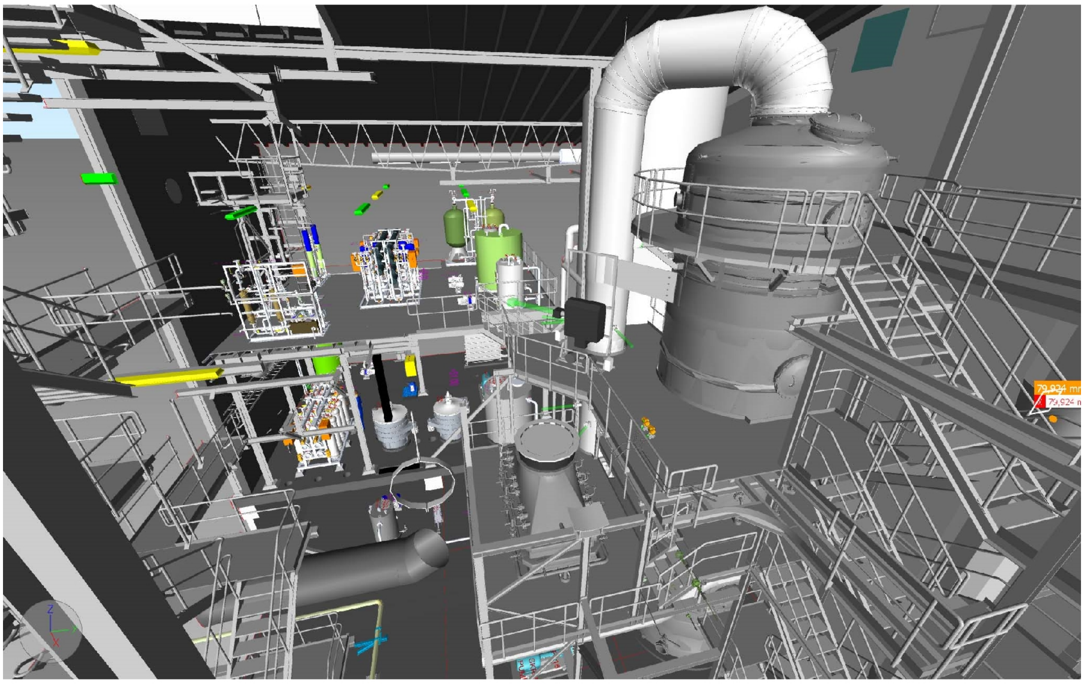
CALAMBIO

SCRUBBER AND SCRUBBER CONDENSATE TECHNOLOGY



1 GENERAL

Flue gases from combustion usually consist of more or less moisture. The moisture originates from on the one hand moisture in the fuel and on the other hand from combustion of hydrogen.

If the moisture is condensed to water this latent heat can be recovered for low temperature recovery. A typical application is preheating the return side of a district heating network.

As the efficiency of a boiler is (usually) related to the lower heating value of the fuel (excluding the potential energy in the moisture) the efficiency of the boiler formally rises from about 88-90% to up to 118% or thereabouts.

There are also other applications. In for example waste to energy combustion the scrubber can be used to substantially reduce emissions of sulphur, chlorides, ammonia, and heavy metals etc. sometimes the design has to be adopted specially for this application. These plants can be built with or without heat recovery. The preferences can also be seamlessly adopted instantly.

There are also several applications within the chemical industry and food industry.

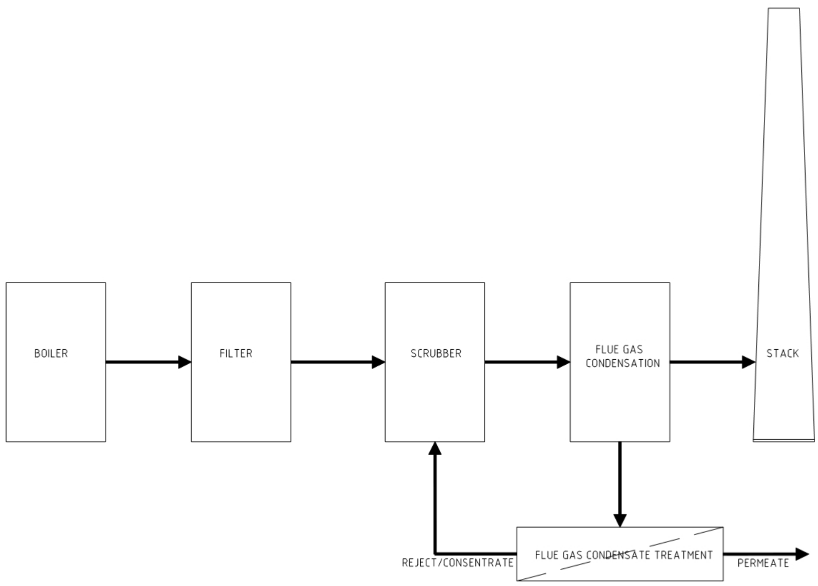


Figure – Typical flow diagram for solid fuel firing combined with scrubber technology.

2 SCRUBBER TECHNOLOGY

In a Waste to Energy application, we advocate a solution based on two (or more) stage scrubbers. This solution allows for proper handling of the flue gas condensate and simplifies condensate cleaning.

This solution is also becoming more interesting also for biomass combustion as it finally solves the problem of ammonia in the condensate.

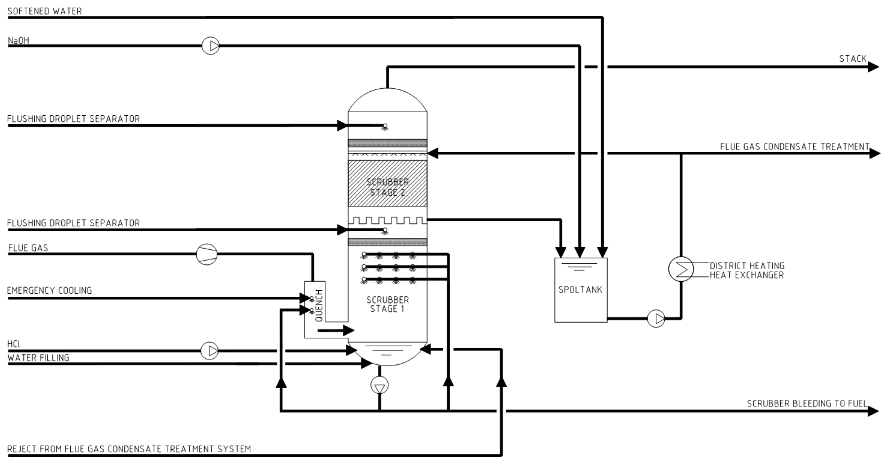


Figure – Typical flow diagram for a two-stage scrubber.

The two-stage scrubber typically consists of three major part.

- The quench
- The acid stage.
- The heat recovery stage

2.1 The quench

The objective of the quench is to rapidly cool down the flue gases to the dew point by means of spraying a high-water flow co-current with the flue gas.

In practice the quench is a part of the flue gas duct placed immediately before the scrubber tower. The quench is usually manufactured from highly corrosion resistant steel or glass fibre reinforced plastic (GAP). Final decision depends on design temperatures and flue gas composition.

The water flow through the quench is usually serviced by the same water circuit as the downstream acid stage.

When water is sprayed into the flue gas it will result in the flue gas temperature falling to the saturation temperature and an increase in the water temperature.

There will be a continuous consumption of water in the quench. If the scrubber is equipped with heat recovery this will later be recovered in the second stage of the scrubber.

2.2 The acid stage scrubber

The acid stage of the scrubber is integrated with a water storage and usually based on spray nozzles. The objective of the acid stage is Purely to separate:

- Particles
- Heavy metals
- Chlorides
- Ammonia

Particles are separated up to 93-97% in this stage. There will thus be no particles to handle in the condensing stage and this lessens the demands on the condensate cleaning plant. Heavy metals I flue gases are mainly bound to particles and will be separated in the acid stage.

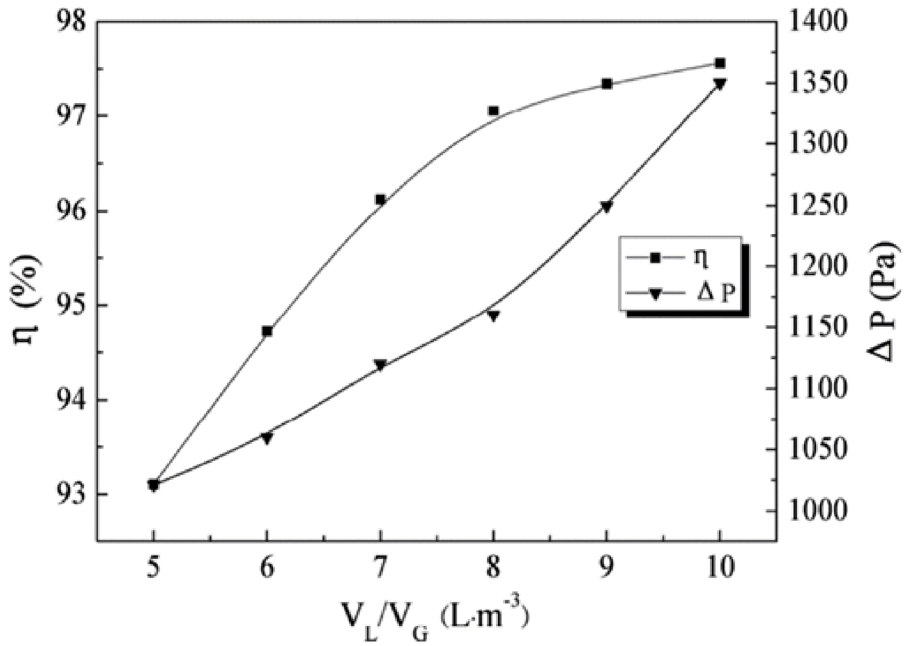


Figure – Water/ flue gas flow as a function of separation in the acid stage of the scrubber.

At low pH ammonia is converted to ammonium, i.e., a salt that is easily soluble in water. This results in ammonia being effectively separated in this stage. Typical separation is 99%. You can comfortably say that there will be no ammonia slip to the atmosphere.

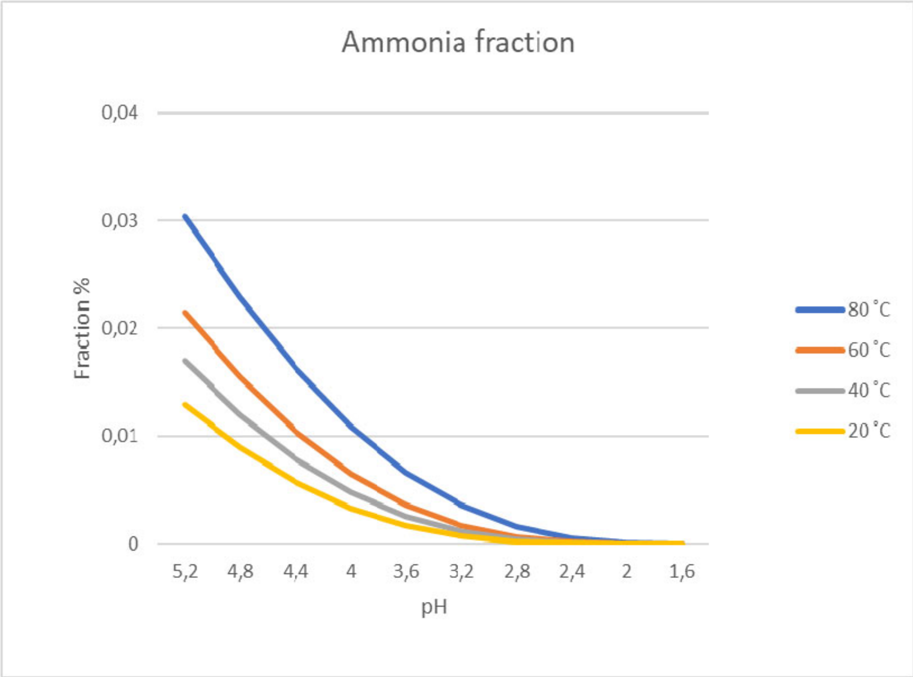


Figure – Typical separation of ammonia as a function of pH.

A low pH in the acid stage can be achieved by dosing of HCl or (for free) by means of a high natural HCl content in the fuel (if not fully separated in the bag filter as can be the case in SCR applications) For BFBC applications and municipal waste HCl is usually not necessary except for start-up.

Halogens such as HF, HCl, HBr are effectively separated in this stage.

- HF – 50–70% separation
- HCl – 98% separation
- HBr – 90% separation

SO_3 is easily solved in water and is not affected by pH. SO_2 is less favourably separated in this acid environment.

Some of the acid condensate must be drained continuously in order to control the salt content. The drain is a limited volume. This small stream can be returned to the furnace. Either directly to the furnace or mixed with the fuel. Both solutions require a fair bit of afterthought in order not to introduce corrosion problems. Properly designed this will work very well.

The drained water is replaced by reject from the condensate cleaning plant. There is no need for external water supply.

For some less complicated designs there is no need for an acid stage, and this can be omitted. More strict emission regulations tend to make the acid stage more or less compulsory for all types of plants except the smallest.

2.3 Heat recovery stage

The possible thermal output from the condensing stage of a flue gas scrubber is up to about 25% of the lower heating value of the fuel input. Exact figures depend on fuel composition with regards to moisture and hydrogen. It also depends on the temperature levels of the energy consumer. A district heating network based on 45°C return temperature and 90°C feed temperature will gain much more than a system with 55°C return temperature. A hot water system with return temperatures of 90°C will not be able to take advantage of the condensing stage.

The heat recovery or condensing stage is usually filled with packings. The objective of the packings is to generate a very large surface area where the water flow and flue gas get in contact.

The main objective of the condensing stage is to recover the latent heat of the flue gas. This recovery will increase the water flow out from this stage.

The condensing stage always has a water circuit separated from the acid stage.

In the condensing stage also SO_2 will be separated. Separation will be close to 100%.

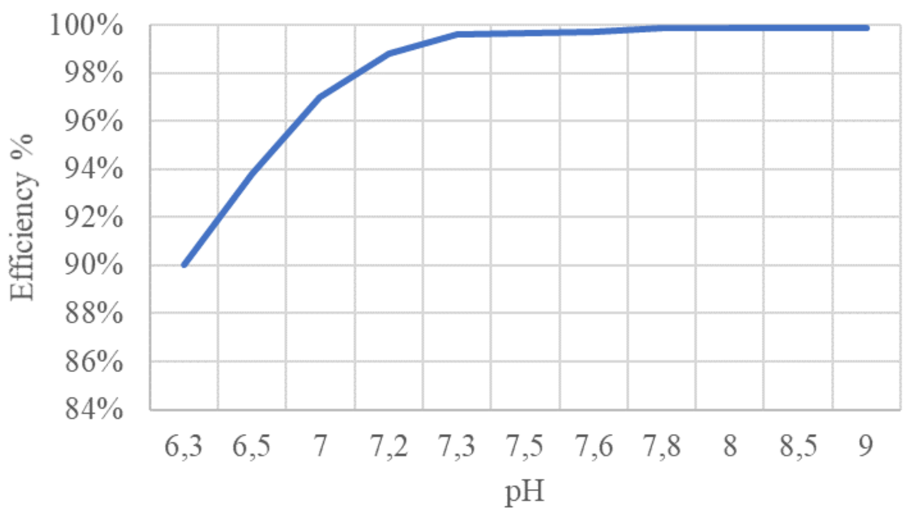


Figure – Separation of SO_2 as a function of pH.

3 SCRUBBER ADVANTAGES

The main advantages of scrubber technology as compared to flue gas condensers are:

- Several scrubber stages can be integrated in one single scrubber tower. This is not possible in combination with an integrated tubular cooler. Scrubbers for new plants can usually be built very compact.

- The tank for quench and acid stage will be integrated in the scrubber tower. The condensing stage sump can be, but it is usually more convenient with an external tank.
- Thew stack can be integrated in the scrubber tower. This is usually not the case for tubular heat exchanger designs. Please see the Perstorp boiler #8 example below.
- The scrubber tower can without problems be located outdoor. Pumps and condensate cleaning should be placed indoor.
- A scrubber can be totally made from composites. This makes it very resistant to corrosion and allows for very aggressive fuels as compared to tube heat exchangers. For special application, the scrubber can of course be made from metallic materials. There are composites that can handle up to 200°C and more. Different parts of the scrubber have different demands.
- The scrubber tower is a static box. The pressure drop is very small compared to a tube type flue gas condenser.
- As the internals of the scrubber is not fixed to the scrubber tower the choice of material selection is more or less unlimited. This also make service very easy. The need for service is very limited though.
- A leakage in a tube type condenser results in a total loss of production. In the case of a scrubber the heat exchanger is placed outside the reactor and can be bypassed at any time without loss of any functions except heat recover (if there are not redundant heat exchangers). For combustion of gate fee fuels the possibility to operate the scrubber without heat recovery at all is also favourable.
- Investment and maintenance cost is lower than for tube type condenser (at similar technical standard).
- The multistage scrubber makes a closed loop handling of water and condensate possible.
- Handling of particulates in the acid stages makes Electrostatic precipitators an option for flue gas cleaning for biomass.

4 MECHANICAL CONDENSATE CLEANING

The more heat that is recovered from the flue gas in the scrubber the higher the condensate flow. The condensate will be contaminated and will need to be cleaned before emitted to recipient.

When designing a flue gas condensate treatment system, it is usually a very good idea to make a complete water balance over the entire plant. Our experience is that there are always larger or smaller streams that can be included in a complete system.

Waste streams from other parts plants can be included in the cleaning system. One condensate plant with suitable redundance can service several scrubber units etc. There is also the possibility to substitute expensive ore limited supply of city water with more elaborate cleaning of the condensate. A typical solution is to produce the make-up water for the boilers based on scrubber condensate.

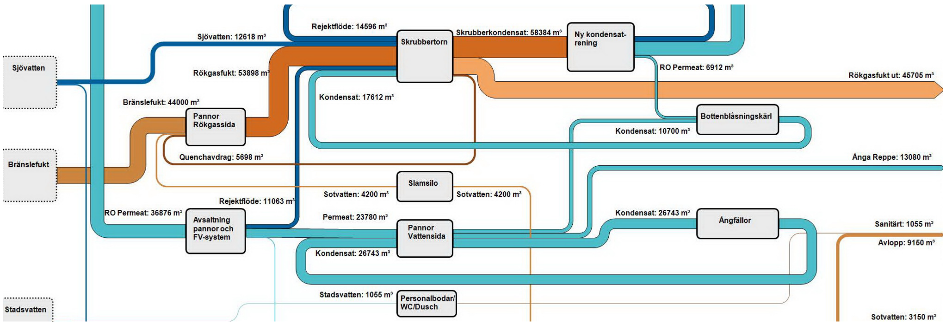


Figure – Example of Sankey diagram for presentation of water flows in Waste to Energy pant.

Calambio recommends use of a combination of membrane technique and ion selective filtration. This setup has several advantages compared to the traditional cleaning based on precipitation, flocking, sedimentation etc.

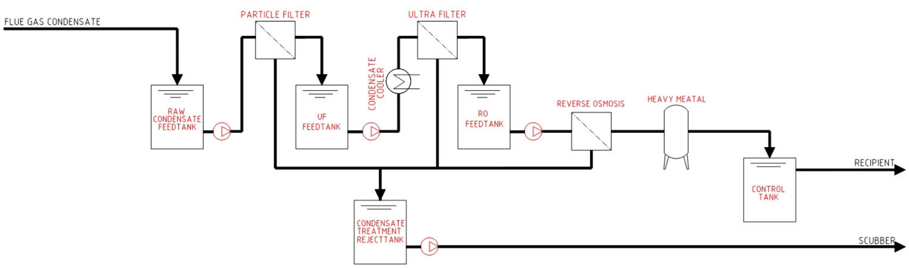


Figure – Typical process flow for condensate cleaning based on membrane technique and ion selective filtration.

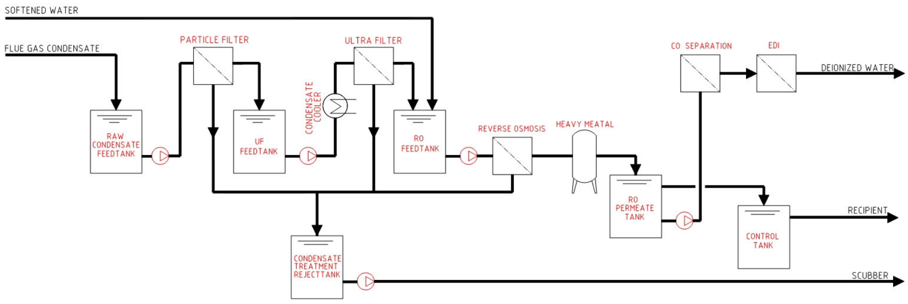


Figure – Typical process flow for production of make-up water.

4.1 Advantages of membrane – ion selective filtration

- Filtering in membranes is based on physical rather than chemical processes and the need for chemicals in the process is very limited. It is mainly restricted to periodical washing of membranes.
- The permeat from ultrafiltration is free from particles and maintains a high and constant quality. It can thus be utilised for production of make-up water. This means that the clean condensate can be recovered and will reduce need for fresh water and energy for the Rankine cycle.
- Heavy metals attached to particles will be totally filtered in the ultra-filters.
- Membranes have a selective filtration, and each stage can be designed in modules. This means that the system can be tailor made for individual needs.
- Condensate cleaning based on membrane technique can easily be complemented should the demands change.
- Membrane technique is a compact design with a limited footprint.
- Membrane based condensate cleaning can be preassembled as skids complete with instrumentation. This minimises site activities.
- The reliability of the equipment is very high. There is no need for complex tuning.
- A major benefit is the possibility to separate ammonium. This means that there will be very low emissions of NH3 to bot air and water. This will make the efficiency of SCR or SNCR higher. There will be no need whatsoever for an ammonia stripper that is a solution with contra dictionary demands between high efficiency and problems with carbonisation.

5 REFERENCE PROJECTS

5.1 Lidköping Energi AB, Lidköping Sweden

The scrubber for Lidköping Energi AB is a part of a complete 20 MW Waste to Energy Co-generation plant designed on EPCM basis by Calambio Engineering. The fuel for the boiler is a mixture of municipal and industrial waste. The scrubber tower and condensate cleaning plant are detail designed by Calambio.

The objective of the scrubber tower is heat recovery and flue gas cleaning.

The flue gas design temperature is 200°C for the quench and 110°C for scrubber tower.

For safety reasons the scrubber is supplied with an emergency cooler.

The scrubber is manufactured from Fibre-reinforced plastic and all interior parts are made from high density polypropylene.

There is no bypass for the scrubber.

Figure – Installation of scrubber tower in Lidköping.

Flue gas condensate treatment consists of particle filtration, ultra-filtration unit, reverse osmosis unit, heavy metal filtration, CO_2 separation unit by gas membrane contactor, existing EDI, and mixed bed unit.

The capacity of flue gas condensate treatment system is 15m^3/h.

The condensate is cleaned further and is used as make-up water for the Co-generation boilers.

Table – Main data for scrubber installation for Lidköping Energi AB

Boiler	20 MW BFBC
Fuel	A mixture of municipal and industrial waste
Heat recovery	5 MW District heating
Particulate filter	Bag filter
Year commissioned	End of 2021
Materials	Fibre-reinforced plastic housing, High density polypropylene interior parts
ID fan	Between bag filter and scrubber. No reheat of flue gas
Stack	Existing fibre-reinforced plastic

Figure – Manufacturing of Quench.

Figure – Manufacturing of scrubber tower.

Figure – Lift of scrubber.

Figure – Manufacturing of ultra-filter skid.

Figure – Manufacturing of Reverse osmosis skid.

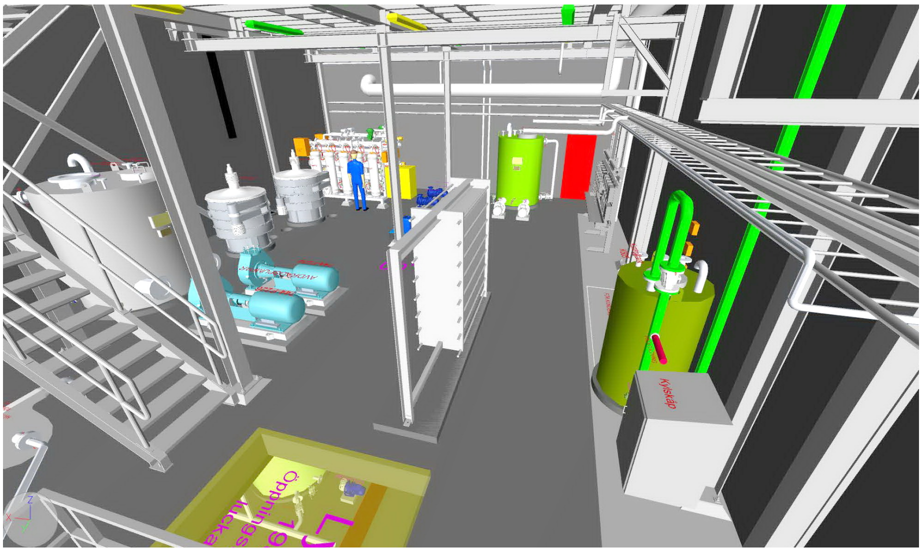


Figure – Layout for part of the condensate cleaning.

5.2 Sunpine AB, Piteå, Sweden

The scrubber for Sunpine AB is delivered by Calambio as a Turnkey design including ID fan. The objective of the scrubber is removal of sulphur from the Flue gases.

The flue gas design temperature is 400°C. For safety reasons the scrubber is manufactured from Duplex and all interior parts are made from Duplex or stainless steel depending on if they are welded or not.

Table – Main data for scrubber installation for Sunpine AB

Boiler	5,4 MW hot oil boiler. Flue gas temperature 350°C
Fuel	Residues from manufacturing of biodiesel from tall oil.
Heat recovery	None
Particulate filter	None
Year commissioned	2020
Materials	Duplex housing, Stainless packing
ID fan	Between bag filter and scrubber. No reheat of flue gas
Stack	Stainless duct along refinery structures.

Figure – Sunpine bio diesel refinery.

Figure – Scrubber installation for Sunpine AB before thermal insulation.

5.3 Västervik Miljö & Energi AB, Boiler #4 Stegegholmsverket, Västervik Sweden

The scrubber at Västervik Miljö AB is a part of a complete 20 MW W2E Co-generation plant designed on EPCM basis by Calambio Engineering. Also, the scrubber tower is detail designed by Calambio.

The scrubber is used for both heat recovery (winter only) and flue gas cleaning in order to fulfil EU 2000:76.

This plant is equipped with a bypass ductwork.

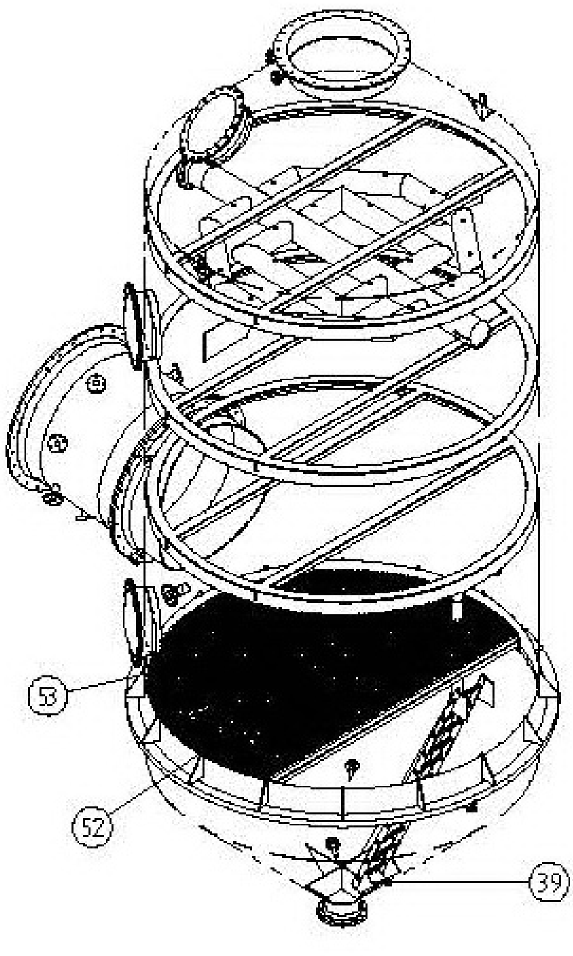


Figure – 3D Model of scrubber for Västervik Miljö & Energi AB.

Flue gas condensate treatment includes precipitation of heavy metals, flocking, coagulation and sedimentation. There is also a polishing continuous sand filter.

Table – Main data for scrubber installation for Boiler #4, Stegeholmsverket, Västervik.

Boiler	20 MW BFBC
Fuel	Municipal and industrial waste 0-100% each.
Heat recovery	3,7 MW
Particulate filter	Bag filter
Year commissioned	2013
Materials	GRP housing, PP packings.
ID fan	Between bag filter and scrubber. No reheat of flue gas
Stack	Duplex core.70 m high. GRP ducts.

Figure – Västervik Miljö & Energi AB, Stegholmsverket.

Figure – Manufacturing of scrubber tower for Västervik Miljö & Energi AB.

Figure – Example of flocks in the flocking tank.

5.4 Lantmännen Reppe AB, Lidköping, Sweden

The scrubber for Lantmännen Reppe AB is installed in order to reduce odour from fermentation tanks in a Vodka Distillery. The distillery was fully rebuilt and upgraded by Calambio on an EPCM basis in 2010.

In the fermentation tanks carbon dioxide and aromatic hydrocarbons are produced. Alcohols are separated to a very high degree. Hydrocarbons with low partial pressures such as acetaldehyde would need very high pH in order to be fully separated. This is not convenient with regards to the off air. A two-stage solution is possible but not considered necessary at the time of installation.

Figure – Upper part of CO_2-scrubber for Lantmännen Reppe AB.

5.5 Vattenfall AB Boiler #1, Västerbyverket, Götene, Sweden

The plant was originally built for Vattenfall AB in 2001 on an EPCM basis by Calambio engineering AB. The plant is now under ownership of Götene Vatten & Värme AB.

The plant produces 120 bar steam for Arla Foods AB dairy some 500 meters away. There is also production of district heating for the Community of Götene.

The objective of the scrubber tower is recovery of latent heat in the flue gases for production of district heating.

There is no bypass for the scrubber.

Figure – Scrubber tower, Västerbyverket, Götene.

The condensate cleaning consists of a sand filter only. Polymers are added through a static mixer.

Table – Main data for scrubber installation for Boiler #1 Västerbyverket, Götene.

Boiler	24 MW BFBC
Fuel	Bark and wood residues 30-50% moisture
Heat recovery	2,3 MW
Particulate filter	Bag filter
Year commissioned	2001
Materials	Duplex housing. stainless packings
ID fan	Between bag filter and scrubber. No reheat of flue gas
Stack	Duplex. 40 m high

Figure – Detail, externally removable spray nozzles. Scrubber tower Västerbyverket.

Figure – District heat exchanger for scrubber circuit. Västerbyverket, Götene.

Figure – 2 x 100% capacity circulation pumps for scrubber. Västerbyverket Götene.

5.6 PC Såget, Herrljunga Sweden

PC Såget is a small district heating production plant located in Herrljunga, Sweden. The plant is based on combustion of wood dust and bark in an adiabatic incinerator completed with a heat recovery boiler. Flue gas cleaning is by means of a multiclone.

The complete plant is designed on an EPCM basis by Calambio.

The main objective of the scrubber is heat recovery for district heating as well as bettering the particulate control. The dust load in the condensate is substantial.

Figure – Scrubber tower with bypass. PC Såget, Herrljunga, Sweden.

This scrubber is equipped with a bypass.

The condensate cleaning is very basic and involves coagulation, sedimentation, and sand filter only. Also, pH is controlled.

Table – Main data for scrubber installation for PC Såget.

Boiler	5 MW incinerator and heat recovery boiler
Fuel	Saw dust and bark. Up to 55% moisture
Heat recovery	1,35 MW
Particulate filter	Multiclone (Dust load 250 mg/Nm^3)
Year commissioned	2004
Materials	Stainless steel housing. PP packings
ID fan	Between Multiclone and scrubber. No reheat of flue gas
Stack	Duplex. 28 m high

Figure – Condensate cleaning for PC Såget. Heat exchanger for district heating is also shown in the middle.

5.7 Perstorp Specialty Chemicals Boiler #8, Perstorp Sweden

This scrubber for Perstorp was built by Calambio on an EPCM basis in 2007. The objective of the installation was flue gas cleaning for a boiler burning on the one hand high sulphur heavy fuel oil and on the other hand up to 16 MW of hazardous liquid waste. The complete plant was designed by Calambio.

The installation is combined from several different sub suppliers.

The flue gas cleaning design fully integrates the scrubber, a wet electrostatic precipitator and also on top of this the stack.

Figure – Perstorp Specialty Chemical. Combined scrubber, wet ESP, and stack.

As there was already a surplus of low temperature heat there is no heat recovery at all in this plant.

The complete design is made from glass fibre reinforced plastic.

Flue gas condensate treatment is reintroduced in the same system as for Boiler#6.

Table – Main data for scrubber installation for Perstorp Specialty Chemicals Boiler #8.

Boiler	16 MW Calambio Incinerator and 40 MW D-type dual drum steam boiler.
Fuel	Heavy fuel oil and hazardous liquid waste.
Heat recovery	None
Particulate filter	Wet ESP integrated in scrubber
Year commissioned	2007
Materials	GRP
ID fan	New fan between filter and scrubber. No reheat of flue gas
Stack	GRP on top of scrubber. 50 m high

Figure – Detail of emission monitoring. Perstorp Boiler #8.

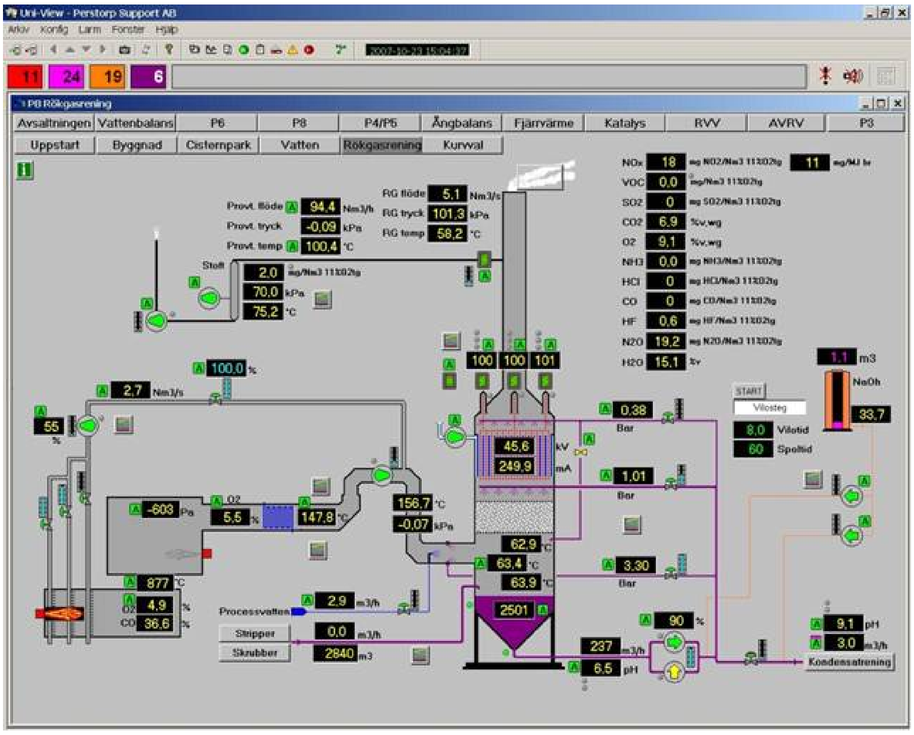


Figure – HMI view of combined scrubber/ wet electrostatic precipitator for Perstorp Specialty Chemicals AB. All emissions comply with EU 2000:76 and relevant BAT conditions.

Figure – Interior of quench for combined scrubber/ wet ESP for Perstorp Specialty Chemicals.

5.8 Perstorp Specialty Chemicals Boiler #6, Perstorp Sweden

The scrubber for Perstorp was built by Calambio on an EPCM basis in 2000. The objective of the installation was heat recovery from an industrial steam boiler in order to find additional heat to supply both the industrial estate and the local community with district heating.

A Duplex single scrubber was chosen in combination with stainless packing material in order to allow for dry operation as a way to increase availability without the need for a dedicated bypass.

The installation is made completely outdoor.

Figure – Scrubber tower at Perstorp AB

Flue gas condensate treatment includes precipitation of heavy metals, flocking, coagulation and sedimentation. There is also a polishing continuous sand filter.

Table – Main data for scrubber installation for Boiler #6, Perstorp Specialty Chemicals

Boiler	CFBC 55 MW_{th}
Fuel	Wood chips, peat, lignite, slaughterhouse waste (40' tonnes/annum) and other sorted industrial waste
Heat recovery	District heating. Up to 7 MW or 50-70% of the heat load depending on season.
Particulate filter	Bag filter.
Year commissioned	2000
Materials	Duplex scrubber and piping
ID fan	New fan between filter and scrubber. No reheat of flue gas
Stack	New Duplex liner in existing steel stack.

Figure – Condensate cleaning Perstorp AB.

6 MORE INFORMATION

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