals (expressed as mg/l waste water) separately. Clearly, if the activated carbon bound heavy metals are excluded, the waste water from the SO_2 stage has a heavy metal concentration which is about as low as the concentration in the condensate.
As for Måbjergvaerket, at Sönderborg Kraftvarmevaerk the waste water treatment of the HCl stage must cope with the most heavily contaminated water. In this conventional neutralisation, precipitation, sedimentation and filtration based waste water cleaning plant almost 100% of the Hg, Cd and Pb is removed. From sample (1) to sample (3) the concentration of most metals was reduced by more than 90%.

The separate neutralisation, precipitation, sedimentation and filtration based waste water cleaning plant of the SO_2 stage is exposed to much lower heavy metal concentrations. A number of the analysed metal concentrations are near or at the detection limit. The concentrations of heavy metals, which were present in detectable amounts, were reduced by 70-100% from sample (2) before waste water cleaning to sample (4) after cleaning.

An evaluation of the cleaning efficiency of the UF and RO systems, which are used for condensate cleaning, is not possible to make based on analysis data. The concentrations of most pollutants in sample (5) before cleaning are near the detection limit, and so are the concentrations in samples (6) after UF and (7) after RO.

The heavy metal concentrations in clean waste water are shown below.



	HCl stage (3)	SO2 stage (4)	RO permeate (7)
Hg [ug/l]	0,70	0,05	0,05
Cd [ug/l]	0,35	0,08	0,05
Pb [ug/l]	4,8	1,5	1,5
Cu [ug/l]	15	20	1,5
Ni [ug/l]	69	1,9	1,5

Figure 29. Heavy metals in treated waste water at Sönderborg Kraftvarmevaerk

Figur 29. Tungmetaller i renat avloppsvatten på Sönderborg Kraftvarmevaerk

4 Waste water cleaning efficiencies of the visited plants

All of the visited plants showed good waste water cleaning efficiencies, reaching waste water emission levels well below the required levels. In this chapter the cleaning efficiencies of the different technologies used by the visited plants are summarized and discussed.

A summary of the cleaning technologies was shown in Table 1 above. It is repeated here:

	Acidic stage	**SO_2 stage**	**Condensate**
Absorbed flue gas components	**HCl, SO_3, NH_3, heavy metals**	**SO_2**	**Mainly heat recovery**
Sysav 4	Precipitation of waste water from all stages, No NH_3 removal required, SCR and NH_3 injection downstream		
Gärstadverket	Precipitation, NH_3 stripping	Recycled to ash	Polishing in sand and carbon filter
Sysav 1&2	Recycled to boiler, including NH_3	Ion-exchanger	
Värmekällan	Recycled to boiler, including NH_3	Carbon filter and ion-exchanger	
Måbjergvaerket	Precipitation, low NH_3 levels	Sent away to external treatment	Carbon filter + RO
Sönderborg	Precipitation, low NH_3 levels	Precipitation	UF + RO

4.1 Precipitation and filtration of all waste water

Reference plant with this technology: Sysav line 4

The conventional precipitation and filtration based waste water treatment of Sysav 4 is efficient in removing heavy metals. The concentrations of most of the metals in the waste water were reduced by 99-100% after the lamella clarifier of the first precipitation and flocculation stage. (The calculated removal efficiencies of Co and Tl, based on the analyses of samples taken during the visit to the plant, were lower, but this may be explained by the fact that the concentrations were low and near the detection limit. Also the calculated removal efficiencies of Cr, Ni and As were lower. However, the reproducibility of the Cr and Ni analyses was proven to be very low, and the same was suspected to be the case also for the As analysis.)

Also the concentration of suspended solids, which is very high in the waste water from Sysav 4 due to the limestone used in this plant, was reduced by 100% after the lamella clarifier.

The concentration of suspended solids and heavy metals in the sludge obtained from the clarifier was 4-6 times as high as the concentration in the water before precipitation, which indicates a volume reduction by 4-6 times of the contaminated water which needs disposal. The volume of the sludge is reduced further by filtration in a filter press.

After polishing in the sand and activated carbon filters, the concentration of suspended solids was reduced from 5 mg/l to <2 mg/l. Also some more heavy metal reduction took place in the polishing step, reducing the concentrations of Cd and Pb by an additional 80%.

NO_x reduction at Sysav 4 is made by tail-end SCR after the wet flue gas cleaning. Therefore, the ammonium concentration is low in the waste water from the flue gas cleaning and no ammonia removal is required.

4.2 Precipitation and filtration of waste water from the acidic and SO_2 stages

Reference plants: Måbjergvaerket, Sönderborg Kraftvarmevaerk. Gärstadverket

The removal efficiencies of the conventional precipitation and filtration based cleaning of the acidic (HCl) stage waste waters at Måbjergvaerket and Sönderborg Kraftvarmevaerk have efficiencies similar to the cleaning efficiencies at Sysav 4. The analyses of samples taken during our visits showed that most of the heavy metal concentrations were reduced by 100%. (Again with the exception of Tl and Co, which were present at low levels, and Cr, Ni and As, which had poor analysis reproducibility.) Chlorides and sulphates were not removed. The waste water contained no or almost no ammonium, even though Måbjergvaerket has NO_x reduction by SNCR.

The separate precipitation and filtration based cleaning of the waste water from the neutral (SO_2) stage of Sönderborg Kraftvarmevaerk was equally efficient. This waste water contains some suspended solids from carbon which is used in the SO_2 scrubber. 97% of the suspended solids were removed in the cleaning step, including carbon filter polishing at Måbjergvaerket and sand filter polishing at Sönderborg Kaftvarmevaerk, according to samples analysed after our visit.

The removal efficiencies of the acidic waste water cleaning at Gärstadverket were not possible to calculate based on samples taken during our visit. Also calculations based on old data from 2008 obtained from the plant gave inconclusive results. This can be explained partly by the fact that the waste water is not heavily contaminated by heavy metals. Only Hg and Cu were present in concentrations above the emission limit. The removal of these metals was in the range of 90-100% after the sand filter polishing step.

The waste water from the acidic stage of Gärstadverket contains 400-500 mg/l ammonium salts, which derive from excess ammonia in the flue gas from the SNCR type NO_x reduction of the plant. The ammonia is removed in the ammonia stripper installed in the acidic waste water cleaning after the sand filter polishing step. The calculated ammonia removal was 97-99%, based on data from 2008.

4.3 Ion-exchange based cleaning of waste water from the condensation stage

Reference plants: Värmekällan, Sysav line 1&2

The efficiency of the condensate cleaning of Värmekällan in Skövde was difficult to evaluate, since all heavy metal concentrations except Hg were near or below the emission limit already before cleaning. The Hg concentration was decreased by 90% already in the activated carbon filter before the ion-exchanger steps, from 11 μg/l to 1 μg/l.

In the Hg selective ion-exchanger, after the activated carbon filter, an additional 95% of the Hg was removed, resulting in a Hg concentration below the detection limit. 80% of the Cd was also removed here.

Before the heavy metal ion-exchanger step the concentrations of almost all heavy metals were below the detection limit, so the actual activity of the ion-exchangers could not be evaluated. However, some Pb and Zn removal took place in this step.

The efficiency of the As selective step was impossible to evaluate, since the As concentration was below the detection limit throughout the whole waste water cleaning.

In the waste water from the condensation stage of Sysav 1&2 the heavy metal concentrations are 3-30 times as high as the concentrations in Skövde. 90-100% of the Cd, Pb and Zn were removed in the heavy metal ion-exchanger of Sysav 1&2, together with 75% of the Hg. The remaining 0,3 mg/l of Hg was reduced by 99% to a level below the detection limit after the Hg selective ion-exchanger step.

The heavy metal selective ion-exchanger columns at Sysav 1&2 are regenerated automatically. The resin in Hg selective ion-exchanger has to be exchanged with 3-5 year intervals. The ion-exchangers of Värmekällan are not equipped with automatic regeneration, and therefore also must be exchanged when they become exhausted, which is after two years operation for the heavy metal selective ion-exchangers according to plant experience.

In both plants the ammonium concentration was low in the waste water from the condensation stage, 15 mg/l for Sysav1+2 and below the detection limit for Värmekällan. The acidic waste water from Värmekällan was not analysed, but according to old data from 2008 more than 2000 mg/l ammonium, deriving from ammonia injection in the SNCR system, is absorbed in the acidic waste water. The analysed acidic water from Sysav 1&2 contained no ammonium, although also this plant is equipped with SNCR.

4.4 Membrane based cleaning of waste water from the condensation stage

Reference plants: Måbjergvaerket, Sönderborg Kraftvarmevaerk.

The heavy metal removal efficiencies of the RO step of Måbjergvaerket were 99-100%, as calculated from both the analysis of samples taken during our visit and older analysis data obtained from Måbjergvaerket in 2008. Chlorides and sulphates, as well as the low ammonium concentration of appr 1 mg/l in the condensate, are also reduced by 99-100%.

The activated carbon filter before the RO contributed to the cleaning process by removing more than 90% of the incoming Hg and 40% of the incoming Pb.

In the condensate sample from Sönderborg Kraftvarmevaerk all heavy metal concentrations were below or close to the detection limit already before cleaning. The concentrations were also far below the emission limits of the plant.

Also the suspended solids content was below the detection limit. Due to these low levels, it was not possible to calculate any removal efficiencies of the UF step before the RO, and the calculated removal efficiencies of the RO itself were too low to be realistic.

Both Måbjergvaerket and Sönderborg Kraftvarmevaerk have considered the possibility to reuse the RO permeate as boiler feed water, after additional cleaning in the regular demineralisation plant at the site.

At Måbjergvaerket this option was implemented when the RO was installed. However after the RO membrane fouling problems encountered during straw firing and the decreased running times of the mixed-bed filters in the demineralisation plant after this, the RO permeate is not reused at present.

Sönderborg Kraftvarmevaerk is making plans for tests with using RO permeate in the demineralisation plant. Although the qualities of the RO permeates of both plants are very similar (near the detection limit of many components), the higher conductivity of the RO permeate from Måbjergvaerket, 7 mS/m as compared to 1 mS/m for the Sönderborg plant, indicates that this RO permeate may be more difficult to reuse. Also the much higher contaminant concentration in the untreated condensate from the Måbjerg plant supports this theory. Another factor which speaks in favour of RO permeate reuse at Sönderborg is the fact that here the RO is preceded by UF membrane filtration UF may be less sensitive to clogging than activated carbon filters, and moreover may be more efficient in removing biopolymers which may cause fouling and clogging of the RO membranes. (Since no special analyses of different types of organic substances were made in this study, we have no knowledge of the actual biopolymer contents in the waste waters from the visited plants.)

4.5 Ammonia removal

Reference plant: Gärstadverket

Four of the visited plants had NO_x reduction by SNCR. This often leads to a rather high ammonia content in the flue gas. This ammonia is absorbed in the waste water from the first stage of the wet flue gas cleaning, i e in the acidic stage.

In two of the plants, Sysav line 1&2 and Värmekällan, absorbed ammonia is returned to the boiler when the waste water from the HCl stage is recycled. Thus no high ammonium levels are found in the cleaned waste water which is discharged from these plants.

In Gärstadverket, where waste water from the HCl stage is discharged to recipient after cleaning, an ammonia stripper is installed. The stripper removes the absorbed ammonia from the acidic waste water before this water is cleaned further together with the waste water from the condensation stage, and finally discharged.

In Måbjergvaerket the ammonia slip in the flue gas is not very high, which leads to a low level of absorbed ammonia in the acidic waste water. Less than 1 mg/l of ammonium was found in the water.

Sysav line 4 is equipped with tail-end SCR, so that ammonia is not injected into the flue gas until after the wet flue gas cleaning plant. Sönderborg Kraftvarmevaerk has neither SNCR nor SCR.

4.6 Carbon dioxide removal

Reference plants: Gärstadverket, Värmekällan, Måbjergvaerket

Some degassing of CO_2 is achieved by aeration and mixing in tanks at several of the visited plants. The benefit of CO_2 removal is that the required amount of neutralisation chemicals is lowered when the buffering bicarbonates and carbonates are removed from the water. In plants where frequent pH adjustment of the waste water is needed, e g in plants with ion-exchange based waste water treatment where the different ion-exchanger types have different pH optima, the consumption of neutralisation chemicals can be quite high.

In plants, where ammonia stripping is made on waters with high calcium content, CO_2 stripping is often recommendable to diminish the risk of carbonate deposition at the high pH which is used in the ammonia stripper. In Gärstadverket, which was the only one of the visited plants which has an ammonia stripper column, the stripper is installed after precipitation and filtration of the acidic condensate. Before the precipitation and filtration a CO_2 stripper column is installed.

Also Värmekällan and Måbjergvaerket are equipped with columns for CO_2 removal.

5 Waste water quality

The large variations in waste composition, between different WtE plants as well as within one specific plant, result in large variations also in the composition of the waste water from the flue gas cleaning. In designing an optimal waste water treatment plant one has to consider a broad range of requirements, since the waste water cleaning must be designed to meet the emission limits for discharge of water for all the design fuels of the plant.

The design of the waste water treatment plant also must take into consideration what type of particle filtration and other flue gas cleaning equipment is used at the plant, and how efficient this equipment is.

Recycling of waste water within the plant may reduce the need of cleaning equipment, or on the other hand may lead to an accumulated concentration of pollutants in a smaller total amount of waste water which needs treatment.

As a basis for discussions with suppliers of waste water cleaning equipment, an attempt was made to summarize and compare the waste water and condensate qualities of the six visited plants. The result of this comparison is discussed below.

5.1 Waste water sampling and reproducibility of analyses

At one of the visited plants, Sysav 4, samples were collected over a period of time. Four partial samples, collected in hourly intervals, were pooled and sent to the laboratory. During the sampling period pH, conductivity and temperature were checked several times by portable instruments and it was concluded that the variations over time were within reasonable limits.

At the other five plants the samples were collected as random samples at one single occasion. One sample, sample 1 at Sysav 1&2, was collected as two consecutive samples, 1a and 1b, which were analysed separately. The concentrations of all components, except for nickel, were within 0-10% of each other for the two consecutive samples.

To check the reproducibility of the laboratory, one of the samples, sample 4 from Sysav 1&2, was divided into two separate samples, 4a and 4b, which were analysed individually. This test showed that the reproducibility of the laboratory was within 0-10% for all components except thallium (the concentration of which was close to the detection limit in this sample) and chromium and nickel (possible due to general reproducibility problems when analysing particle bound elements). From this it was concluded that the analyses of chromium and nickel were not reliable. Therefore, chromium and nickel are not included in the discussions of metal removal efficiencies in this report.

The sampling at Gärstadverket was made during a period of unstable operation and dust filter problems at the plant, and the resulting analyses data were very different from typical plant data. Therefore the results were not used in this report. Instead, mean values of analyses during 2008, which were supplied to us, were used in the report.

5.2 Detection limits and emission limits

The detection limits of the analysed elements and the methods of analysis used are shown in the table below. Also included are the emission limits for discharges of waste water from the cleaning of exhaust gases according to the directive 2000/76/EC on the incineration of waste (which are equal to the national Swedish emission limits[10]).

Table 2. Detection limits
Tabell 2. Detektionsgränser

	Detection limits	Method	Emission limits
Susp solids [mg/l]	2	SS-EN 872:2005	45
Hg [ug/l]	0,05	SS-EN ISO 17852	30
Cd [ug/l]	0,05	ICP-MS	50
Co [ug/l]	0,3	ICP-MS	
Tl [ug/l]	0,05	ICP-MS	50
As [ug/l]	1,5	ICP-MS	150
Pb [ug/l]	1,5	ICP-MS	200
Cr [ug/l]	0,5	ICP-MS	500
Cu [ug/l]	1,5	ICP-MS	500
Ni [ug/l]	1,5	ICP-MS	500
Zn [ug/l]	5	ICP-MS	1500
Chlorides [mg/l]	1	SS 028136	
Sulphates [mg/l]	150	Hach Lange	
Ammonium [mg N/l]	0,01		

5.3 Waste water from the acidic (HCl) stage

The waste waters from the acidic (HCl) stage have the highest concentrations of chlorides as well as of heavy metals. The concentrations are shown in the figure below. (Chloride and sulphate data from Skövde are from 2008, since no sample was taken from the acidic stage when the plant was visited. Typical data according to BREF[11] are included for comparison.)

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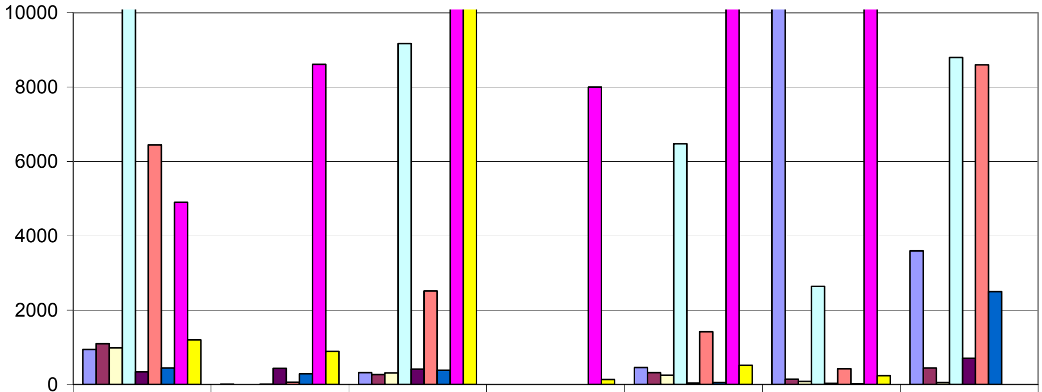
[10] Naturvårdsverkets föreskrifter om avfallsförbränning, NFS 2002:28

[11] Reference document on the best available techniques for waste incineration (August 2006)



	Sysav 4	Gärstad	Sysav 1+2	Skövde	Måbjerg	Sönderborg	BREF
■ Hg [ug/l]	940	7	320		460	47000	3600
■ Cd [ug/l]	1100	0,4	270		320	140	450
■ As [ug/l]	980	4	310		250	86	50
■ Pb [ug/l]	22500	6	9170		6480	2640	8800
■ Cr [ug/l]	344	437	413		44	31	700
■ Cu [ug/l]	6450	64	2520		1420	424	8600
■ Ni [ug/l]	444	291	382		56	22	2500
■ Chlorides [mg/l]	4900	8616	82000	8000	32000	31000	
■ Sulphates [mg/l]	1200	892	16000	130	520	240	

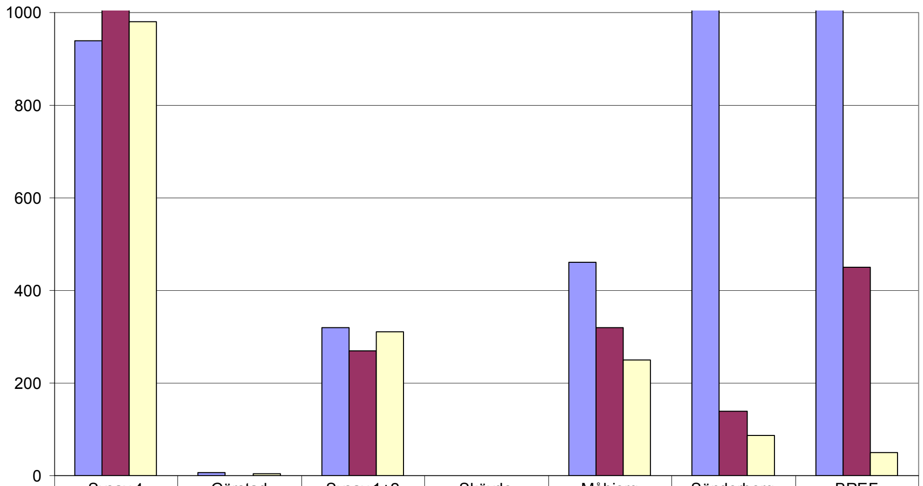
Figure 30. Untreated waste water from the acidic stage

Figur 30. Orenat kondensat från HCl-steget

According to the figure above, the untreated waste waters from Sysav are the most heavily contaminated, with the highest concentrations of Hg, Cd, Pb, Cu and Zn, although the chloride content at the sampling occasion was much lower than the typical 35 000 mg/l. Sysav is the largest of the visited plants, and uses a broad mixture of waste fuels from the domestic and industrial sectors, which may explain why it has the most contaminated untreated water.

The untreated waste water from the acidic stage of Sönderborg was very high in Hg at this particular time of sampling.

Also heavy metals which occur in lower concentrations have the highest levels in the acidic waste water from Sysav 4, as can be seen in the figure below where the vertical axis has a higher resolution than in the figure above. (The Cr values are included for information, although the reproducibility of the Cr analysis was below 10%.) No data were available from Värmekällan in Skövde.



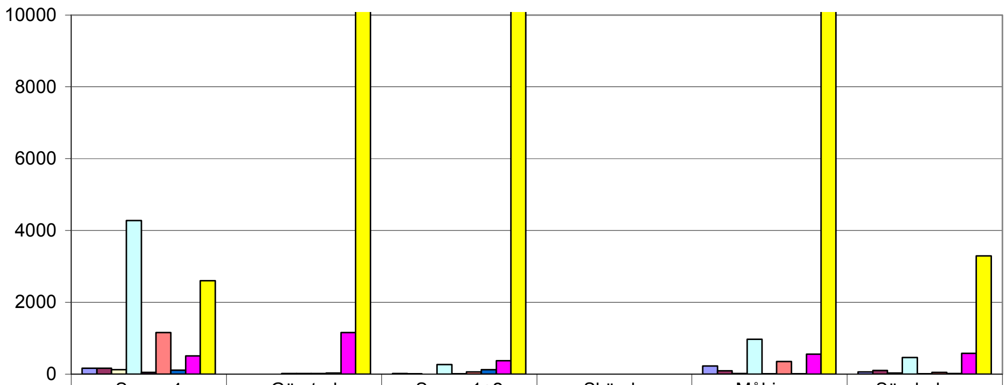
	Sysav 4	Gärstad	Sysav 1+2	Skövde	Måbjerg	Sönderborg	BREF
■ Hg [ug/l]	940	7	320		460	47000	3600
■ Cd [ug/l]	1100	0,4	270		320	140	450
□ As [ug/l]	980	4	310		250	86	50

Figure 31. Heavy metals in untreated waste water from the acidic stage

Figur 31. Tungmetaller i orenat kondensat från HCl-steget

5.4 Waste water from the neutral (SO_2) stage

The waste waters from the neutral (SO_2) stage have the highest sulphate concentrations.

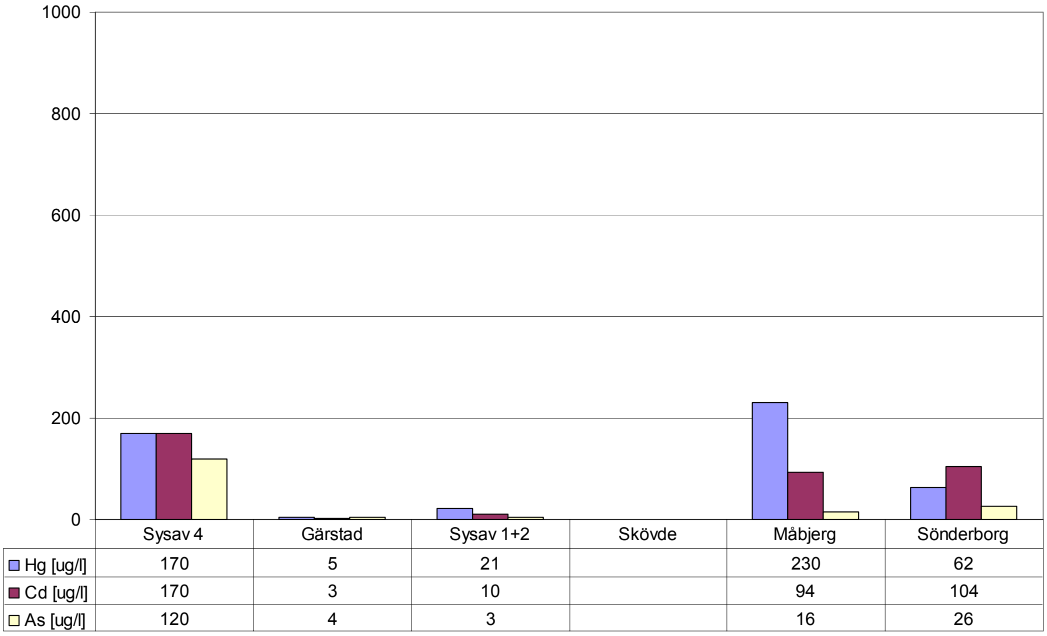


	Sysav 4	Gärstad	Sysav 1+2	Skövde	Måbjerg	Sönderborg
■ Hg [ug/l]	170	5	21		230	62
■ Cd [ug/l]	170	3	10		94	104
□ As [ug/l]	120	4	3		16	26
□ Pb [ug/l]	4280	20	267		976	470
■ Cr [ug/l]	51	17	12		7	15
■ Cu [ug/l]	1160	16	59		348	47
■ Ni [ug/l]	118	32	125		15	16
■ Chlorides [mg/l]	510	1160	370		560	580
■ Sulphates [mg/l]	2600	43211	20000		57000	3300

Figure 32. Untreated waste water from the neutral stage

Figur 32. Orenat kondensat från SO_2-steget

Some chlorides are also captured by the neutral stage, together with sulphates and heavy metals. The concentrations, however, are much lower than in the acidic stage. See the figure below where the vertical axis has a higher resolution than in the figure above. (Again the Cr and Ni values are included only for information, as the reproducibility of the analyses was below 10%.) No data were available from Värmekällan in Skövde.



	Sysav 4	Gärstad	Sysav 1+2	Skövde	Måbjerg	Sönderborg
🟦 Hg [ug/l]	170	5	21		230	62
🟥 Cd [ug/l]	170	3	10		94	104
🟨 As [ug/l]	120	4	3		16	26

Figure 33. Heavy metals in untreated waste water from the neutral stage

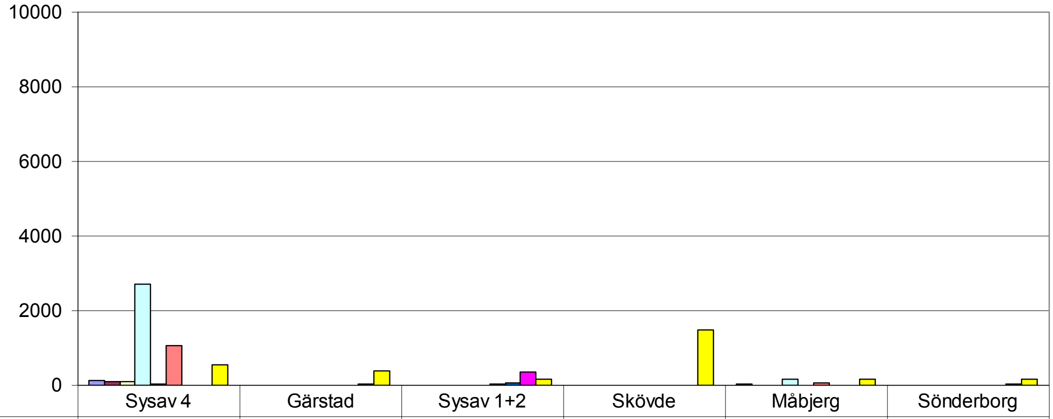
Figur 33. Tungmetaller i orenat kondensat från SO_2-steget

5.5 Waste water from the condensation stage

The waste water (condensate) from the heat recovery stage is much cleaner. All heavy metals, except Zn and for Sysav 4 also Pb and Cu, are in the range of 100 µg/l or lower.

At three of the visited plants, Gärstad, Skövde and Sönderborg, almost all heavy metal concentrations, were near the detection limit, below 2 µg/l. Only Zn, Hg and Pb, and for Skövde also Cu, had higher concentrations.

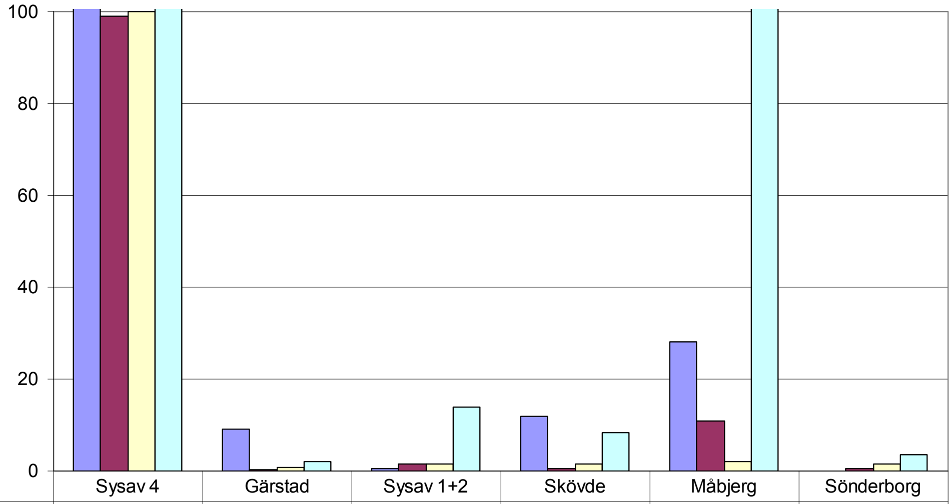
The concentrations are shown for two different concentration ranges in the diagrams below.



	Sysav 4	Gärstad	Sysav 1+2	Skövde	Måbjerg	Sönderborg
□ Hg [ug/l]	120	9	0,5	12	28	0,05
■ Cd [ug/l]	99	0,2	1,4	0,5	11	0,4
□ As [ug/l]	100	0,7	1,5	1,5	1,9	1,5
□ Pb [ug/l]	2720	2	14	8	161	4
■ Cr [ug/l]	17	2	2	0,5	1,0	0,7
■ Cu [ug/l]	1050	2	18	7	59	1,5
■ Ni [ug/l]	9	2	50	1,5	6	1,5
■ Chlorides [mg/l]		24	350		6	29
■ Sulphates [mg/l]	540	390	150	1500	150	150

Figure 34. Untreated waste water from the condensation stage

Figur 34. Orenat kondensat från kondenseringssteget



	Sysav 4	Gärstad	Sysav 1+2	Skövde	Måbjerg	Sönderborg
□ Hg [ug/l]	120	9	0,5	12	28	0,05
■ Cd [ug/l]	99	0,2	1,4	0,5	11	0,4
□ As [ug/l]	100	0,7	1,5	1,5	1,9	1,5
□ Pb [ug/l]	2720	2	14	8	161	4

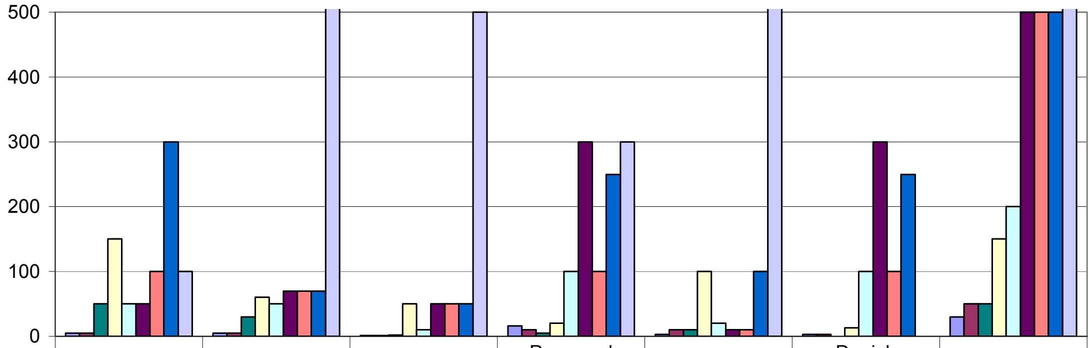
Figure 35. Heavy metals in untreated waste water from the condensation stage

Figur 35. Tungmetaller i orenat kondensat från kondenseringssteget

5.6 Emission limits of waste water

The emission limit values for discharges of waste water from flue gas cleaning are normally set at a much lower level than required in the EC directive on the incineration of waste[12], due to national or regional requirements. The Danish national recommendations[13] are included in the diagrams below.

The guaranteed emission levels of the water treatment plants are adjusted to the emission limits. In the diagrams below the emission limits, proposed new emission limits or guaranteed emissions, are shown for some of the visited plants.



	Guarantees Sysav 4	Emission limits Gärstad	Emission limits Skövde	Proposed emission limits Måbjerg	Guarantees Sönderborg	Danish emission limit guideline	2000/76/EC
□ Hg [ug/l]	5	5	1	16	3	3	30
■ Cd [ug/l]	5	5	1	10	10	3	50
■ Tl [ug/l]	50	30	1,5	5	10		50
□ As [ug/l]	150	60	50	20	100	13	150
□ Pb [ug/l]	50	50	10	100	20	100	200
■ Cr [ug/l]	50	70	50	300	10	300	500
■ Cu [ug/l]	100	70	50	100	10	100	500
■ Ni [ug/l]	300	70	50	250	100	250	500
□ Zn [ug/l]	100	700	500	300	1000		1500

Figure 36. Emission limits for discharge of waste water from flue gas cleaning

Figur 36. Utsläppsgränser för utsläpp av avlopp från rökgasrening

Limits for Hg and Cd, in particular, are often set at very low levels, down to 1 µg/l, as can be seen for Skövde below.

The proposed new emission limits for Måbjergvaerket also hold the reservation that the levels for Hg and Cd may be revised in the future, from the proposed 16 µg/l for Hg and 10 µg/1 for Cd to 3 µg/l for both Hg and Cd.

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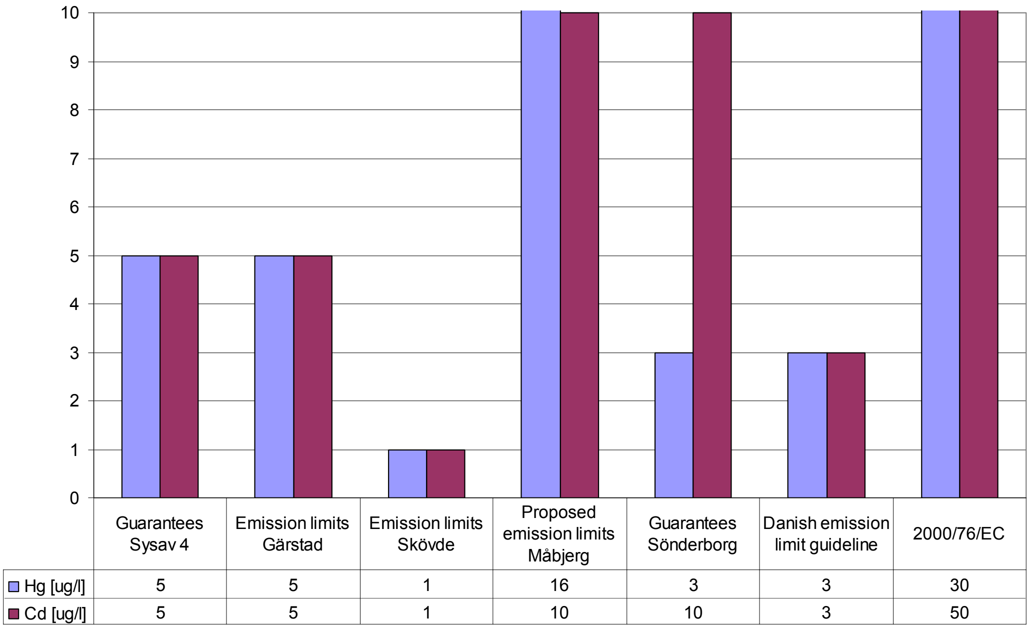
[12] Directive 2000/76/EC on the incineration of waste

[13] ”Tilslutning af industrispildevand til offentlige spildevandsanlaeg”, Vejledning fra Miljöstyrelsen nr 2 2006



	Guarantees Sysav 4	Emission limits Gärstad	Emission limits Skövde	Proposed emission limits Måbjerg	Guarantees Sönderborg	Danish emission limit guideline	2000/76/EC
🟦 Hg [ug/l]	5	5	1	16	3	3	30
🟥 Cd [ug/l]	5	5	1	10	10	3	50

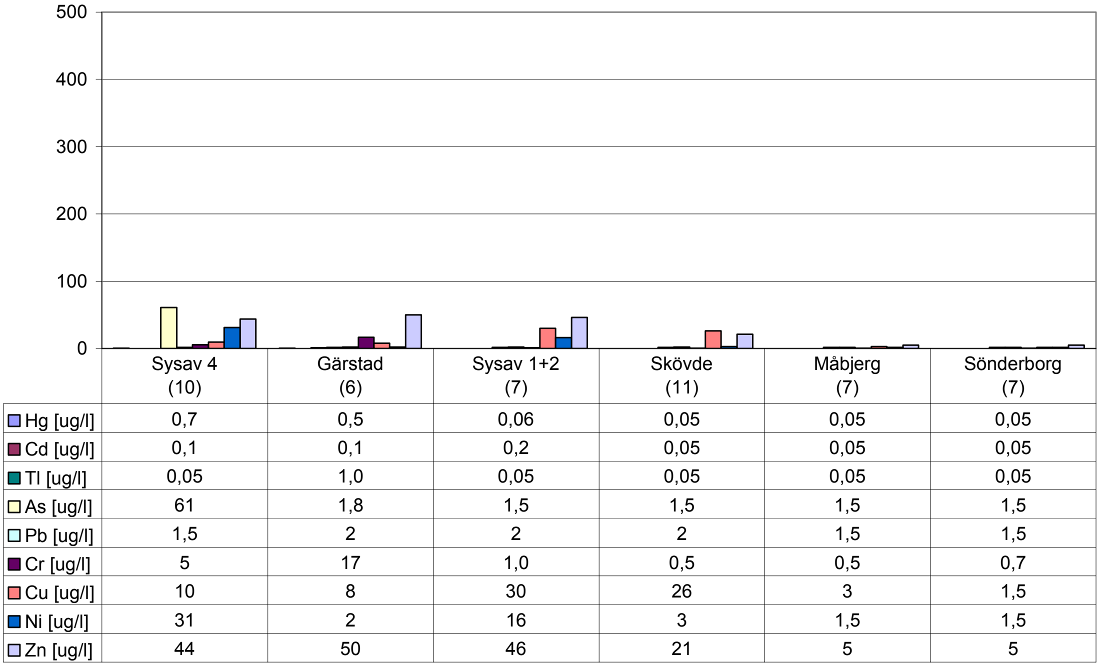
Figure 37. Emission limits for Hg and Cd in waste water from flue gas cleaning

Figur 37. Utsläppsgränser för utsläpp av Hg och Cd till avlopp från rökgasrening

5.7 Waste water after cleaning

The actual emission levels of the visited plants are well within the required limits. The concentrations of most of the heavy metals were below 5 µg/l, only the levels of Zn and Cu from the Swedish plants as well as Ni and As from Sysav and Cr from Gärstad were present in higher concentrations.

The emission levels are shown below. To facilitate comparison with the emission limits in Figure 36, the same scale is used for the emission levels in Figure 38 below.



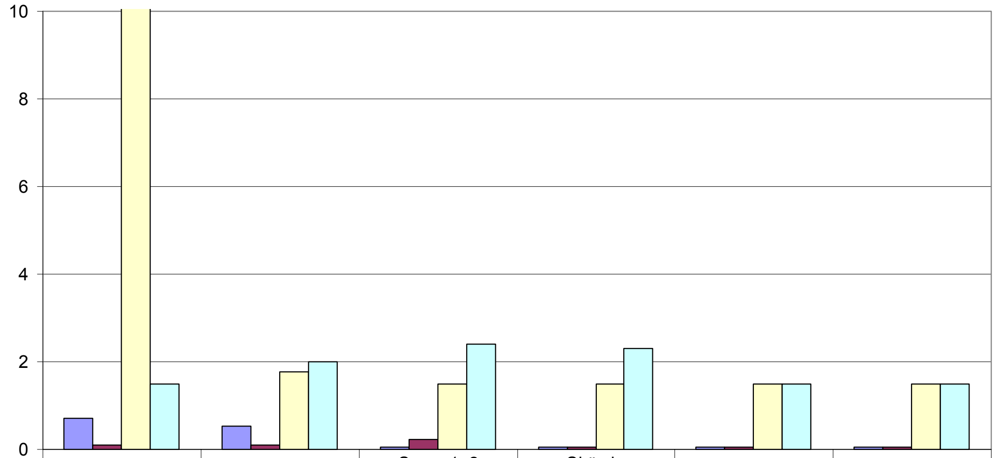
	Sysav 4 (10)	Gärstad (6)	Sysav 1+2 (7)	Skövde (11)	Måbjerg (7)	Sönderborg (7)
■ Hg [ug/l]	0,7	0,5	0,06	0,05	0,05	0,05
■ Cd [ug/l]	0,1	0,1	0,2	0,05	0,05	0,05
■ Tl [ug/l]	0,05	1,0	0,05	0,05	0,05	0,05
□ As [ug/l]	61	1,8	1,5	1,5	1,5	1,5
□ Pb [ug/l]	1,5	2	2	2	1,5	1,5
■ Cr [ug/l]	5	17	1,0	0,5	0,5	0,7
■ Cu [ug/l]	10	8	30	26	3	1,5
■ Ni [ug/l]	31	2	16	3	1,5	1,5
□ Zn [ug/l]	44	50	46	21	5	5

Figure 38. Heavy metals in cleaned waste water before discharge (same scale as Figure 36)

Figur 38. Tungmetaller i renat vatten före utsläpp (samma skala som Figur 36)

In many cases the concentrations were below the detection limit of the laboratory. This can be seen in the diagram below. The detection limit of Hg and Cd was 0,05 µg/l and the detection limit of As and Pb was 1,5 µg/l. In the membrane treated waste water from the Danish plants the levels were below the detection limit. In the ion exchanger treated waste water from Skövde and Sysav 1&2 the levels were close to the limit.

To facilitate comparison with the Hg and Cd emission limits in Figure 37, the same scale is used for the emission levels in Figure 39 below.



	Sysav 4 To recipient (10)	Gärstad Clean cond (6)	Sysav 1+2 After Hg ion exch (7)	Skövde After As ion exch (11)	Måbjerg RO permeate (7)	Sönderborg RO permeate (7)
Hg [ug/l]	0,7	0,5	0,06	0,05	0,05	0,05
Cd [ug/l]	0,1	0,1	0,2	0,05	0,05	0,05
As [ug/l]	61	1,8	1,5	1,5	1,5	1,5
Pb [ug/l]	1,5	2	2	2	1,5	1,5

Figure 39. Hg, Cd, As and Pb in cleaned waste water before discharge (scale as Figure 37)

Figur 39. Hg, Cd, As och Pb i renat vatten före utsläpp (samma skala som Figur 37)

5.8 Design data for discussions with suppliers of waste water treatment plants

Based on the waste water compositions of the visited plants, typical condensate qualities were set up, as design data for discussions with suppliers of waste water cleaning equipment. The design data in the table below was used in the discussions.

High sulphate concentrations were given as design data for waste water from the acidic (HCl) stage as well as for waste water from the condensation stage. This was made because the waste water from the neutral (SO_2) stage is sometimes treated together with waste water from the HCl stage and sometimes together with waste water from the condensation stage.

Table 3. Waste water before cleaning
Tabell 3. Orenat vatten från rökgasrening och kondensering

	Waste water from HCl stage		**W water from condensation**	
	Min conc	**Max conc**	**Min conc**	**Max conc**
Susp solids [mg/l]	1	3 500	1	200
Hg [ug/l]	1 000	10 000	1	50
Cd [ug/l]	100	1 000	1	10
Co [ug/l]	1	100	1	5
Tl [ug/l]	1	100	1	5
As [ug/l]	100	1 000	0,5	5
Pb [ug/l]	1 000	10 000	1	400
Cr [ug/l]	100	1 000	0,5	5
Cu [ug/l]	1 000	10 000	1	70
Ni [ug/l]	100	1 000	1	20
Zn [ug/l]	10 000	100 000	10	1000
Chlorides [mg/l]	5 000	50 000	10	100
Sulphates [mg/l]	1 000	10 000	100	10 000
Ammonium [mg N/l]	1	2 500	1	200

Two emission levels, one medium level and one low level, were given as design data for the clean condensate after the waste water treatment plant. See table below.

No design data were given for sulphate and chloride emissions, as the visited plants had no emission limits for these compounds. Local requirements on sulphate and chloride emissions may exist, however, for other plants.

Table 4. Required clean water emission levels
Tabell 4. Krav på utsläpp av renat vatten

	Medium levels	**Low levels**
Susp solids [mg/l]	10	10
Hg [ug/l]	5	1
Cd [ug/l]	5	1
Co [ug/l]	50	5
Tl [ug/l]	20	5
As [ug/l]	20	5
Pb [ug/l]	20	5
Cr [ug/l]	50	5
Cu [ug/l]	50	5
Ni [ug/l]	50	5
Zn [ug/l]	500	50
Chlorides [mg/l]	-	-
Sulphates [mg/l]	-	-
Ammonium [mg N/l]	20	20

6 Concepts for waste water cleaning

6.1 Summary of concepts for waste water cleaning

The choice of technology for the cleaning of waste water from the wet flue gas cleaning and condensation stages is dependent on the choice of dust and SO_2 removal technology at the plant. Based on the experience of the visited plants and on discussions with equipment suppliers, the following concepts were found to be relevant for WtE plants:

Table 5. Concepts for cleaning of waste water from wet flue gas cleaning and condensation
Tabell 5. Teknikalternativ för vattenrening efter våt rökgasrening och kondensering

Type of flue gas cleaning		**Concepts for waste water cleaning**	**Reference plants**	**No**
Dust and acid gas removal	**NO_x removal**			
*ESP *Wet scrubbing with HCl and cond stage	None or SCR/SNCR with low ammonia slip	*Precipitation/filtration of all waste water	Sysav 4	1
	SNCR with high ammonia slip	*Precipitation/filtration of all waste water *Ammonia stripping		2
*ESP *Wet scrubbing with HCl and cond stage	None or SCR/SNCR with low ammonia slip	*Precipitation/filtration of HCl stage water *Filtration, ion-exch or RO of condensate	Måbjerg, Sönderborg	3
	SNCR with high ammonia slip	*Precipitation/filtration of HCl stage water *Filtration, ion-exch or RO of condensate *Ammonia stripping		4
*Fabric filter with lime injection *Wet scrubbing with HCl and cond stage	None or SCR/SNCR with low ammonia slip	*Precipitation/filtration of HCl stage water *Filtration, ion-exch or RO of condensate		5
	SNCR with high ammonia slip	*Precipitation/filtration of HCl stage water *Filtration, ion-exch or RO of condensate *Ammonia stripping	Gärstad	6
*Fabric filter with lime injection *Wet scrubbing with HCl and cond stage	None, SCR/SNCR with low ammonia slip or SNCR with high ammonia slip	*Recycling of HCl stage water *Filtration, ion-exch or RO of condensate	Sysav 1&2 Skövde	7

In the concepts above it is assumed that the waste water from the SO_2 stage is re-used without treatment, as e g ash slaking water, or is treated either together with waste water from the HCl stage or together with waste water from the condensation stage.

6.2 Typical features of the concepts for waste water cleaning

Some characteristics and advantages and disadvantages of the waste water cleaning concepts are summarized below.

6.2.1 ESP and precipition/filtration of all waste water

Reference plant: Sysav line 4

Large, 70-80 MW_{th}, WtE plants in Sweden are often built with electrostatic precipitators and wet scrubbers with conventional precipitation and filtration based water treatment technology. All waste waters are treated together in the water treatment plant, although only the acidic (HCl) stage waste water is neutralised in the first neutralisation step and waste water from the condensation stage is led directly to the precipitation steps where all waste water is cleaned.

This approach results in very robust water cleaning which does not require more than moderate dust removal, so that both ESP and fabric filter technology is applicable. However it also requires a very large and spacious water treatment plant, since the water treatment must be designed for the whole waste water flow, both the small and heavily contaminated acidic water flow and the very much larger and cleaner condensate flow.

Due to the choice of ESP, which does not remove any SO_x from the flue gas, the waste water from the scrubbers may be quite high in sulphate. Even if sulphate is precipitated in the waste water treatment, the solubility of calcium sulphate may still be too high compared to the emission limits for the cleaned waste water. In plants located by the sea this is generally no problem. Here ESP is sufficient for flue gas cleaning, since cleaned waste water with high concentrations of chloride and sulphate can be discharged to the sea.

In plants with restrictions on sulphate content in the cleaned water it is often not possible to clean the SO_2 stage water together with the other water, since the sulphate concentration in the discharged clean water will be to high. In this case, if there is no alternative use for the SO_2 stage water e g as ash slaking water, semi-dry flue gas cleaning with lime injection and fabric filter is a better choice than ESP.

6.2.2 Fabric filter and precipition/filtration only of HCl stage water

Reference plants: Gärstadverket, Måbjergvaerket before installation of RO

At Gärstadverket a similar concept is used, but with fabric filter instead of ESP. However, Gästadverket uses a more risky bypass for the condensate water. Here the condensate is bypassed past the entire precipitation and sedimentation train, and only treated in the final polishing step in the sand and activated carbon filter. This puts great demands on the cleaning efficiency of the polishing step.

The small flow of waste water from the SO_2 stage is recycled to the slag bunker, which eliminates the need of cleaning.

The advantage of the Gärstadverket approach is that the precipitation and sedimentation equipment can be designed for a much smaller flow. Another advantage is that the ammonia stripping, which is needed at Gärstadverket, is also designed for the small flow of treated water from the HCl stage where the main part of the ammonium is found.

At Måbjergvaerket the same concept was used originally. However, the original condensate cleaning with sand filter and activated carbon filter has been retrofitted with RO cleaning technology, as described below.

6.2.3 ESP, precipition/filtration only of HCl stage water, RO for condensate cleaning

Reference plants: Måbjergvaerket, Sönderborg Kraftvarmevaerk

At the two Danish plants the treatment of the waste water from the condensation stage is completely separated from the treatment of the acidic waste water. The reason for this is mainly that the condensation stages of these two plants were retrofitted when the boilers had already been in operation for some years. Here the acidic waste water from the HCl stages is treated in the originally installed precipitation and filtration type water treatment plants.

In Sönderborg also the neutral waste water from the SO_2 stage is treated this way, in a separate water treatment plant, since the SO_2 stage was also retrofitted after some time. In Måbjergvaerket the waste water from the SO_2 stage is sent to a neighbouring gypsum plant for treatment.

The condensate from these plants is cleaned in RO membranes, which guarantees a high cleaning efficiency for both salts and metals. Pre-filters are installed before the RO. Måbjergvaerket uses activated carbon filtration and Sönderborg UF filtration as pre-filtering technology, and bag filters to capture particles before the membrane filters.

Since the chosen RO technology produces a concentrated waste water flow, and not a filter sludge which can be dewatered and disposed of, this concept necessitates a sink for the RO concentrate. Both plants use the feed water of the HCl scrubbers as sink for the RO concentrate. (Both plants are equipped with ESP, and therefore need more feed water in the HCl quench stage than would be needed in a plant with fabric filter and lower flue gas temperature.) Since the waste waters from the HCl stages in both Måbjerg and Sönderborg are bled off and cleaned in separate waste water treatment plants, there is no risk of problems due to enrichment of contaminants in the HCl stages.

6.2.4 Heavy metal ion-exchangers for condensate cleaning

Reference plants: Sysav line 1&2 in Malmö, Värmekällan in Skövde

The RO technology can easily cope with large water flows, which makes it suitable for both small and large plants. For small plants, in the 20 MW_{th} range, heavy metal selective ion-exchangers may be an alternative to RO technology for condensate treatment.

Heavy metal ion-exchangers are best suited for small flows of not very contaminated condensate, as in Skövde, since the ion-exchanger consumption is directly proportional to the absorbed amount of heavy metals. When ion-exchangers are used for more heavily contaminated condensates, like at Sysav 1&2, regeneration equipment may be necessary or the ion-exchanger replacement costs may become considerable.

Regeneration of heavy metal ion-exchangers, which is installed at Sysav 1+2, produces highly contaminated waste water from the regeneration step. This waste water must not be discharged to recipient. At Sysav 1+2 the regeneration water is used as feed water in the acidic (HCl) stage. Thus, the contaminants are ultimately recycled to the boiler and the semi-dry flue as cleaning as the waste water from the HCl stage is recycled.

The ion-exchanger based option may become expensive in plants with high heavy metal concentrations in the waste water from the condensation stage. For plants with low contaminant concentrations, and therefore long ion-exchanger running times, this option may be favourable due very little need for operation and maintenance.

6.2.5 Recycling to boiler of HCl stage water

Reference plants: Sysav line 1&2 in Malmö, Värmekällan in Skövde

RO or ion-exchange based condensate cleaning is preferably used at plants were the acidic waste water is recycled without cleaning. The recycling of acidic waste water to the boiler leads to an enrichment of pollutants in the flue gas and consequently in the waste water from the wet flue gas cleaning. The enrichment of pollutants, especially chlorides, may lead to corrosion problems in the boiler and flue gas treatment.

Unless very low chloride content in the fuel can be guaranteed, recycling of acidic condensate to the boiler should be made only at plants where chlorides are captured and removed in the dust filter. Therefore, this concept should be used only in plants equipped with semi-dry or dry flue gas cleaning with lime injection and fabric filter. For plants with ESP this concept is not applicable.

6.2.6 Ammonia stripping

Ammonia stripping may be necessary in plants which use SNCR for NO_x reduction.

With calcium containing waste waters the ammonia stripper should have a CO_2 stripper installed upstream, to remove as much bicarbonates and carbonates as possible and minimize the risk for carbonate scaling in the ammonia stripper. Since the ammonia stripping is performed at highly alkaline pH, there is a high risk of carbonate scaling.

To minimize the risk of scaling, ammonia strippers should also be installed as one of the last steps in the waste water cleaning train. This means that ammonia stripping must be made on the whole cleaned waste water flow, in the case where all waste water is treated in one single precipitation/filtration plant. If the acidic waste water, which contains most of the ammonium, is treated in a separate precipitation/filtration plant, the ammonia stripper is installed after this plant. This eliminates the need for stripping the whole flow, since the ammonium content is low in the waste water from the condensation stage.

If the acidic waste water is recycled to the boiler, no ammonia stripping is necessary. In this case also the ammonia is recycled to the boiler, where it is destroyed or used as a reactant in the SNCR system. In plants with SCR systems installed downstream of the wet scrubbing and condensation, the ammonium levels are normally low in the waste waters and therefore no ammonia removal is necessary here either.

7 Costs

In this chapter the costs of different waste water cleaning concepts are discussed.

7.1 Conditions of the cost calculations

The investment costs are based on budgetary proposals from suppliers, obtained in 2011. These budgetary proposals were made for the waste water and cleaned water design data which was discussed in chapter 5.8.

7.1.1 Yearly operation hours

Cost estimations were made for 8.000 h per year of operation of the wet flue gas cleaning and 5.000 h per year for the condensation and heat recovery stage.

7.1.2 Plant size

The calculations were made for two plant sizes.

For the large plant, of 80 MW_{th}, a typical acidic waste water flow was estimated to be 3 m^3/h (8.000 h/year) and a typical condensate flow 15 m^3/h (5.000 h/year).

For the small plant, of 20 MW_{th}, the estimated flows were 1 m^3/h of acidic waste water (8.000 h/year) and 4 m^3/h of condensate (5.000 h/year).

7.1.3 Unit costs of consumables

Operation costs are based on the following costs per unit:

Table 6. Unit costs
Tabell 6. Enhetspriser

Unit costs		
50% NaOH	SEK/ton	3000
30% HCl	SEK/ton	2000
Electricity	SEK/MWh	900 (incl 300 el certif cost)
Steam	SEK/MWh	700
Labour	SEK/h	500
Precipitation agent	SEK/ton	38 000
$FeCl_3$	SEK/ton	1 800
Polymer	SEK/ton	30 000

7.1.4 Estimated consumption of neutralisation chemicals

In the tables below, costs for pH adjustment chemicals have been included. This includes chemicals for pH adjustment to pH 9 before the heavy metal precipitation plant, to pH 5 before the Hg selective ion-exchanger and pH 8 before the As filter and to pH 11 before the ammonia stripper. Also included are the costs for neutralisation before discharge of cleaned waste water.

Not included are the costs for neutralisation of acidic waste water from the HCl stage. The chloride content of this water depends on the type of flue gas cleaning used. In plants with ESP all chlorides in the flue gas are led to the flue gas scrubbing plant. This leads to very high chloride concentrations in the waste water from the HCl stage, and to high lime consumption for neutralisation of this water. In plants with semi-dry or dry flue gas cleaning chlorides are absorbed by lime already in the fabric filter. Thus the waste water from the HCl scrubber will have a lower chloride concentration, and less lime will be needed for neutralisation. Thirdly, in plants where the waste water from the HCl stage is recycled, either to the boiler or to the semi-dry flue gas cleaning system, it is optional to neutralise this water or to recycle it without prior neutralisation. If the HCl stage water is recycled without neutralisation, more chloride will circulate through the boiler and to the semi-dry flue gas cleaning, and more lime injection will be needed here.

So, all different WtE plants will consume a large amount of lime to neutralise chlorides. This will subsequently result in a large amount of residue which needs to be disposed of. Depending on whether chlorides are absorbed in a semi-dry or dry flue gas cleaning plant or in waste water from the HCl scrubber, more or less lime will have to be added to the flue gas and waste water respectively. The location of the WtE plant is also relevant, since discharge of non-precipitated chlorides and sulphates is only possible if this can be accepted by the recipient. Normally this requires that the plant is located by the sea. The final choice of where the neutralisation chemicals are used in the WtE plant is decided by factors e g plant location and costs of residue disposal.

For the same reason, the costs for neutralisation of waste water from the condensation stage have been excluded from our calculations. This cost is mainly dependent on the amount of carbon dioxide absorbed in the condensation scrubber. Thus, the bicarbonate and carbonate concentration of the condensate is very sensitive to the operation of the scrubbers and to the design pH. An increase of 0,5 pH units leads to a much increased carbon dioxide absorption, and vice versa. On the other hand, costs for neutralisation chemicals may be lowered considerably if a carbon dioxide stripper is installed.

To sum up, the neutralisation costs included in the calculations are based on the assumption that all plants have a certain cost for neutralisation of flue gas cleaning residue or of waste water. The costs for neutralisation to pH 7 have not been included in the calculations. Included in the calculations are only costs which are specific for the waste water treatment technologies. These costs are based on estimated consumptions, assuming that the waste water has already been neutralised to pH 7. The data used as estimated consumptions are based on actual chemicals demand for pH adjustments of typical flue gas condensates. These experience based consumptions are higher than theoretical consumptions, due to the buffering capacity of the condensate.

7.2 Yearly costs

Cost estimations for the different waste water treatment options are summarized in the tables below.

7.2.1 Precipition/filtration of all waste water

The main components of this type of waste water treatment are:

- 1 neutralisation tank with mixer and CO_2 degassing where pH increased to appr 3
- 1 neutralisation tank with mixer where pH is increased to appr 9
- 1 precipitation tank where precipitation agent and $FeCl_3$ is dosed
- 1 flocculation tank with mixer where polymer is dosed
- 1 lamella separator with sludge discharge system to storage tank
- Filter press
- Sand filters
- Chemical dosing equipment and pH measurement
- Programming of DCS

Chemical storage tanks, building and platforms are not included in the investment prices below.

Table 7. Cost of precipitation/filtration of all waste water
Tabell 7. Kostnad för fällning/filtrering av hela vattenflödet från våt rökgasrening och kondensering

	Large plant (18 m^3/h)		**Small plant (5 m^3/h)**	
		kSEK/year		**kSEK/year**
Investment	7 MSEK		5 MSEK	
Capital cost	10% of inv	700	10% of inv	500
pH adjustment from pH 7 to 9	0,8 kg + 1,2 kg NaOH+HCl per m^3	960	0,8 kg + 1,2 kg NaOH+HCl per m^3	270
Precip/flocc chemicals	Hg binder/$FeCl_3$ 24 ton/year	500	Hg binder/$FeCl_3$ 7 ton/year	150
Labour	1000 h/year	500	700 h/year	350
Maintenance	1,5 % of inv	100	1,5 % of inv	75
Total cost		**2760**		**1345**

Major costs for this alternative are capital costs and costs for chemicals and labour. For the large plant the required staffing is estimated to 20 h per week and for the small plant to 14 h per week. This type of waste water treatment is very spacious and typically requires a floor area of 300 m^2.

To reach the most strict emission requirements of 1 µg/l, a 99,9% Hg removal ratio is required for the highest Hg concentrations according to the design data in chapter 5.8. When this removal ratio is required, a Hg selective police filter should be installed after the precipitation/filtration plant. This gives an increased cost of appr 30 kSEK/year for the large plant and appr 15 kSEK/year for the small plant.

7.2.2 Precipition/filtration of HCl stage water

The main components of this type of waste water treatment are the same as for the system for precipitation/filtration of all waste water above.

Table 8. Cost of precipitation/filtration of HCl stage waste water
Tabell 8. Kostnad för fällning/filtrering av vattenflödet från surskrubbersteget

	Large plant (3 m^3/h)		**Small plant (1 m^3/h)**	
		kSEK/year		**kSEK/year**
Investment	4,5 MSEK		3,5 MSEK	
Capital cost	10% of inv	450	10% of inv	350
pH adjustment from pH 7 to 9	0,8 kg + 1,2 kg NaOH+HCl per m^3	230	0,8 kg + 1,2 kg NaOH+HCl per m^3	75
Precip/flocc chemicals	6 ton/year	100	2 ton/year	40
Labour	500 h/year	250	400 h/year	200
Maintenance	1,5 % of inv	70	1,5 % of inv	50
Total cost		**1100**		**715**

7.2.3 Membrane cleaning of condensate

The main components of this type of waste water treatment are:

- Particle filters for coarse particle separation
- Softener
- Ultra filter (UF) for fin particle separation
- Reversed osmosis with 2 steps (RO)
- Pump tanks before UF and RO
- Chemical dosing equipment and pH measurement
- Programming of DCS

Chemical storage tanks, building and platforms are not included in the investment prices below.

Table 9. Cost of membrane cleaning of waste water from the condensation stage
Tabell 9. Kostnad för membranfiltrering av kondenseringsstegets vatten

	Large plant (15 m^3/h)		**Small plant (4 m^3/h)**	
		kSEK/year		**kSEK/year**
Investment	5 MSEK		2,5 MSEK	
Capital cost	10% of inv	500	10% of inv	250
RO membranes	Exchanged every 5 year	200	Exchanged every 5 year	50
UF membranes	Exchanged every 5 year	165	Exchanged every 5 year	55
RO electricity	30 kW per 15 m^3/h	135	8 kW per 4 m^3/h	35
Labour	100 h/year	50	100 h/year	50
Maintenance	0,5 % of inv	25	0,5-1 % of inv	15
Total cost		**1065**		**455**

Major costs for this alternative are capital costs, costs for new membranes and electricity cost. Costs for operation and maintenance are normally low for membrane based water treatment plants.

Due to the rather high electricity consumption in the RO unit, this alternative is sensitive to the electricity cost. The membrane lifetime is also very important.

As for the precipitation/filtration alternative above, a Hg selective police filter at an increased cost of appr 50 kSEK/year may be required to reach the most strict emission requirements according to the design data in chapter 5.8.

7.2.4 Ion-exchange cleaning of condensate

The main components of the large plant are:

- 4 bag filters for coarse particle separation
- 2 activated carbon filter with 2800 l of activated carbon
- 2 heavy metal selective ion-exchangers, with regeneration, with 1800 l of resin
- 2 Hg and Cd selective ion-exchangers for 1800 l of resin
- As filters with 1800 l of resin
- Programming of DCS

The main components of the small plant are:

- bag filters for coarse particle separation
- 1 activated carbon filter with 700 l activated carbon
- 2 heavy metal selective ion-exchangers, with regeneration, with 450 l of resin
- 1 Hg and Cd selective ion-exchanger with 450 l of resin
- 1 As filter with 450 l of resin
- Programming of DCS

Chemical storage tanks, building and platforms are not included in the prices below.

Table 10. Cost of ion-exchange of waste water from the condensation stage
Tabell 10. Kostnad för jonbytesbaserad rening av kondenseringsstegets vatten

	Large plant (15 m^3/h)		**Small plant (4 m^3/h)**	
		kSEK/year		**kSEK/year**
Investment	2,7 MSEK		1,5 MSEK	
Capital cost	10% of inv	270	10% of inv	150
pH adjustment from pH 7 to pH 5 and 8	1,6 kg + 2,4 kg NaOH+HCl per m^3	360	1,6 kg + 2,4 kg NaOH+HCl per m^3	95
Heavy metal resins	Exchanged every 5 year	40	Exchanged every 5 year	10
Hg resins	Exchanged every 0,5-2 year	230-920	Exchanged every 0,5-2 year	60-240
As resins	Exchanged every 2 year	105	Exchanged every 2 year	30
Labour	100 h/year	50	100 h/year	50
Maintenance	0,5 % of inv	15	0,5-1 % of inv	10
Total cost		**1070-1760**		**405-485**

Major costs for the ion-exchange alternative are costs for renewal of ion-exchanger resins. Costs for operation and maintenance are normally low for this type of plants. An additional advantage is that this alternative is rather compact and requires less space than the other alternatives.

An ion-exchanger based water treatment plant may be very favourable for small WtE plants with limited staffing. However, it can turn out to be very costly if variations in waste composition lead to a higher metal loading on the ion-exchanger than was calculated for. In cases where the calculated heavy metal loading is so high that the ion-exchanger fillings must be renewed very frequently, regeneration equipment should be installed. Regeneration equipment for the heavy metal selective ion-exchanger is included in the investment cost above. Regeneration of Hg and As ion-exchangers is not possible. Therefore, the lifetimes have been set to 5 years for the regenerable heavy metal ion-exchanger, 0,5-2 years for the Hg selective ion-exchanger and 2 years for the As filling material.

The lifetime of the Hg selective ion-exchanger is critical for this plant, since this ion-exchanger is not regenerated. At an average Hg concentration in untreated flue gas condensate of 50% of the maximum concentration according to the design data in chapter 5.8, a Hg ion-exchanger lifetime shorter than 0,5 year is foreseen. If the average Hg concentration is lower, appr 10% of the maximum design concentration, the lifetime of the Hg ion-exchanger will be almost 2 years.

7.2.5 Ammonia stripping

Due to the operation costs for steam, ammonia strippers should always be installed on the acidic waste water from the HCl stage, where the main part of the ammonia is absorbed. In precipitation/filtration based water treatment plants, with precipitation of all waste water, the ammonia stripper should be installed after the first lime addition steps, upstream of the point where the condensate is fed into the waste water treatment plant.

Table 11. Cost of ammonia stripping of HCl stage waste water
Tabell 11. Kostnad för ammoniakstrippning vattenflödet från surskrubbersteget

	Large plant (3 m^3/h)		**Small plant (1 m^3/h)**	
		kSEK/year		**kSEK/year**
Investment	4 MSEK		2 MSEK	
Capital cost	10% of inv	400	10% of inv	200
pH adjustment from 7 to 11	6,4 kg + 9,6 kg NaOH+HCl per m^3	930	6,4 kg + 9,6 kg NaOH+HCl per m^3	310
Steam	70 kW per 3 m^3/h	390	23 kW per 1 m^3/h	130
Labour	100 h/year	50	100 h/year	50
Maintenance	0,5 % of inv	20	0,5-1 % of inv	15
Total cost		**1790**		**705**

Besides the capital costs and costs for pH adjustment to pH 11, ammonia stripping has a high cost for steam. It is therefore very sensitive to the cost of steam.

Ammonia removal by membranes, which may be an option for flue gas condensate from biomass fired plants, is not recommended for waste water from WtE plants, since this technology is very sensitive to particles in the water.

8 Recommendations for new plants

The total costs of the different waste water treatment concepts are summarized below.

Table 12. Annual costs of the different waste water cleaning concepts
Tabell 12. Årliga kostnader för vattenrening med de olika teknikalternativen

Concepts for waste water cleaning	Large plant kSEK/year	Small plant kSEK/year	Concepts no
*Precipitation/filtration of all waste water	**2760**	**1345**	1
*Precipitation/filtration of all waste water (with Hg ion-exch police filter)	**2790**	**1350**	1
*Precipitation/filtration of HCl stage water *Ion-exchange of condensate (2 year Hg ion-exch lifetime)	1100 + 1070 = **2170**	715 + 405 = **1120**	3, 5
*Precipitation/filtration of HCl stage water *Ion-exchange of condensate (0,5 year Hg ion-exch lifetime)	1100 + 1760 = **2860**	715 + 485 = **1200**	3, 5
*Precipitation/filtration of HCl stage water *RO of condensate	1100 + 1065 = **2165**	715 + 455 = **1170**	3, 5
*Recycling of HCl stage water *Ion-exchange of condensate (2 year Hg ion-exch lifetime)	**1070**	**405**	7
*Recycling of HCl stage water *Ion-exchange of condensate (0,5 year Hg ion-exch lifetime)	**1760**	**485**	7
*Recycling of HCl stage water *RO of condensate	**1065**	**455**	7
*Ammonia stripping of HCl stage water	**1790**	**705**	2, 4, 6

The pros and cons of the above concepts are summarized below.

8.1 Precipitation/filtration of all waste water

From the table above it can be seen that the concept with the highest total annual cost is when all waste water is precipitated and filtrated. (2,8 and 1,3 MSEK/year for the large and small plant respectively.) This option is very labour consuming and has the highest costs for labour as well as for chemicals. The high cost for chemicals is due to the high consumption of chemicals for flocculation and precipitation, but also due to the fact that the waste water needs pH adjustment to pH 9 in the precipitation step. Another disadvantage is the fact that a lot of space is required for this type of waste water treatment. The advantage of this concept is that it is not dependent on the choice of flue gas cleaning, but can be used with any flue gas cleaning technology.

Table 13. Pros and cons of concept with precipitation/filtration of all waste water
Tabell 13. För- och nackdelar med fällning/filtrering av allt vatten

Advantages	Disadvantages
Applicable for both ESP and fabric filters	High capital costs
Well proven technology in WtE plants	Very high chemicals consumption
	Labour intensive
	Spacious

8.2 Precipitation/filtration of waste water from HCl stage, ion-exchange or RO of condensate

The options where only the acidic waste water from the HCl stage is precipitated and filtrated have lower annual costs. The total cost of the ion-exchange concept and the RO concept is almost the same, provided that the Hg concentration of the condensate is within limits as discussed above. (2,2 and 1,1-1,2 MSEK/year for the large and small plant respectively.) For the large plant these concepts have 20-25% lower total costs than the concept where all water is precipitated and filtrated. A major cost in the ion-exchange and RO concepts is the cost of ion-exchange resins and membranes respectively. This cost is highly dependent on the lifetimes. For the ion-exchanger concept an additional uncertain factor is the heavy metal content of the waste water. All deviations from the design concentrations of heavy metals have an immediate influence on the lifetime of the ion-exchanger. Therefore, this concept can become very expensive for plants with highly contaminated fuels with a high heavy metals concentration, especially with a high Hg concentration which leads to a high consumption of non-regenerable Hg selective ion-exchanger.

Table 14. Pros and cons of concept with precipitation/filtration HCl stage water, ion-exchange or RO of condensate
Tabell 14. För- och nackdelar med fällning/filtrering av surskrubbervatten, jonbyte eller RO av kondensat

Advantages	Disadvantages
Applicable for both ESP and fabric filters	The ion-exchange option can become very expensive for waste water with high heavy metals content, especially Hg and Cd
For the large plant this option is more economical than precipitation/filtration of all waste water	Even with a smaller precipitation/filtration plant than above, this option is still quite labour intensive and spacious

The option where the condensate is bypassed past the entire precipitation and sedimentation train, and only treated in the final polishing step in sand and activated carbon filters, is not discussed here. The economy of this option could be very good. The total cost would be only about half of the total cost of the ion-exchange and RO concepts, since it would be based on a small precipitation and filtration plant for the acidic water supplemented with a sand and carbon filter based polishing step for the whole condensate flow. This option, however, was considered to be too risky. New plants with this concept would probably be equipped with ion-exchange or RO police filters, and thus they would actually be built according to the ion-exchange or RO concept.

8.3 Recycling of waste water from HCl stage, ion-exchange or RO of condensate

The most economical options are the two options were the acidic waste water can be recycled and only the condensate needs cleaning. (1,1 and 0,4-0,5 MSEK/year for the large and small plants respectively.) The costs of these options are less than half compared to when all waste water needs cleaning. These options are only feasible in plants which are equipped with semi-dry or dry flue gas cleaning with lime injection and fabric filter, where the chlorides are removed so that they do not accumulate in the flue gas and waste water. For plants with ESP this concept is not applicable.

This concept requires low heavy metal contents in the waste water. It can become very expensive for plants with highly contaminated fuels with a high heavy metals concentration, especially with a high Hg concentration which leads to a high consumption of non-regenerable Hg selective ion-exchanger.

Table 15. Pros and cons of concept with recycling of HCl stage water, ion-exchange or RO of condensate
Tabell 15. För- och nackdelar med recirkulering av surskrubbervatten, jonbyte eller RO av kondensat

Advantages	**Disadvantages**
Lowest cost	The cost of the ion-exchange option is highly dependent on the Hg resin consumption
Does not require much labour nor space	Only for plants with dry or semi-dry flue gas cleaning

Recycling of waste water also eliminates the need for ammonia stripping, since the ammonia is recycled.

8.4 Ammonia stripping

In the options, where the acidic waste water is not recycled, ammonia removal may be necessary.

The cost of ammonia stripping is considerable. (1,8 and 0,7 MSEK/year for the large and small plant respectively.) This cost is due to high consumptions of chemicals for pH adjustment and of steam.

Table 16. Pros and cons of concept with ammonia stripping
Tabell 16. För- och nackdelar med ammoniakstrippning

Advantages	**Disadvantages**
SCR is often even more expensive than	High chemicals cost

SNCR + ammonia stripping	High steam consumption

The cost of ammonia stripping needs to be discussed in a context of total costs for NO_x reduction, where the total cost of SNCR and ammonia stripping is compared to the cost of SCR.

9 Proposal for future research

One of the dominant costs of all the waste water treatment plants is the cost of neutralisation chemicals. This cost is always high, irrespective of the choice of waste water treatment technology.

Besides the high cost for chemicals, the plants also have high costs for the disposal of residues. These residues may arise in the flue gas treatment, when dry or semi-whet flue gas cleaning is used. In plants with flue gas filters without injection of lime or sodium bicarbonate, the high chloride and bicarbonate concentrations in the waste water from the wet flue gas cleaning may lead to high amounts of residues, especially in locations where neutralisation by precipitation with lime is required due to restrictions on chloride concentrations in the clean waste water.

The total costs of neutralisation chemicals and residue disposal may be the critical factor which determines which flue gas treatment technology is the most economical.

It would be interesting to make a case study on the economy of different flue gas cleaning technologies. In the study flue gas cleaning systems with and without lime injection should be compared. Parameters which should be discussed include location (permission to discharge chlorides to recipient or not), costs of disposal of residues from flue gas cleaning and waste water cleaning, total lime consumption (for a certain reduction of chlorides and sulphates in the flue gas) for different cleaning systems.

Another area which should be investigated further is the total waste water balance of WtE plants, how different types of waste water can be recycled and how the total water consumption can be minimized.

10 References

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Appendices

A Analyses

Analysis data of samples taken during visits to the plants are shown in this appendix. For Gärstadverket average data from 2008 are shown instead of data from samples taken during the visit. For Värmekällan in Skövde additional HCl stage data from 2008 are included.

A.1 Sysav combustion line 4

	HCl stage (1)	SO2 stage (2)	Cond stage (3)	HCl + SO2 stage after tank 1 (4)	After second neutr tank (5)	After lamella separator (6)	Sludge to filter press (7)	After second precip tank (8)	Outlet to recipient (10)
Susp solids [mg/l]	3200	13000	180	2400	1200	2	6600	5	2
Hg [ug/l]	940	170	120	380	250	3	1120	0,5	0,7
Cd [ug/l]	1100	170	99	440	260	0,32	1000	0,77	0,11
Co [ug/l]	51	10	1,3	28	15	4,1	61	3,8	3,7
Tl [ug/l]	12,2	2,24	0,385	5	2,87	0,081	13,4	0,106	0,051
As [ug/l]	980	120	100	450	250	69	780	67	61
Pb [ug/l]	22500	4280	2720	9570	5640	3,8	25900	6	1,5
Cr [ug/l]	344	51	17	140	75	4,8	321	4,8	5,4
Cu [ug/l]	6450	1160	1050	2840	1790	9,3	8180	12	9,7
Ni [ug/l]	444	118	8,6	341	197	32	302	32	31
Zn [ug/l]	148000	32000	29100	52400	32000	64	136000	69	44
Chlorides [mg/l]	4900	510		18000	11000	10000	10000	11000	9800
Sulphates [mg/l]	1200	2600	540	1100	450	740	940	730	730
Amm nitrogen [mg/l]	4,3	2,9	0,18	4	2,3	2,1	2,1	2	1,5
Conductivity [mS/m]	63	3,9	1,6	47	28,5	27,05	27,4	30	26,4
pH	1,2	6	8,5	1,6	9,6	8,3	8,8	8,4	7,6
Alkalinity [mg/l]	5		230		100	55	74	60	42
	Blue = below detection limit Red = questionable analysis results								

Figure 40. Analyses from Sysav 4

Figur 40. Analyser från Sysav 4

A.2 Gärstadverket combustion line P4

	HCl stage (1)	HCl stage after NH3 stripper (4)	HCl + cond stage bef sand filter (5)	Clean condensate (6)	SO2 stage (7)	Cond stage (8)	Sludge to filter press (11)
Susp solids [mg/l]							7900
Hg [ug/l]	7	0,4	1,9	0,5	5	9	3,2
Cd [ug/l]	0,4	0,17	0,11	0,11	3	0,2	38
Co [ug/l]	8	3,9	2,0	2,0	20,0	2	110
Tl [ug/l]	0,5	0,4	0,2	1,0	1,0	0,1	1,15
As [ug/l]	3,5	2,1	0,9	1,8	4	0,7	71
Pb [ug/l]	6	2,0	2,0	2,0	20,0	2	1130
Cr [ug/l]	437	128	58	17	17	2	590
Cu [ug/l]	64	36	13	8	16	2	5480
Ni [ug/l]	291	6,7	2,3	2,0	32	2	364
Zn [ug/l]	82	50	50	50	411	59	4740
Chlorides [mg/l]	8616	9395	3082	1916	1160	24	4300
Sulphates [mg/l]	892	1296	470	254	43211	390	4600
Amm nitrogen [mg/l]	433	5	7	4	17	14	75
Conductivity [mS/m]							2000
pH	1,0	9,6	9,4	8,5	7,2	7,2	9,5
Alkalinity [mg/l]							390
	(1), (4), (5), (6), (7) and (8) are average values from 2008 (11) are analysis data from sample taken during visit at plant						

Figure 41. Analyses from Gärstadverket

Figur 41. Analyser från Gärstadverket

A.3 Sysav combustion line 1&2

	HCl stage (duplicate sample) (1)	HCl stage (duplicate sample) (1b)	SO2 stage (2)	Cond stage (3)	SO2 + cond stage (duplicate sample) (4a)	SO2 + cond stage (duplicate sample) ((4b)	After heavy metal ion-exchangers (5)	After Hg ion-exchanger (6)	Outlet to recipient (7)
Susp solids [mg/l]	36	36	2	2	2	2	2	7	3
Hg [ug/l]	320	300	21	0,52	33	32	8,2	0,3	0,06
Cd [ug/l]	270	270	10	1,4	8,9	9,1	0,05	0,062	0,22
Co [ug/l]	42	41	0,54	0,3	0,43	0,45	0,3	0,3	0,3
Tl [ug/l]	3,22	3,16	0,114	0,05	0,065	0,106	0,05	0,05	0,05
As [ug/l]	310	310	3,4	1,5	1,5	1,5	1,5	1,5	1,5
Pb [ug/l]	9170	9200	267	14	353	358	2,2	2,1	2,4
Cr [ug/l]	413	416	12	2,1	3,6	2,6	1,5	0,97	0,96
Cu [ug/l]	2520	2440	59	18	69	64	34	33	30
Ni [ug/l]	382	506	125	50	43	28	29	22	16
Zn [ug/l]	39900	40900	1900	208	905	908	54	55	46
Chlorides [mg/l]	82000	75000	370	350	380	340	630	480	330
Sulphates [mg/l]	16000	14000	20000	150	20000	20000	21000	22000	21000
Amm nitrogen [mg/l]	0,01	0,01	55	15	0,17	0,19	0,33	0,33	0,22
Conductivity [mS/m]	2900	3000	2900	37	2900	2900	3000	3100	3100
pH	0,4	0,4	5,6	6,5	4,1	4,1	5,1	5,2	10,6
Alkalinity [mg/l]				68					460
	Blue = below detection limit Red = questionable analysis results								

Figure 42. Analyses from Sysav 1&2

Figur 42. Analyser från Sysav 1&2

A.4 Värmekällan

	HCl stage (data from 2008) (1)	After cond tank (2)	Cond stage (duplicate sample) (4a)	Cond stage (duplicate sample) (4b)	Cond stage (5)	After carbon filter (6)	After Hg ion-exchanger (7)	After heavy metal ion-exchanger (8)	After heavy metal ion-exchanger (9)	After As ion-exchanger (10)	After As ion-exchanger (11)
Susp solids [mg/l]		4	2	2	2	2	2	2	2	2	2
Hg [ug/l]		12	11	1,2	4	1	0,05	0,077	0,05	0,058	0,05
Cd [ug/l]		0,54	1,00	0,7	0,61	0,84	0,18	0,05	0,05	0,05	0,05
Co [ug/l]		0,3	3,4	0,4	0,3	0,3	0,3	1,7	0,3	0,3	0,3
Tl [ug/l]		0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
As [ug/l]		1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Pb [ug/l]		8,4	10	7,7	7	5,1	2,9	2,6	1,5	1,5	2,3
Cr [ug/l]		0,5	419	37	2	0,66	0,59	3,9	0,98	0,5	0,5
Cu [ug/l]		7,1	19	8,6	23	9,3	4,9	12	16	4,9	26
Ni [ug/l]		1,5	122	19	6	2,6	4,7	315	4,1	10	3
Zn [ug/l]		51	56	49	52	67	91	36	8,2	12	21
Chlorides [mg/l]	8000		400	320	460	430	410	390	420	330	390
Sulphates [mg/l]	130	1500	1200	1000	840	750	750	730	1100	800	690
Amm nitrogen [mg/l]	2300	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Conductivity [mS/m]		330	350	350	350	340	330	320	350	330	320
pH		6,9	3,2	3,1	3,2	3,2	3,3	3,4	7,4	9,7	8,3
Alkalinity [mg/l]		350							150	190	190
	Blue = below detection limit Red = questionable analysis results										

Figure 43. Analyses from Värmekällan in Skövde

Figur 43. Analyser från Värmekällan i Skövde

A.5 Måbjergvaerket

	HCl stage (1)	HCl stage (2)	SO2 stage (3)	Dioxin stage (4)	Cond stage (5)	Cond stage (6)	RO permeate (7)
Susp solids [mg/l]	14	14	3	2	2	2	2
Hg [ug/l]	460	0,05	230	15	28	1,8	0,05
Cd [ug/l]	320	0,37	94	40	11	11	0,05
Co [ug/l]	3,3	1,7	1,8	0,3	0,3	0,3	0,3
Tl [ug/l]	3,34	2,53	0,97	0,26	0,06	0,07	0,05
As [ug/l]	250	550	16	5,4	1,9	2,8	1,5
Pb [ug/l]	6480	14	976	552	161	99	1,5
Cr [ug/l]	44	12	7,3	3	0,96	0,96	0,5
Cu [ug/l]	1420	104	348	185	59	36	2,5
Ni [ug/l]	56	92	15	1,5	6	1,5	1,5
Zn [ug/l]	27600	75	14800	3910	974	980	5
Chlorides [mg/l]	32000	34000	560	23	6	6	
Sulphates [mg/l]	520	540	57000	150	150	150	150
Amm nitrogen [mg/l]	0,03	0,25	0,29	1	0,6	0,57	0,05
Conductivity [mS/m]	24000	7400	6900	16	10	10	7
pH	0,3	4,2	6	5,1	4,6	4,6	5,4
Alkalinity [mg/l]			65				
	Blue = below detection limit						
	Red = questionable analysis results						

Figure 44. Analyses from Måbjergvaerket

Figur 44. Analyser från Måbjergvaerket

A.6 Sönderborg Kraftvarmevaerk

	HCl stage (1)	SO2 stage (2) filtrate	SO2 stage (2) sediment	HCl stage (3)	SO2 stage (4)	Cond stage (5)	After UF (6)	RO permeate (7)	RO conc (8)
Susp solids [mg/l]	9		130	18	4	2	2	2	2
Hg [ug/l]	47000	0,05	62	0,70	0,05	0,05	0,05	0,05	0,05
Cd [ug/l]	140	8,8	104	0,35	0,08	0,38	0,5	0,05	0,47
Co [ug/l]	3,9	0,32	1	1,000	0,3	0,3	0,3	0,3	0,3
Tl [ug/l]	1,33	0,07	0	0,05	0,05	0,05	0,05	0,05	0,05
As [ug/l]	86	1,5	26	58	1,5	1,5	1,5	1,5	1,5
Pb [ug/l]	2640	2,2	470	4,8	1,5	3,6	5,2	1,5	3,5
Cr [ug/l]	31	2,1	15	5,2	1,6	0,72	1,2	0,68	0,66
Cu [ug/l]	424	21	47	15	20	1,5	2	1,5	2
Ni [ug/l]	22	6,2	16	69	1,9	1,5	4,4	1,5	1,5
Zn [ug/l]	26200	1190	1727	5	5	5	5,8	5	7,2
Chlorides [mg/l]	31000	580		25000	700	29			
Sulphates [mg/l]	240	3300		670	3100	150	150	150	150
Amm nitrogen [mg/l]	0	0,01		0,66	0,03	0,01	0,01	0,01	0
Conductivity [mS/m]	29000	780		5800	810	7,1	6,6	1	5
pH	0,2	2,8		7,8	9,1	6,6	7,2	5,4	6,4
Alkalinity [mg/l]				36	36	24	38	5	24
	Blue = below detection limit Red = questionable analysis results								

Figure 45. Analyses from Sönderborg Kraftvarmevaerk

Figur 45. Analyser från Sönderborg Kraftvarmevaerk

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