Thermal Flue Gas Desulfurization Wastewater Treatment Processes for Zero Liquid Discharge Operations

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Technical Update, December 2010

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ABSTRACT

This report presents a worldwide inventory of power plant flue gas desulfurization (FGD) blowdown treatment systems using thermal technologies to achieve zero liquid discharge (ZLD) water management. The number of thermal treatment systems presently operating is very few, with the majority using chemical pretreatment followed by evaporation in a brine concentrator and crystallizer and finally dewatering of the residual salts. Of the operating thermal ZLD systems identified, six are located in Italy and only one in the United States.

Keywords

Flue gas desulfurization (FGD)
Zero liquid discharge (ZLD)
Brine concentrator
Crystallizer
Pretreatment
Softening
Blowdown

EXECUTIVE SUMMARY

This study identifies and summarizes the existing experience of the treatment of flue gas desulfurization (FGD) wastewaters using thermal methods. Although many FGD wastewater treatment systems are in operation, most generating stations use the physical/chemical treat-and-discharge method in dealing with the FGD wastewaters. This study was able to identify fewer than 10 true power plants with FGD thermal treatment system applications in operation worldwide today. Due to unresolved operational problems or the high cost of operating such systems, several FGD zero liquid discharge (ZLD) systems have been shut down or were installed but never commissioned.

Of the recently installed thermal FGD ZLD applications, six are located in Italy. All are coastal plants that use once-through cooling and discharge their non-FGD waters to the sea. One plant is located in the United States. Three plants were visited in order to find and witness firsthand the operational details of these operations. It should be noted that provision of information for this report by the case study sites was voluntary, and personnel were not obligated to provide all lessons learned. Therefore, some design and/or operational issues experienced at the case study sites might not be included or comprehensively described.

The majority of the operating plants visited or investigated appears to have well-operating ZLD systems and are currently not experiencing major problems, other than those normally encountered in typical water management operations. The plants' staff appeared to be satisfied with the performance of their FGD water treatment operations. All of the plants use wet limestone–forced oxidation (LSFO) scrubbers.

Most of the treatment systems found in this study are employed at generating stations that are burning coal with a relatively low sulfur and chloride content. Consequently, because the LSFO purge volume is a function of the buildup of gypsum and impurities from the coal—mainly chlorides—the blowdown rates for treatment were found to be relatively small. Fuel sources with higher impurities will require larger treatment systems.

The six ZLD applications in Italy use similar design concepts, consisting of pretreatment followed by evaporation in a brine concentrator and crystallizer with final dewatering of the crystal residuals. Pretreatment typically consisted of an initial dealkalization/metal removal and clarification process followed by softening, which changes the high calcium chloride concentration to the more easily handled sodium chloride.

Other processes employed to treat the FGD wastewaters include the use of clarifiers followed by crystallizers and, in one case, spray drying only. Some of the European plants consider the salt residuals a saleable by-product that is used for road deicer or salt mine stabilization. Such use depends on the impurities contained in the residual.

Because of the high cost for chemicals, the option of using softening versus nonsoftening in the pretreatment should be considered. Without the transformation of the calcium chloride to the less soluble and less corrosive sodium chloride, the use of a vacuum or multi-effect crystallizer might be warranted to reduce the high energy costs associated with evaporating a solution with a very high boiling point elevation and corrosivity.

The process selection with regard to the pretreatment and thermal system design is a function of many variables that are site and plant specific. Before choosing a treatment system, a careful review of the parameters peculiar to the specific FGD system and the overall plant circumstances is warranted.

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INTRODUCTION

Overview

With the recently imposed, more stringent air quality standards many U.S. power plants have or are planning to install flue gas desulfurization (FGD) systems to meet sulfur dioxide emissions regulations. The FGD systems generate a wastewater blowdown, which contains various troublesome contaminants including boron and heavy metals, as well as high levels of TDS and chlorides and other constituents. In most installations today, the FGD purge water streams are chemically treated to remove the metals and other pollutants to a sufficient degree to allow subsequent discharge to the environment, either individually or combined with the plant's overall wastewater effluents, depending on the specific NPDES permit.

As effluent restrictions become more rigorous and renewed NPDES permits reflect stricter regulation of specific pollutants, more power plants will have to consider the option of zero liquid discharge (ZLD) for their FGD wastewaters. Due to the high chloride concentrations in the FGD purge streams, ZLD will typically include "thermal" processes to evaporate the brine stream. (Membrane separation would typically not be considered since the TDS is too high to offer much benefit as a pre-concentration step for the relatively small wastewater streams involved.) Thermal treatment is a costly approach compared to the traditional "chemically treat-and-discharge" option. ZLD may, however, provide opportunities to recycle wastewater, thereby reducing the plant makeup water demand.

The number of operating FGD-ZLD installations worldwide is small. To date, most such installations are located in Europe, at locations where there are environmental restrictions or other considerations that favor the thermal ZLD application.

This study, which focuses on only the thermal treatment options, presents a listing and description of the presently and formerly operating FGD-ZLD plants and experience. Due to the many different influences involved, there are many variations of equipment types and sizes. Process implications as well as cost estimates and cost comparisons of the treatment alternatives are presented in this document.

The thermal treatment processes of the FGD-ZLD systems typically include one or more of the following:

- Chemical pretreatment (Lime, sodium sulfide, ferric chloride, soda ash, other)
- Evaporation using Brine Concentrators

- Evaporation using Crystallization
- Dewatering
- Spray Dryers

The terms “FGD purge water” and “FGD blowdown”, as used in this document, carry different meanings. To minimize confusion the term “purge water” is used to describe the water that is discharged from the FGD and sent to a dewatering system to remove the gypsum. The residual water is then either routed to a treatment system or, more commonly, a portion of it is recycled back to the FGD with only a smaller fraction going to treatment. The FGD water fed to the treatment system is considered the FGD “blowdown”.

Goal

The primary goal of this study is to identify and evaluate thermal ZLD - FGD treatment systems employed at coal fired power stations worldwide. It is intended that the information presented will help station operators understand the state-of-the-art ZLD processes in operation today and give insights into the lessons learned, limitations and potential issues involved in selecting the thermal FGD - ZLD process approach from present and past experience.

Scope

The scope of this study was to gather technical and operating information and experience of thermal treatment processes that have been, are or will be employed worldwide to achieve Zero Liquid Discharge (ZLD) for FGD wastewaters at coal-fired power plants. In the process of conducting site interviews, three municipal solid waste (MSW) ZLD systems, operating on wet FGD wastewaters, were identified, and a limited effort was conducted to summarize these MSW/FGD applications.

Approach and Information

The information for the FGD purge water treatment was obtained through site visits and plant operator interviews as well as vendor contacts, available literature, EPRI records and the author’s personal knowledge and experience with the technologies involved. In addition to the above, power companies, which had conducted their own investigations on this subject, were interviewed.

It should be noted that provision of information for this report by the case study sites was voluntary, and plant personnel were not obligated to provide all lessons learned. Thus some design and/or operational issues experienced at the case study sites may not be included or be comprehensively described.

2

TREATMENT TECHNOLOGY AND CHEMISTRY

Overview

The total sum of experience of presently and formerly operating and "in-work" plants worldwide, as well as pilot and demonstration projects, is very limited. The projects and plants identified and reviewed during the course of this study are presented in Table 3-1, 3-2 and 3-3.

It must be noted that ZLD facilities are often in flux. ZLD processes and technologies may change due to changing regulatory or process requirements, water characteristics, equipment or technology improvements, equipment retirement due to obsolescence, malfunctions or inefficiencies or general plant circumstances. Several of the plants listed have functional FGD-ZLD systems installed, but then, either before or after startup, the stations determined that they could meet their NPDES requirements by chemical treatment alone and chose to treat-and-discharge rather than to operate the ZLD. (These plants are identified later in this document.) These systems are preserved, but may be put back into service if changing circumstances require their use.

Note: The term mothballed is used to describe a procedure where a system is stored in a preserved condition by prior cleaning, sealing and storage as necessary for protection against environmental damage. A mothballed system can be restarted without major overhaul or sold as an essentially operational unit.

Treatment Approach to FGD Purge Waters

All of the power plant FGDs investigated in this study use limestone – forced oxidation (LSFO) FGD systems. Although the majority of the installations investigated employ chemical pretreatment followed by brine concentration, crystallization and solids dewatering, some plants have taken a different approach for their thermal processing to achieve zero liquid discharge.

Technologies Applied

1. Pretreatment

The pretreatment processes used for suspended solids removal, metals precipitation and de-alkalization (alkalinity reduction) consist of chemical addition/reaction and clarification. These basic processes are in common use in the power industry and are summarized in EPRI Technical Report 1014073, "*Flue Gas Desulfurization (FGD) Wastewater Characterization and Management*", 2007 Update, March 2008.

1.1. Dealkalization – Metals Removal – Clarification

The FGD water from the upstream gypsum dewatering operations contains relatively high levels of suspended solids (depending on the dewatering equipment used) and residuals including alkalinity. Lime is added to reduce the alkalinity and to precipitate metals. Sodium sulfide (i.e. sodium sulfide or various organo-sulfides such as TMT-15 or Nalmet) are used to precipitate the metal. Sulfide precipitation, which is a cumbersome process operation, is used as necessary if more substantial metals removal is required to meet a lower metals standard in the effluent. Ferric chloride is added as a flocculant to enhanced settling and precipitation of heavy metals by adsorption if sulfide precipitation is not practiced.

Many of the FGD treatment plants investigated had provisions for sulfide metals precipitation but found that they could meet their metals reduction goals by use of lime and ferric chloride alone without employing sodium sulfide.

The TSS, alkaline and metals treatment is carried out in two or three reaction vessels, with lime typically added in the first vessel for pH control, followed by either ferric chloride or sodium sulfide. The reaction vessels provide the necessary holdup time for the reaction to proceed before moving on to the next step.

Some FGD treatment systems separated the precipitate in dedicated clarifiers while others pass the reaction tank effluents on to the next process step, usually consisting of a softener.

The choice of using clarification before softening is dependent of the feed water composition and whether or not the softener sludge will be recycled back to the FGD to supplement the limestone makeup. If the metals are not removed from the softener feed, then the calcium carbonate sludge can be laden with heavy metals, usually preventing reuse as a supplement to the virgin limestone feed to the FGD.

1.2. Softener

The FGD softening operations are carried out in industry standard reaction clarifiers. The softener serves a dual purpose in the treatment process:

- Hardness removal for downstream treatment
- Transformation of calcium chloride to sodium chloride

Hardness removal from the brine concentrator feed is only beneficial if the evaporator is operated in an “un-seeded” mode. When processing in a “seeded” mode, then at least some calcium hardness is necessary for the calcium sulfate seed slurry operation. In some of the softening operations encountered, a portion of the water by-passes the softener and is routed directly to the brine concentrator feed tank (see brine concentrator discussion) to ensure a minimum level of calcium in the feed to meet the seed slurry process needs.

Changing the calcium to sodium chloride in the softener has a large impact on the downstream operation, most significantly in the crystallizer.

- In comparison to calcium chloride, sodium chloride has a relatively moderate solubility. Furthermore, the solubility vs. temperature curve for sodium chloride is relatively flat. The resultant boiling point rise and corrosiveness in a crystallizer operating on sodium chloride is, therefore, benign.
- Calcium chloride, on the other hand, is very soluble and has a steep solubility vs. temperature curve. With recirculating brine containing significantly more chloride, the boiling point rise in the crystallizer is more than two times that experienced with sodium chloride. The combination of the higher chloride level and the higher operating temperature results in a much greater corrosion potential.

The significance of softening vs. non-softening operations is discussed in detail in Section 7 of this document.

2. Thermal Systems

2.1. Brine Concentrator

Brine concentrators (BCs) are specialized designs of vertical tube, falling film evaporators (VTE) that are typically coupled with a mechanical vapor compression cycle (MVR). The MVR cycle , when evaporating process streams such as cooling tower blowdown, is approximately five times more energy efficient than a single effect steam-driven evaporator.

With more than 50 U.S. power plants using one or more brine concentrators, mainly in cooling tower blowdown and general plant wastewater treatment service, this technology is generally well known to power plants operating in the arid regions of the country [*Summary of Zero Liquid Discharge (ZLD) Water Management Installations at U.S. Power Plants, Technical Update 1015592, December 2008*].

BCs recover 70% to 95% (or higher) of the feed water as very pure distilled water, typically less than 10 ppm TDS. The degree of recovery depends on the chemical composition and concentration in the feed water. The maximum operating level for brine concentrators are typically 140,000 to 180,000 mg/l total dissolved solids (TDS) and 50,000 to 100,000 mg/l total suspended solids (TSS). The actual TDS and TSS concentrations are feed water dependent.

BC feed waters from cooling tower blowdown or FGD chemical treatments are often saturated in calcium sulfate and silica, which poses a scaling concern for the BC heat transfer surfaces. After passing through a front-end heat exchanger (to recover the heat in the outgoing distillate) and a deaerator, the wastewater mixes with the recirculating brine in the evaporator body, called the sump. Scale inhibitors are often added to minimize scaling of the heat exchanger and deaerator (front end) section.

Concentrated brine is circulated from the sump to the top of the vertical tubes where it is evenly distributed and flows down the inside of the tubes as a thin film. Only a small portion of the brine evaporates per pass down the tubes. The evaporate, i.e. newly generated steam, exits the bottom of the heat transfer tubes with the brine and the steam is drawn into the suction of the mechanical vapor compressor after passing through demister pads to remove entrained brine droplets to help purify the distillate and to protect the compressor.

The compressor elevates the steam pressure by 25% to 40% and re-energizes the steam by raising its saturation temperature enough to provide the driving force for evaporation as it enters the condenser section. As the steam condenses, it gives up its heat of condensation to the recirculating brine, causing more brine to evaporate, thus completing energy cycle. The condensate is collected and discharged through the feed heat exchanger, thereby recovering its sensible heat for the incoming feed.

High steam purity is required to prevent salt buildup on the rapidly moving compressor impeller. This translates to a distillate product quality of typically less than 10 ppm TDS, assuming no volatiles in the system. If volatiles are present, the TDS can be 100 mg/l or higher, deepening on the type of volatiles and the processing conditions. While distillates from cooling tower blowdown treatment are typically used for boiler makeup, feeding the water directly to a mixed bed demineralization, the distillates from the FGD treatment systems seem to contain a higher level of impurities and are usually mixed with the general plant service water.

The seeded slurry process minimizes scale formation of calcium sulfate and silica. Calcium sulfate is inversely soluble with respect to temperature and readily scales hot heat transfer surfaces. To prevent or minimize such scaling, BCs are normally operated in a "seed slurry" mode, where seed is available for the saturated calcium sulfate to preferentially precipitate on its "own" crystal surfaces rather than on the hot evaporator tubes. Calcium sulfate is artificially added at startup, after which the seed level is self-sustained by further precipitation from the brine.

Most BCs require only an annual cleaning service to remove the little tube scale that builds up with time. Process upsets like plugging of the brine distributor system by sloughed off wall deposits may necessitate additional cleaning service.

In some applications the hardness and other sparingly soluble components in the feed are present at sufficiently low levels as not to pose a heat transfer scaling problem. In such cases, the evaporator can be run in an "unseeded" mode.

A brine concentrator flow schematic is shown in Figure 2-1.

BC systems were developed in the early 1970s with the first systems installed in the Four Corners area in the Southwest (Arizona, Colorado, Utah and New Mexico). Since that time, many brine concentrators have been added all over the world and have become a mainstay of power plant ZLD operations, with the majority used for cooling tower blowdown treatment. The application to FGD wastewaters is, however, similar. The major difference for FGD applications is the high chloride content, which may require a different material selection for this service.

BCs are capable of greatly reducing wastewater volume, but they still leave a small brine (slurry) concentrate blowdown. In arid areas, where the use of solar evaporation ponds is feasible, ponding is usually the preferred and most economical means of disposal of the concentrate. In areas where solar evaporation is not possible, the concentrate stream is usually subjected to further volume reduction in a crystallizer, sometimes followed by a dryer. A few plants, especially small ones, feed the brine concentrator blowdown directly to a dryer. In one FGD treatment application, brine concentrator blowdown is disposed of by mixing it with fly ash.

At present, there are four main suppliers of brine concentrators world-wide: Veolia-HPD, GE-RCC, Aquatech and IGEA.

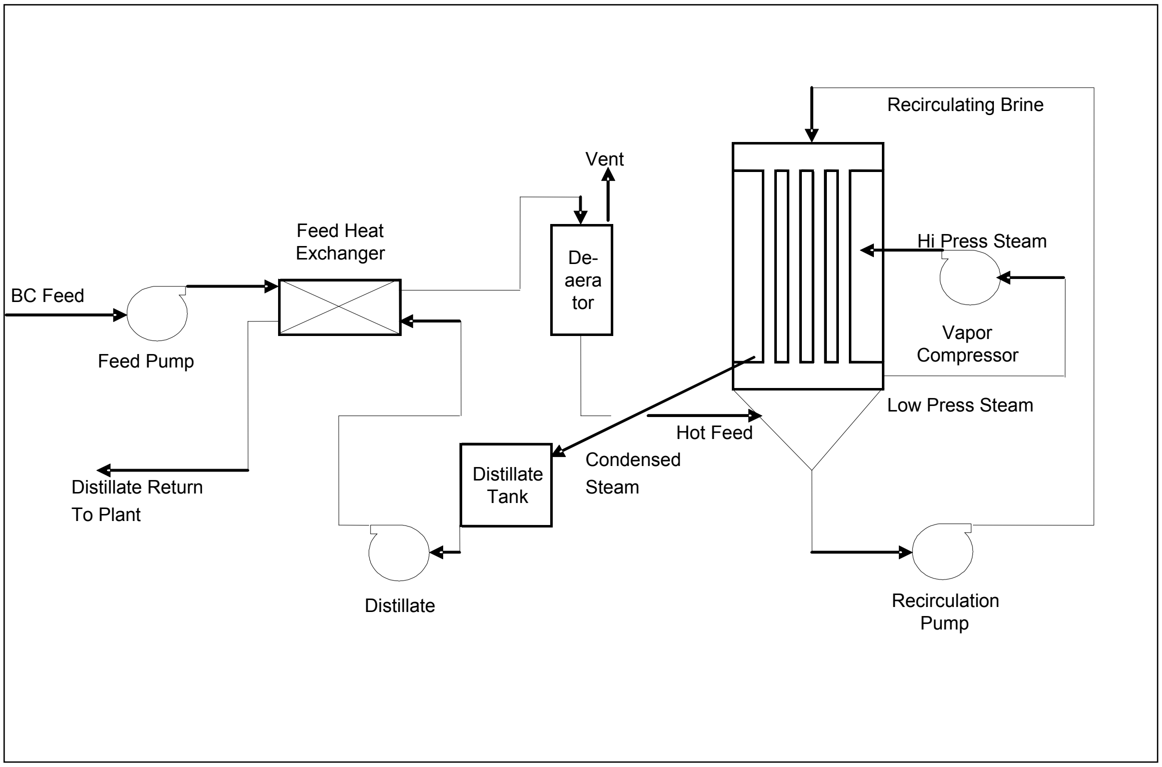


Figure 2-1
Brine Concentrator Flow Schematic

2.2. Crystallizer

Crystallizers are normally employed in regions where solar evaporation ponds are not an option due to a lack of available land, suitable solar evaporation rates or plant specific issues. In normal ZLD operations, crystallizers are the final step in the volume reduction (to dryness) process.

Due to the severe duty of processing hot, concentrated and corrosive salt solutions, the materials of construction are often exotic titanium, high molybdenum or nickel/chrome alloys. Some crystallizers employ rubber lined vessels. Additionally, since the boiling point rise of the concentrated salt solutions is high, the crystallizer requires higher temperature steam (compared to a BC) so that the energy needs are generally greater in comparison to that of brine concentrators. The severe processing environment also translates to frequent cleaning and high maintenance. The need for high corrosion resistance makes the crystallizer costs per gpd much higher compared to a brine concentrator.

Due to the high cost of these systems, the normal treatment sequence consists of a brine concentrator followed by a crystallizer unless the ZLD feed rate is extremely small. The brine concentrator accounts for the bulk of the volume reduction task.

There are several different crystallizer types. Most of the larger designs, and all crystallizers encountered in this FGD study, utilize a forced circulation process. Brine is recirculated through a shell and tube heat exchanger where it is heated under sufficient pressure to suppress boiling in the tubes using either plant steam or steam from a mechanical vapor compressor. Generally, sufficient pressure is achieved by locating the heat exchanger well below the liquid evaporating surface. The hot brine slurry is then discharged into the flash chamber, which is at lower pressure. The steam flashes off until it reaches thermodynamic equilibrium. The newly formed process steam is drawn off and fed to either a vapor compressor (see brine concentrator energy cycle below) or a condenser. The condensate is often used as boiler (when there are no volatiles) or alternately, as cooling tower makeup or to other plant uses. Crystallizer distillate is often of somewhat lower quality than that from a brine concentrator. A flow schematic of a forced circulation crystallizer system is shown in Figure 2-2.

With the filtrate or centrate returned to the crystallizer after dewatering, the concentration of the most soluble components (like nitrates) can become exceedingly high. There is some blowdown as liquid accompanies the residual solids as moisture. Depending on the nature of the crystals, some liquid may also be absorbed as water of hydration when the crystals cool in the dewatering process. If very soluble components are present, a small liquid stream may have to be periodically purged from the crystallizer to prevent excessive TDS buildup in the brine. This small purge stream is sent either to a plant evaporation pond or, more commonly, to off-site waste disposal.

2.3. Mechanical Vapor Compression

In a vapor compression cycle, the process steam generated in the evaporator is compressed to raise its saturation temperature sufficiently to provide the thermal driving force for further evaporation of the brine inside the tubes by giving up its latent heat on the outside of the tubes in the condenser. The temperature increase must be high enough to overcome the brine's boiling point rise (BPR) and to provide the desired heat transfer delta T to drive the process.

Brine concentrators, which operate at a relatively small temperature increase (delta T), typically use single stage, centrifugal compressors or rotary blowers. The latter often requires two rotary blowers arranged in series in order to provide the necessary pressure increase. Crystallizers, which deal with much greater BPRs, usually have positive displacement, mechanical compressors. Most systems are driven by electric motors, although steam turbines can be considered when the economics are favorable for steam over electric drives.

In a single effect evaporator, the energy required to evaporate 1 kg of water is about 2,257 KJ per kg (970 BTU per pound). Mechanical vapor compression is used in brine concentrators and crystallizers, when possible, to reduce this high energy requirement.

2.4. Thermal Vapor Compression

The energy for evaporation in crystallizers, where the process volumes are much smaller compared to brine concentrators, is provided by either mechanical compressors or plant steam, depending on process variables and plant steam availability.

For small crystallizers, when only low pressure plant steam is available, the crystallizers are usually designed as single or double effect units. If plant steam is available at 150 to 200 psig, however, then a 25% percent energy reduction can be realized by use of a thermo-compressor (TVC) or steam jet. A portion of the process steam from the vapor body is drawn into compressor's venturi before being fed to the crystallizer heater along with the motive steam.

Thermal compression systems usually have two or more such compressor units to allow for operation at variable processing rates.

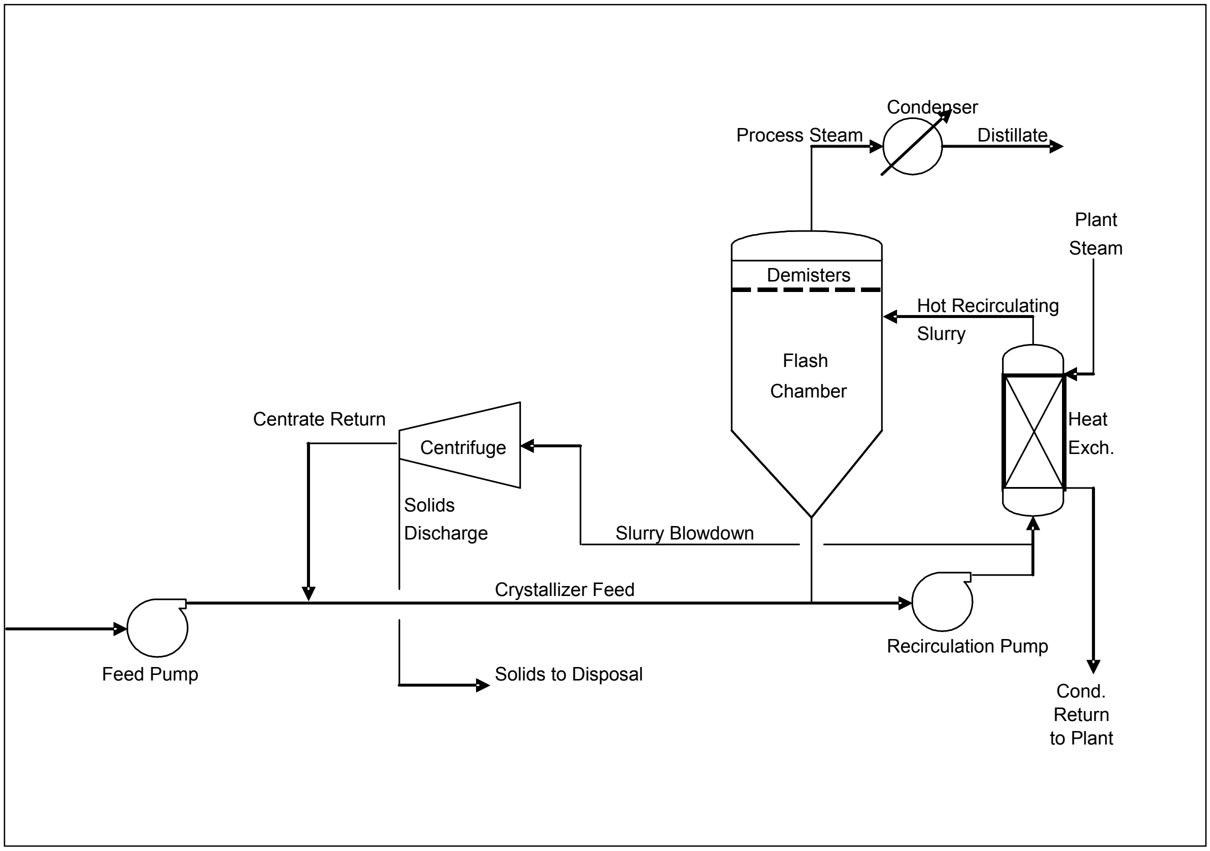


Figure 2-2
Forced Circulation Crystallizer

3. Dewatering

Aside from the scrubber purge water dewatering for the removal of gypsum, the thermal ZLD has two other streams calling for dewatering:

- The pretreatment clarifier underflow (dealkalization and/or softeners), which is usually done by use of a filter press.
- The crystallizer solids, which are typically accomplished using a belt pressure filter or a centrifuge.

3.1. Clarifier Sludge Dewatering

Of the FGD systems investigated in this study, sludge dewatering was done by use of a filter presses, although centrifugation would be an alternative. Since these are standard technologies in the power industry, they are not further discussed in this document.

3.2. Crystallizer Solids Dewatering

While the harvesting of crystallizer solids can be done using standard dewatering processes, it is usually conducted using either a belt pressure filter or centrifuge.

Centrifuges are usually found in use with larger crystallizer systems. A common dewatering system for many of the current coal FGD ZLD applications is a Flat Bed Belt Pressure Filter, which is also common in non-FGD crystallizer applications in the power industry. Depending on the nature of the salts, both types of dewatering systems result in a product containing about 10% to 25% moisture.

Figure 2-3 displays a flow schematic of the belt pressure filter operation. The belt pressure filter consists of a feed pressure chamber, a pneumatic pressure bladder and a moving belt arrangement to transport and discard the dried cake. The feed slurry is pumped into the pressure chamber, where it is trapped and squeezed by the inflating bladder against the belt filter cloth at the bottom of the pressure chamber. The liquid escapes through the filter media. After an adjustable dewatering interval, the pressure chamber releases the residual cake brick, which is then transported by the moving belt to a solids hopper. In order to minimize filter media plugging, the belt is periodically washed in-situ using hot water (crystallizer distillate).

The degree of dryness achieved depends on the dominant salt specie involved, i.e. its hygroscopic nature as it cools. For example, sodium chloride has no waters of hydration and relies on the filter’s physical action to achieve dryness. Sodium sulfate, on the other hand, changes to its $Na_2SO_4.7H_2O$ and $Na_2SO_4.10H_2O$ (hepta and deca forms) as it cools so that residual moisture is absorbed and chemically bound upon cooling. Aside from the moisture, the handling properties are also affected. Sodium chloride is easy to handle in the belt pressure filter, while sodium sulfate becomes sticky and troublesome.

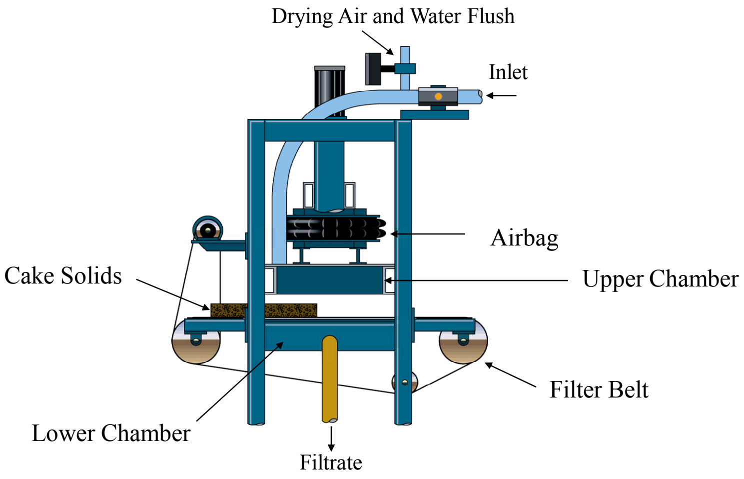


Figure 2-3
Schematic of Flat Bed Belt Pressure Filter *
*Sketch courtesy of the Oberlin Filter Corporation

4. Spray Dryer

Spray dryers, commonly used to dry liquids, slurries and sludges, use thermal energy in the form of hot air or combustion gases to evaporate the wastewater stream to complete dryness in a single process step. Feed capacities typically range up to 11 m^3/h (50 gpm).

A flow schematic of a spray dryer system is presented in Figure 2-4. Spray dryers consist of large, conical vessels. The drying gases are introduced con-currently with the feed at the volume and temperature necessary to fluidize and evaporate the droplet moisture. The feed is introduced at the vessel top via a spray nozzle or a rotary atomizer wheel to produce a fine mist, which is injected into the chamber. The droplets enter the vessel with sufficient velocity to disburse them evenly over the vessel cross section without reaching the vertical wall perimeter. If the feed were to impact on the walls, it would potentially cause some of the liquid to by-pass the drying process by collecting and draining to the bottom of the vessel. Further, as brine would evaporate on the vessel walls it would lead to corrosion of the metal surfaces and in an unwanted solids build-up on the walls.

The droplets evaporate almost instantaneously once in contact with the hot gases. Due to evaporative cooling and the brief hold-up time in the chamber, the maximum solids temperature is typically well below the gas exit temperature, which is usually 100 to 140°C (212 to 284°F).

Upon drying, the gases, process vapors and solids are blown through the conical bottom into a cyclone or bag filter for particle separation. The dried solids are collected in a hopper. The gases are discharged to atmosphere or the stack.

The gas inlet temperatures for wastewater applications depend on several factors, but can range from 140°C (285°F) to more than 550°C (1,000°F). The ultimate product density is a function of the atomized inlet droplet size and the general solids characteristics. Droplet size and feed dispersion can be varied by choosing different spray nozzles or atomizing wheel designs.

Since none of the corrosive brine reaches the vessel walls, spray dryers can be made of low-alloy steel. Compared to other evaporative processes, sprayer dryers are, however, very energy intensive – typically requiring 1.5 MJ of energy to deliver 1 MJ for evaporation.

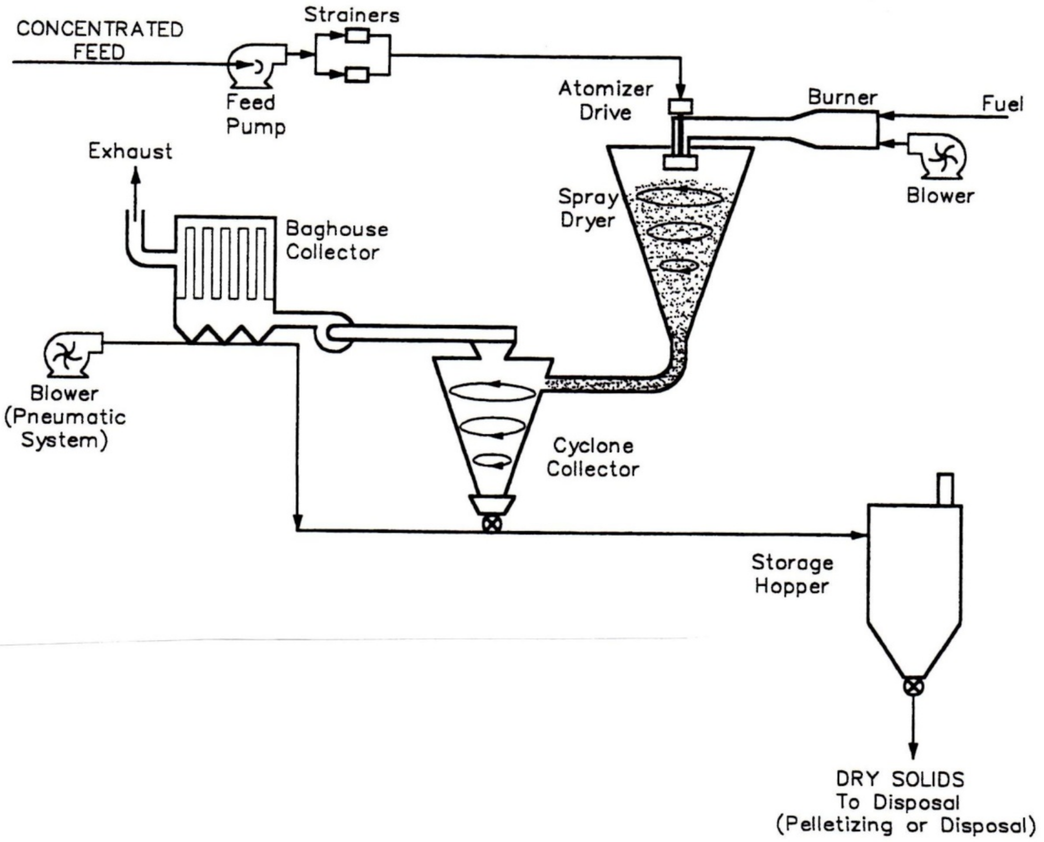


Figure 2-4
Spray Dryer Flow Schematic

Energy Consumption for Thermal Processes

Based on operational experience, energy consumptions of the above described treatment processes are summarized in Table 2-1. While expressing steam consumption in kWh is not common, it is presented as such to provide a basis for comparison of the various treatment processes.

Table 2-1
Energy Consumption of Various Processes

TECHNOLOGY		**kWh /m^3 (mmBTU/m^3)**	**kWh / 1,000 gal (mmBTU/m^3)**
Chemical Treatment / Clarifiers	Negligible *)		
Brine Concentrator – MVR		21 – 24	80 - 90
Crystallizer – MVR		53 – 66	200 – 250
Crystallizer – Plant Steam	1 kg steam/ 1 kg evaporated	635 (2.2 mmBTU/m^3)	2,400 (8.2 mm BTU/m^3)
Crystallizer – Plant Steam & thermal compression (Plant steam at •1050 kPa 150 psi)	~0.7 kg steam/ 1 kg evaporated	445 (1.5 mm BTU/m^3)	1,680 (5.7 mm BTU/ m^3)
Spray Dryer	~ 1.5 MJ / MJ for evaporation	950 (3.2 mm BTU/m^3)	3,600 (12.3 mm BTU/m^3)
Dewatering – Belt Filter	Negligible *		
Dewatering - Centrifuge	Negligible *		

* *Negligible in comparison to the other ZLD treatment processes*

FGD Blowdown Characteristics

The chemical characteristics of FGD blowdown is a function of many parameters including coal composition, FGD type, makeup water, limitations due to FGD metallurgy or salt solubilities, lime stone quality, recycle rates and operating philosophy. Of the above influencing factors, the coal composition has the biggest influence on gypsum production as well as chloride, trace metal and boron concentrations. Since FGD blowdown is typically used to control the chloride level in the FGD water loop, this component is typically the driving parameter, which dictates the blowdown volume. The wastewater rates are, therefore, in great part a function of plant size (MW) and the coal type (including chloride level) burned.

In general, the FGD blowdown waters are either acidic or near neutral pH, contain high levels of chlorides and have relatively high concentrations of metals and boron.

The main troublesome components and their typical concentration ranges are:

- High TDS (15,000 – 60,000 mg/l)
- High Chlorides (5,000 – 30,000 mg/l)
- Boron (up to 800 mg/l)
- Heavy metals
- Mercury
- Ammonia

A detailed description of FGD purge waters can be found in Section 2 of the "*EPRI Technical Manual: Guidance for Assessing Wastewater Impacts on FGD Scrubbers*", Technical Report 1013313, published in 2006; and Technical Report 1014073, "*Flue Gas Desulfurization (FGD) Wastewater Characterization and Management",* 2007 Update, March 2008. The characterization in these documents is based on the evaluations of eight power stations. An abbreviated version of the FGD purge water compositions, identified in this referenced EPRI reports, is presented here in Table 2-2.

Table 2-2
FGD Wastewater Characteristics from EPRI Study of Eight Stations [1]

	Median	Range	
		Low	**High**
	(mg/l)	***(mg/l)***	***(mg/l)***
pH	7.3	6.2	7.3
TDS	14,000	6,000	50,000
TSS	13,000	33	140,000
Calcium	750	670	4,000
Magnesium	1,100	390	4,400
Sodium	670	72	4,800
Chloride	2,400	690	23,000
Fluoride	15	6.5	51
Alkalinity (as CaCO3)	4,100	3,000	5,300
Sulfate	3,200	1,700	6,700
Nitrogen (TNK)	24	2.4	58
Boron	260	15	480
Arsenic	.02	0.04	0.1
Mercury	0.006	0.0001	0.0085
Selenium	1.1	.07	1.8

[1] *Excerpt from: "EPRI Technical Manual: Guidance for Assessing Wastewater Impacts on FGD Scrubbers", Technical Report 1013313*

Based on the experience of this work, the chemical composition of FGD wastewaters encountered in this study are shown in Table 2-3.

Table 2-3
"Example" Chemical FGD Blowdown Composition of Operating Plants

COMPONENTS	Power Magazine EPRI *)	Springfield	Torrevaldaliga	Sulcis	La Spezia	Fusina	Brindisi
	(7 Plants)						
pH	4.5 – 9	7.3	3 - 6	9	5.5	9.5 - 10	9.5 - 10
TS	14,000 – 170,000						
TSS		200	80	80	15,000	80	80
TDS		30,600					
Sodium	670 – 4,800	160					1,800
Calcium	750 – 4,000	8,700	12,000	1,200	8,400	8,400	4,200
Magnesium	1,100 – 4,800	1,760	2,350	1,200	1,700	1,700	250
Bicarbonate		300	600	80	600		80
Chloride	1,000 – 28,000	15,000	30,000	23,000	25,000	25,000	22,800
Fluoride		35					
Nitrate (as N)		98		300	300	300	
Sulfate	1,500 – 8,000	3,500	17,700	1,700	1,200	1,200	1,700
Silica			20	10	20		10
Boron		880	500		500		
Arsenic			10				

Although the FGD supplier and type are often different for each power block within a generating station, the wastewaters from all the FGD operations, found in this study, are typically blended and treated as one stream. Much of the FGD purge water is returned to the FGD after the saleable gypsum is removed. Enough of the purge water is, however, blown down to the treatment system to control the buildup of chlorides and other troublesome components.

FGD Blowdown Treatment Options

The FGD wastewater treatment operations identified in this study use the following processes to achieve ZLD water management for the scrubbers:

- Solids removal - clarification
- Metals precipitation
- Chemical (soda ash) softening
- Brine Concentrator
- Crystallizer
- Dewatering using pressure filter
- Spray Dryer
- Fly ash wetting / stabilization

- Recycling / evaporation ponds (this approach is utilized at some southwestern US power plants, but is not considered to be a thermal treatment process and, therefore, not further discussed)

Figure 2-5 depicts the five options of how the above technologies are employed at the various power plants identified. All six of the Italy FGD applications employ Option 1. These installations are relatively recent, with commissioning dates ranging from 2008 to 2009.

Some of the Option 4 FGD blowdown treatments via crystallizers (only) have been employed since the middle 1990's.

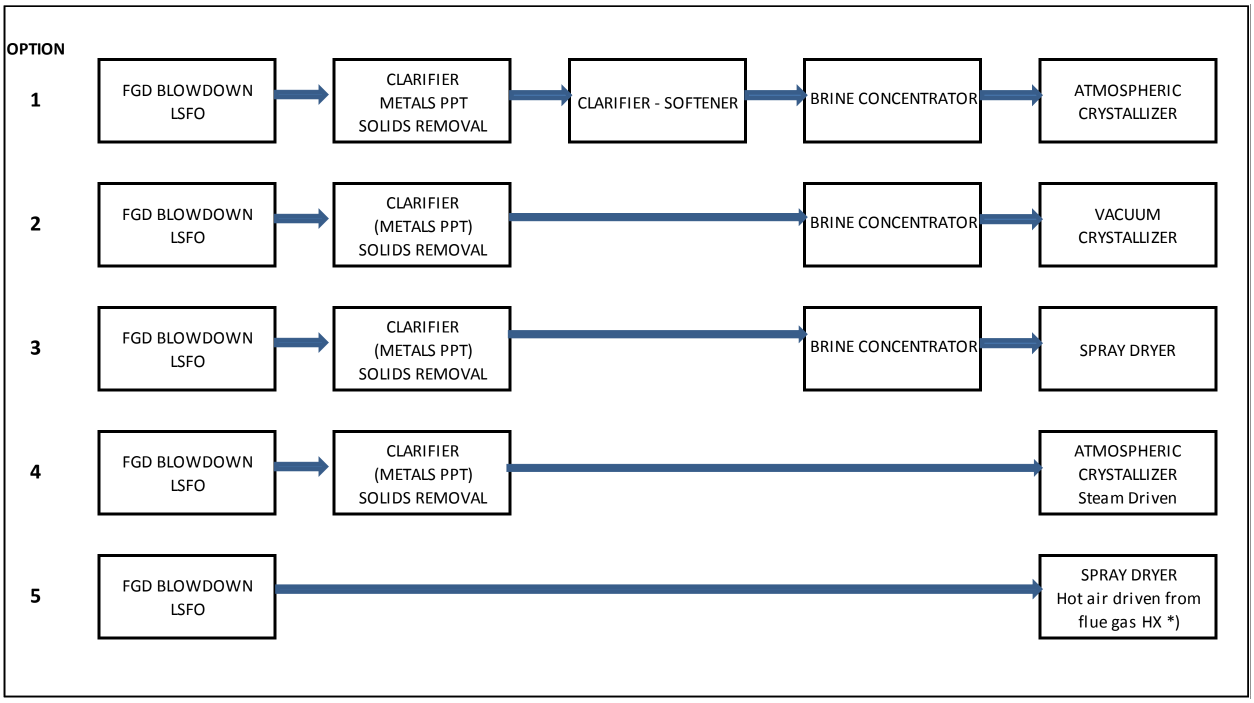


Figure 2-5
Thermal FGD Wastewater Treatment Options

3

OPERATING EXPERIENCES

As previously stated, there are very few thermal ZLD applications on wet coal power plant FGD treatment installations presently in operation. Some of the thermal FGD – ZLD systems have been mothballed, either before or after startup. As of this writing, one plant is presently in its design stage.

A listing of the thermal coal FGD – ZLD plants that were identified in this study is presented in Tables 3-1 and 3-2. A general description and present status of the same are found in Sections 4 and 5 of this document.

Table 3-1
Thermal FGD ZLD Installations - Recent Coal Power Plant Applications

Plant	**Owner/ Operator**	**ZLD Supplier**	**Process Train** ***(See Legend)***	**Com-Missioned** ***Year***	**Operational Status**
La Spezia	ENEL	Aquatech	ChPT + BC + CRX+BPF	2008	Operational
Fusina	ENEL	Aquatech	ChPT + BC + CRX+BPF	2009	Preserved for later use
Sulcis	ENEL	Aquatech	ChPT + BC + CRX+BPF	2009	Operated Intermittently
Brindisi	ENEL	Aquatech	ChPT + BC + CRX+BPF	2009	Operational
Torrevaldaliga	ENEL	Aquatech	ChPT + BC + CRX+BPF	2009	Operational
Monfalcone	a2a SpA	Veolia – HPD	ChPT + BC + CRX+BPF	2008	Operational
Iatan Generating Station	Kansas City P&L	Aquatech	BC + Fly ash Stabiliz.	2008	Operational 1)
Kusile Power Plant		GE – RCC	CLF + BC	2011	In Design Phase
Nordjyllands-værket	Elsam Vattenfall A/S	Anhydro A/S	SPD	2005	Operational

Legend to Tables 3-1, 3-2 and 3-3
BC – Brine Concentrator
BPF – Belt pressure filter
ChPT – Chemical pretreatment
CLF – Clarifier
CRX – Crystallizer
SPD – Spray Dryer

Table 3-2
Thermal FGD ZLD Installations – Other Coal "Non-Operating" Systems

Plant	Owner/ Operator	ZLD Supplier	Process Train *(See Legend)*	Com-Missioned *Year*	Operational Status
Milliken Generating St.	Department of Energy Project	GE – RCC	BC	1995	Mothballed/ Abandoned
Matsushima Electric Generating Station	Matsushima	GE – RCC	BC (long term pilot)	1996	Discontinued
Dallman Generating Station	City of Springfield	Aquatech	BC + SPD	2007	Never Installed
Centralia Generating Station	Transalta	Swenson	ChPT + CRX	2002	Mothballed

While the primary focus of this study was coal FGD applications, three municipal solid waste (MSW) ZLD systems operating on wet FGD wastewaters were identified during this project. A limited effort was conducted to summarize these MSW/FGD applications, and these facilities are listed in Table 3-3.

Table 3-3
Thermal FGD ZLD Installations – Non-Coal, Non-Power Plant Installations Waste Incinerators

Plant	**Owner/ Operator**	**ZLD Supplier**	**Process Train** ***(See Legend)***	**Com-Missioned** ***Year***	**Operational Status**
Oberhausen-Buschhausen [2)], Duisburg Germany	GMVA, Oberhausen/ Duisburg, Germany	IGEA	ChPT + CRX	1998	Operational
Herten Waste Incineration Plant 2)	Herten, Germany	IGEA	ChPT + CRX	2005	Operational
SNB NV Power Plant [2)]	SNB NV Moerdijk, Netherlands	IGEA	ChPT + CRX	1995	Operational

4

RECENT OPERATIONAL FGD WASTEWATER TREATMENT PLANTS – ITALIAN COAL POWER PLANT INSTALLATIONS

ENEL SpA

1. ENEL Overview

ENEL SpA, one of Europe's largest power companies, with generating stations located all over the world, installed thermal FGD – ZLD treatment systems at five of its power stations in Italy: Brindisi, Fusina, La Spezia, Sulcis and Torrevaldaliga. These systems, which in part represent upgrades to existing treat-and-discharge installations, were purchased under a single contract from a single U.S. vendor. At the time of this writing Fusina (located near Venice) is in a preserved, non-operating status and Sulcis (located in the island of Sardinia) is operated intermittently, on an "as needed" basis. Fusina is now treating and discharging the FGD purge water to the sea full-time.

All five of the ENEL plants burn low-sulfur, imported coals (<1%S) purchased from world-wide market. Sulcis is the only of the plants designed to burn national high-sulfur coal (6%S). All of the plants are seawater cooled. Plant makeup water is either purchased from water facilities or is sourced from on-site wells. The plant wastewaters, other than FGD blowdown, are treated and reused as part of the integrated plant water supply.

With all five treatment installations supplied by the same vendor and within the same time frame, the systems' basic designs are similar, varying mainly in size of equipment and adaption to the existing plant circumstances.

Following the gypsum separation from the FGD purge water, the treatment scenarios of the five ENEL plants consist, in sequential order, of the following processes:

- Dealkalization / Metals Removal (some with sulfide precipitation/ Clarification using lime and ferric chloride
- Soda Ash Softening
- Brine Concentrator
- Crystallizer
- Salt dewatering using a pressure belt filter.

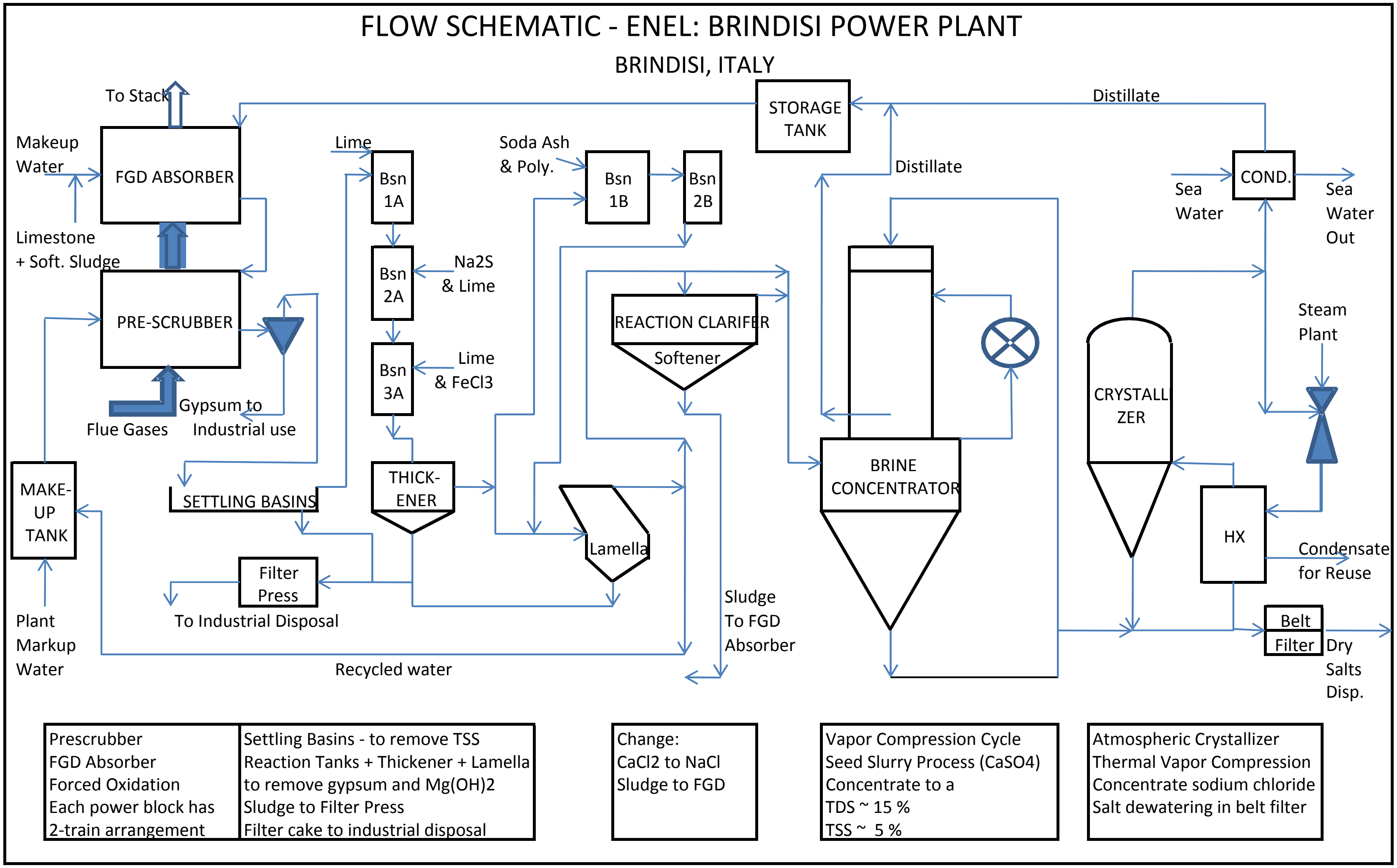
2. ENEL Plant FGD – ZLD Systems

A synopsis of the five ENEL FGD treatment system capacities is presented in Table 4-1. Block flow diagrams for the different sites are presented in Figures 4-1, 4-2 and 4-3.

Table 4-1
ENEL FGD Wastewater Treatment Plants

Power Station	**Plant MW**	**Wastewater Treatment Process Design Capacities**				**Start-up**	**Retrofit/New WW Plant**
		De-Alkalization	**Softening**	**Evaporator(BC)**	**Crystallization**		
La Spezia	1 x 600	30 t/h *132 gpm* (1 x 100%)	15 t/h *66 gpm* (1 x 100%)	15 t/h *66 gpm* (1 x 100%)	4.3 t/h *16 gpm* (1 x 100%)	2008	New thermal ZLD: chemical pretreatment system is retrofit from previous.
Brindisi	4 x 660	500 t/h *2,202 gpm* (1 x 100%)	140 t/h *616 gpm* (2 x 50%)	70 t/h *308 gpm* (2 x 50%)	10.5 t/h *40 gpm* (1 x 100%)	2009	New thermal ZLD: chemical pretreatment system is retrofit from previous.
Torrevadaliga	3 x 660	35 t/h *154 gpm* (1 x 100%)	35 t/h *154 gpm* (1 x 100%)	35 t/h *154gpm* (1 x 100%)	10 t/h *38 gpm* (1 x 100%)	2009	New System
Fusina *)	2 x 320 2 x 165	150 t/h *661 gpm* (1 x 100%)	70 t/h *308 gpm* (1 x 100%)	35 t/h *154 gpm* (2 x 50%)	8.8 t/h *34 gpm* (1 x 100%)	2009	New thermal ZLD: chemical pretreatment system is retrofit from previous.
Sulcis **)	1 x 240	130 t/h *572 gpm* (1 x 100%)	45 t/h *198 gpm* (1 x 100%)	12 t/h 53 gpm (1 x 100%)	2.6 t/h 10 gpm (1 x 100%)	2009	New thermal ZLD: chemical pretreatment system is retrofit from previous.

*) *Shutdown and preserved for future use*
**) *Intermittently operated as needed*



Prescrubber
FGD Absorber
Forced Oxidation
Each power block has
2-train arrangement

Settling Basins - to remove TSS
Reaction Tanks + Thickener + Lamella
to remove gypsum and $Mg(OH)_2$
Sludge to Filter Press
Filter cake to industrial disposal

Change:
$CaCl_2$ to NaCl
Sludge to FGD

Vapor Compression Cycle
Seed Slurry Process ($CaSO_4$)
Concentrate to a
TDS ~ 15 %
TSS ~ 5 %

Atmospheric Crystallizer
Thermal Vapor Compression
Concentrate sodium chloride
Salt dewatering in belt filter

Figure 4-1
Brindisi Power Station - FGD Treatment System Flow Schematic

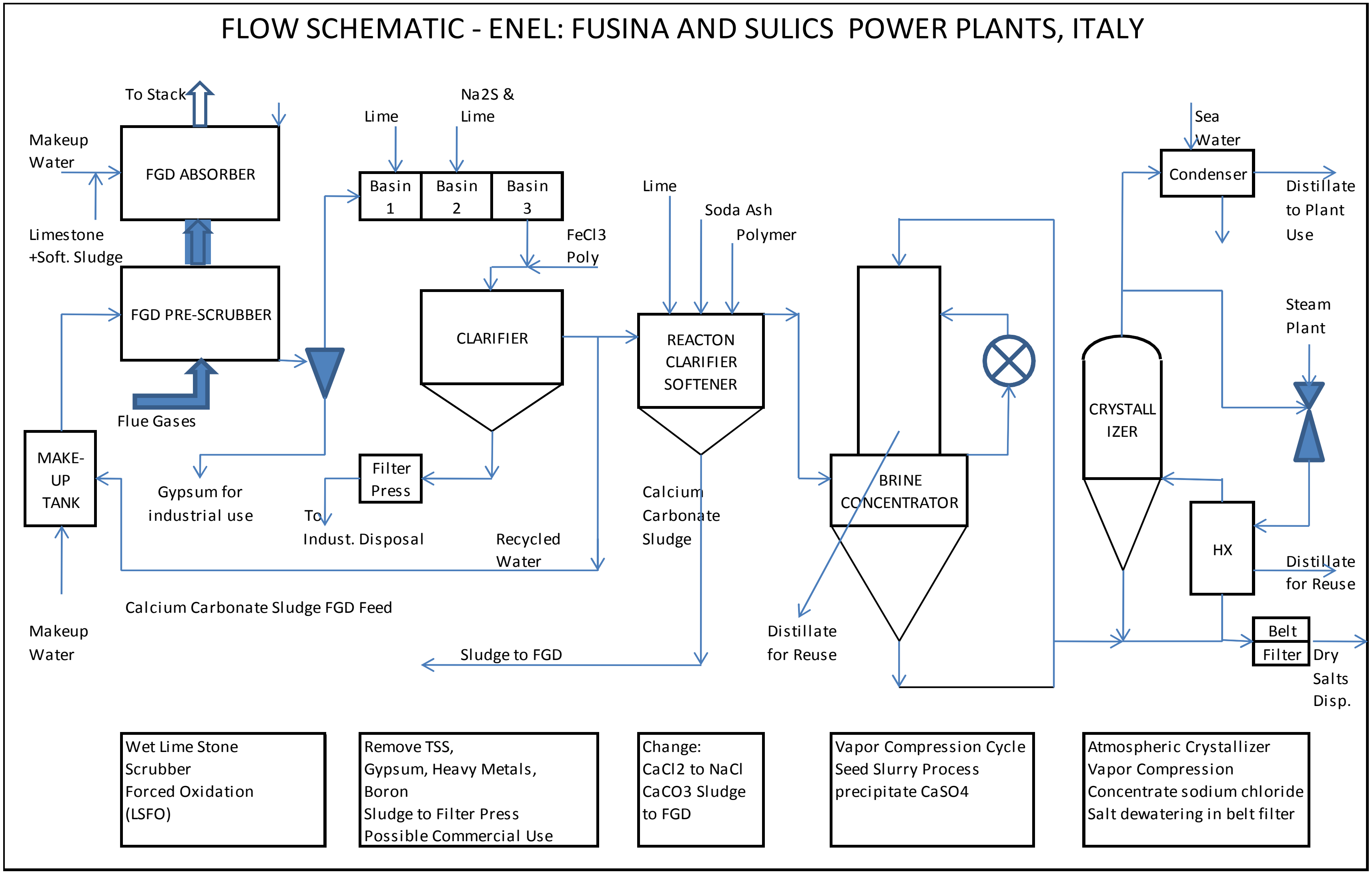


Figure 4-2
Fusina and Sulcis FGD Treatment System Flow Schematic

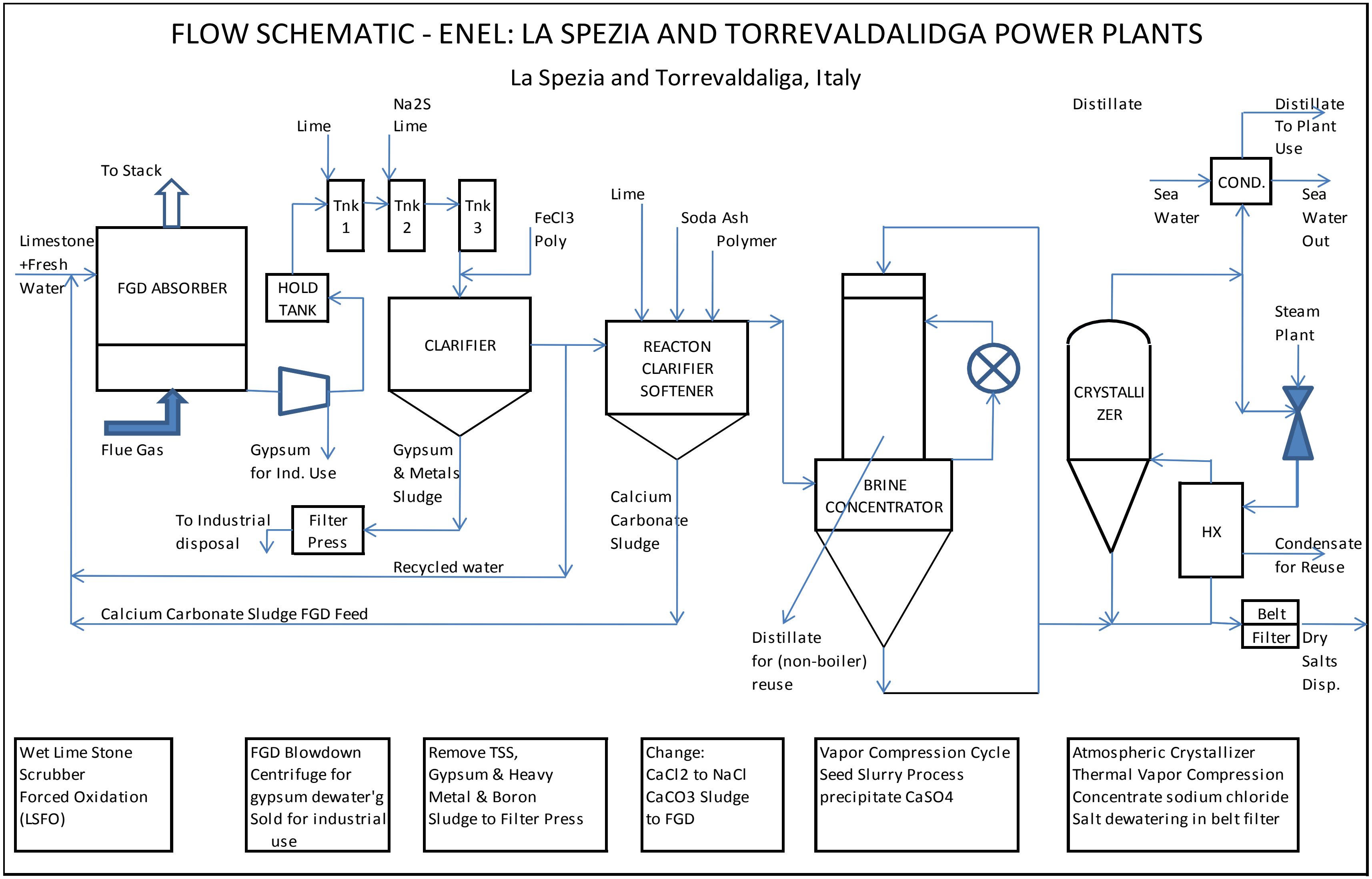


Figure 4-3
La Spezia and Torrevaldaliga - FGD Treatment System Flow Schematic

Below is an outline of the process operation found at all ENEL plants. The La Spezia and Brindisi facilities were visited as part of this study. A more detailed description of these plants is found in the Appendix B - Site Visits.

2.1 ZLD – Pretreatment

The process designs and conditions of the five ENEL plants in Italy can be divided into two groups, each with their own design characteristics:

Group A - Brindisi, (Fusina and Sulcis) Power Plants

- The FGD systems consist of a prescrubber plus an absorber
- Saleable gypsum is extracted from the absorber
- The FGD blowdown is chemically pre-treated in two stages
    - Stage 1: Reaction basins are designed to use lime, sodium sulfide, ferric chloride and polymer additions (the sodium sulfide usage is based on the water chemistry)
    - Stage 2: Reaction clarifier for soda ash softening
- A portion of the pretreated and the softened water is returned to the prescrubber feed tank where they are blended with plant makeup water.

Note: The Fusina and Sulcis ZLD plants are listed in parenthesis as the former is in a preserved /idle state and the latter is only used intermittently.

A block flow schematic of the Brindisi Plant is presented in Figure 4-1. The Fusina and Sulcis operations, as designed, are shown in Figure 4-2.

Group B - La Spezia and Torrevaldaliga Power Plants

- The FGD systems consist of absorbers but there are no prescrubbers
- Saleable gypsum is extracted from the absorber
- The FGD blowdown is chemically pre-treated (for thermal processing) in two stages using three treatment tanks
- Stage 1: Reaction tanks with lime into the first and ferric chloride addition into the second or third tank.
- The design calls for sodium sulfide and polymer to be added respectively into second reactor tank and clarifier. Due to the low metals in the relatively high pH FGD blowdown, the metal concentrations are very low so that sodium sulfide addition has been based on the "as needed" water chemistry requirements.
- The reaction tank effluent goes to a clarifier

- In La Spezia (only), some of the clarifier effluent is blended with FGD makeup water and returned to the FGD
- Stage 2: Reaction clarifier for soda ash softening
- None of the softened water is returned to the FGD system

A block flow schematic describing both the La Spezia and the Torrevaldaliga facilities is presented in Figure 4-3.

2.2 ZLD – Thermal Treatment – Brine Concentrator

Aside from the typical parameters and conditions previously described in the brine concentration technology Section 2, common to all ENEL brine concentrator installations is the following:

- The brine concentrators serve to reduce the wastewater volumes by 70% to 90% or more through evaporating and concentrating the softened FGD water.
- Brine concentrators are operated in a “seeded” mode.
- The systems are operated at slight above atmospheric pressure.
- The energy source is from either a single stage compressor or two blowers in a series arrangement.
- The distillate is used to supplement plant service water.

2.3 ZLD – Thermal Treatment – Crystallizer

Aside from the typical parameters and conditions previously described in the crystallizer technology Section 2, common to all ENEL crystallizers is the following:

- The systems are operated at slightly above atmospheric pressure.
- The feed to the crystallizers is mainly sodium chloride with some sodium and calcium sulfate present.
- The crystallizers are steam driven.
- Some of the crystallizers use thermal vapor compression (TVC) – i.e. thermo-compressors
- The condensers are seawater cooled.
- The distillate is used to supplement plant service water.

2.4 ZLD – Thermal Treatment – Solids Dewatering

The technical highlights of the ENEL crystallizer dewater operations are:

- Oberlin belt pressure filters are used in all facilities
- The salt is collected in 1 m3 (35 ft3) bags, sealed and disposed of at authorized landfill sites.
- The amount of salt collected varies from plant to plant.

2.5 GENERAL NOTES FOR LA SPEZIA AND OTHER ENEL PLANTS

- In both La Spezia and Brindisi the chemical injection systems, including totes and pumps, are located in an area that is protected by clear plastic, perimeter walls.
- The gypsum from the FGD operations is sold for general commercial use.
- La Spezia makeup water for FGD feed storage tank consist of:
    - Industrial water (low level plant wastewater)
    - Pretreated water from the ZLD system, i.e. primary clarifier clarate
    - Fresh plant makeup water as needed to make up the difference
- Torrevaldaliga FGD:
    - Uses the double contact Mitsubishi technology
    - It is a low blow-down flow (6 m3/hr for each of the 3 x 660 MW units), high efficiency system
- The Fusina FGD:
    - The FGD is a Bischoff technology system
    - The ZLD is presently in a preserved /idle state since treat and discharge to an off-site industrial treatment consortium has turned to be a more cost-effective choice. The Fusina plant is permitted to choose this option.
    - FGD wastewater treatment now consist of chemical pretreatment with subsequent discharge to an industrial treatment system that ultimately discharges to the sea
- Sulcis FGD:
    - Unit #2 is a fluidized circulation bed boiler with an internal desulfurization system
    - Unit #3 uses Mitsubishi technology
    - FGD wastewater treatment now consists of chemical treatment and the ZLD is only operated intermittently on an “as needed” basis.

a2a Produzione

1. Overview

a2a Produzione, is an Italian power and utility company with 3,300 MW generating capacity of which 2400 MW are thermal plants. a2a owns and operates the coal fired generating station *Termoelectrico Centrale di Monfalcone*, located in the city of Monfalcone on the coast of north eastern Italy, close to the city of Trieste.

2. Monfalcone FGD

Monfalcone consist of 2 x 160 MW coal fired units, built in 1965, and 2 x 320 MW oil fired units built in 1982 for a total output of 1,000 MW. Located on the Adriatic Coast, the plant uses once-through seawater cooling to minimize its fresh water consumption.

Low sulfur coal is purchased via a long term contract from Russia. The coal has a sulfur content of about 0.3% with a chloride level of about 300 – 400 ppm. The fuel is supplemented with about 6 – 7% biomass, which is added to the boiler as a separate stream. The biomass, sourced from animal farms and petroleum refinery residuals, has a heating value ranging from 3,000 to 4,000 kcal/kg (5,400 to 7,200 BTU/lb). The biomass results in “Green Credits” for the plant.

The FGD system serving both coal units is Mitsubishi technology and consists of a single absorber. The FGD operates at SO2 removal efficiencies of about 95 to 96%. FGD makeup is “industrial water” consisting of mainly city water mixed with some low TDS plant water. Gypsum is dewatered via a belt filter, yielding a product of relatively high quality (the gypsum is almost white), which is sold for construction material use. Most of the filtrate goes to a storage tank before being returned to the absorber. A portion of the waters is blown down for treatment in the ZLD system.

The pertinent FGD blowdown (i.e. ZLD feed water) characteristics are shown in Table 4-2.

Table 4-2
FGD Blowdown Characteristics
Monfalcone Power Station

PARAMETER	*CONCENTRATION* *)
Chloride	20,000 mg/l
TDS	33,000 mg/l
TSS	20,000 mg/l
Boron	150 mg/l
Selenium	4 mg/l
Mercury	1 mg/l
pH	4.5 – 7.5

) Design Data

3. Monfalcone FGD – ZLD System

The ZLD pretreatment is similar to that used for the ENEL plants:

  - Dealkalization - Metals Removal using lime and ferric chloride
  - Soda Ash Softening – clarification

- Brine Concentrator
- Crystallizer

- Crystallizer salt dewatering using a belt pressure filter.

A block flow diagram of the Monfalcone FGD wastewater management program is shown in Figure 4-4. The major pieces of the treatment system are discussed in the following sections.

3.1 ZLD – Thermal Treatment – Pretreatment

- The FGD blowdown from the gypsum dewatering filtrate tank is routed to the pretreatment system consisting of two reaction tanks followed by one reaction clarifier
- Lime is added to the first reaction tank for pH control and metals precipitation. The tank is operated at a high pH.
- The process design called for the second reaction tank to receive soda ash. At this time, no chemicals are added to this tank, however, so that it only serves for additional retention time.
- Soda ash, ferric chloride and polymer are added directly into the reaction clarifier.
- The clarifier sludge goes to a sludge tank and then a filter press.
- The clarate enters a holding tank, which serves as a feed tank for the brine concentrator.
- The target calcium hardness in the clarifier is relatively low, which will be important in the brine concentrator operation.
- Clarifier effluents, exceeding the required calcium hardness level goal, are returned to the front end and the softening loop recycled until the necessary hardness reduction is achieved.
- The softener system produces about 700 t/yr of $CaCO_3$.
- Due to the high metals concentration in the calcium carbonate sludge, it is disposed of at an industrial land fill. (Note that unlike the ENEL systems, the Monfalcone operation has only a single reaction clarifier so that all precipitates, including heavy metals, are contained in the softener sludge.)

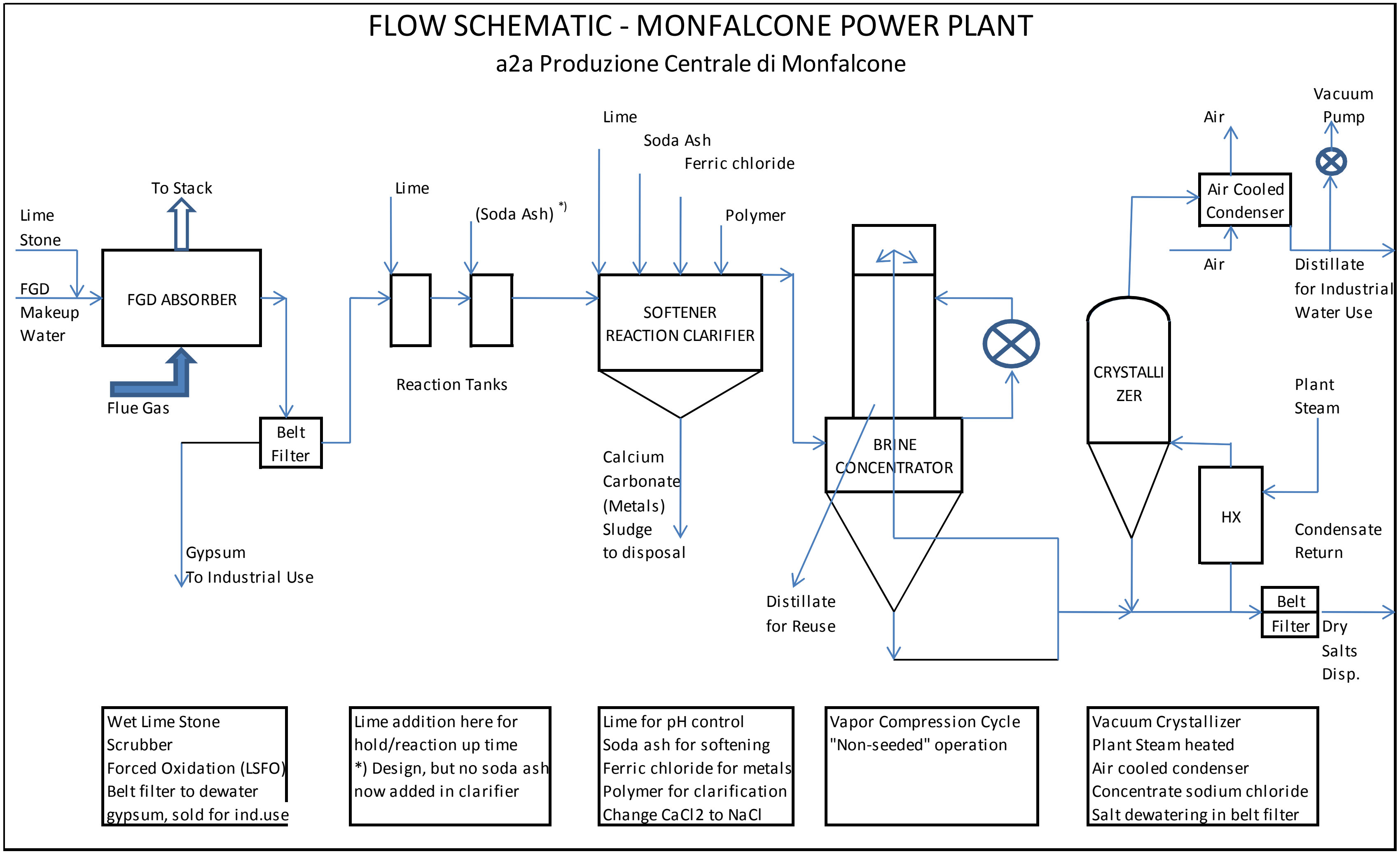


Figure 4-4
Monfalcone Power Station - FGD Treatment System Flow Schemati

3.2 ZLD – Thermal Treatment – Brine Concentrator

The brine concentrator serves to achieve a wastewater volume reduction of about 85% by evaporating the softened FGD water.

- The major processing steps and parameters for the brine concentrator system and operation are:
    - At a design flow of about 10 m^3/h (44 gpm), the brine concentrator feed rate is relatively small.
    - Due to the high quality coal burned at the plant, the FGD blowdown is less than design so that the brine concentrator feed typically amounts to only 75% of design.
    - The brine concentrator is operated at slightly above atmospheric pressure.
    - Evaporation is conducted in an “unseeded” mode and at a concentration factor of less than 8, i.e. about 85% recovery. (Note that the ENEL plants are all operated in a “seeded” mode.)
    - The “unseeded” process is possible due to the efficient calcium hardness removal achieved in the softener.
- Although more frequent evaporator cleaning in the form of scale removal is required by operating in an “unseeded” mode, this processing approach does provide some benefits if the chemical composition of the feed allows such operation. The benefits are mainly in the elimination of solids handling and “seed recycling”, as is required in the ENEL plants.
- The blowdown from the brine concentrator, containing about 20% total dissolved solids (there are no suspended solids), goes to a buffer tank before entering the downstream crystallizer.

The distillate from the evaporator is of high quality with a conductivity of typically less than 40 μS/cm for both the brine concentrator and crystallizer. The distillate from both systems is combined prior to leaving the ZLD. This water goes to general plant use.

3.3 ZLD – Thermal Treatment – Crystallizer

The crystallizer serves to further evaporate and concentrate the brine concentrator blowdown leaving an essentially dry salt as the final product. The salt residual is sealed in plastic bags. The Monfalcone system is a steam driven vacuum crystallizer that is operated at a moderate vacuum. Thermal compression is not used. For a discussion of atmospheric vs. vacuum crystallization, see Sections 7.

The technical highlights of the crystallizer and its operation are:

- The crystallizer capacity is sized to accommodate the brine concentrator blowdown.
- The crystallizer is operated at a moderate vacuum condition.
- The recirculating crystal brine slurry is about 45% total solids.

- The distillate purity is ensured by a washable demister arrangement.
- The distillate quality is typically about the same as for the brine concentrator, although TDS excursions can be experience if foaming conditions occur.
- Under upset conditions, typically due to foaming, as can occur during crystal harvesting and sump liquid replenishing procedures, the conductivity can spike to a relatively high TDS (due to internal foaming).

3.4 ZLD – Thermal Treatment - Dewatering

The technical highlights of the Monfalcone crystallizer dewater system are:

- A single belt pressure filters serves to dewater the crystallizer solids.
- Salt from the filter is collected and filled into 250 kg (550 lb) bags.
- Approximately 300 to 400 t/yr of salt is generated.
- The salt is shipped to Germany, where it is used for salt mine restitution, i.e. salinity stabilization.

Site Visits

General Overview

During the course of this study, three site visits were conducted in Italy, where most of the operating thermal FGD – ZLD systems installations are located. The sites visited were at the following generating stations:

1. ENEL - La Spezia
2. ENEL - Brindisi
3. a2a SpA – Monfalcone

A technical summary of these installations is presented in the previous section, with additional information presented in Appendix A.

All ENEL ZLD systems, including La Spezia and Brindisi were supplied by Aquatech International. The Monfalcone system is a Veolia-HPD system. Both vendors are American companies, although the Monfalcone plant was supplied from the HPD office located in Spain.

According to the plant operators, all three of the facilities visited are running well and they are satisfied with the performance capacity and integrity of their respective ZLD systems. Some modifications were made after commissioning. One of these was a change to a more corrosion resistant material in all of the ENEL crystallizers' seawater condensers (see Section 7, Materials of Construction).

At the time of the visit to Brindisi, another process modification was being tested at this plant. This consisted of soda ash addition to the "first" step clarification process to soften the water that is destined for return to the FGD as makeup. This process change has proven to eliminate or significantly reduce the scale formation that had been experienced in the FGD system components.

Figure 4-5
Site Visit Locations

Detailed Description

The details of each visit can be found in the Appendix A.

Manpower – Staffing

Based on the plant visits conducted, the staffing and personnel issues for the FGD wastewater treatment systems seem to be similar to the operation of other power plant (non FGD) ZLD systems. The plants visited typically employed two operators for each of the three shifts, one inside and one outside. Some plants integrated the FGD treatment operation with the general plant water management, while others incorporated it with their FGD operations.

A common refrain was that a good operation relies on high operator skill level to deal with the diverse treatment processes. This high skill level was not always readily available.

5

OTHER FGD WASTEWATER TREATMENT PLANTS – COAL POWER PLANT INSTALLATIONS

Kansas City Power and Light – Iatan Station

The Iatan Generating Plant – Unit #1, with a nominal capacity of 750 MW, and Unit #2, with a nominal capacity of 850 MW, is owned by Kansas City Power & Light. It is located near Weston, MO. The plant burns Powder River Basin (PRB) sub-bituminous coal but is also capable of burning a 10% blend of Eastern bituminous coal as well.

Units #1 and #2 have a forced oxidation - wet limestone scrubber. A block flow schematic of the FGD ZLD system is presented in Figure 5-1.

The technical FGD wastewater treatment system highlights are:

- The FGD system is designed to use cooling tower blowdown as makeup water.
- The entire FGD discharge purge stream is blown down for treatment.
- The treatment system consists of a pretreatment clarifier, which serves for the removal of suspended solids only. No softening or reagent induced metal precipitation occurs.
- The clarifier effluent goes to two (2) 30 gpm brine concentrators, which recover about 90% of the feed water.
- The brine concentrators, which are in a 2 x 100% configuration, are designed to be operated in a “seeded” mode.
- The design concentration factor is about 10, i.e. 90% recovery.
- The 3 gpm of brine concentrator blowdown is mixed with fly ash for stabilization and sent to the plant’s combustion by-products (lined) landfill.
- Based on the limited experience to date, the use of brine concentrator blowdown for fly ash wetting has proven to be more challenging compared to the use of lower concentration water, but the process has been manageable.

The brine concentrator was commission on service water in 2009, but has only been operating intermittently (at the time of this writing) as the station’s Unit #2 is being brought on-line by 2010. Iatan is unique in its approach of managing and stabilizing the brine concentrator blowdown with fly ash in a landfill. Future work will follow-up to determine the plant’s operating success and experiences with the blowdown management.

During startup on actual FGD wastewater, several material and processing issues were encountered. The power plant is currently addressing these issues. One problem was that the FGD blowdown chemistry is different from design, delivering water with higher TDS and lower calcium than expected.

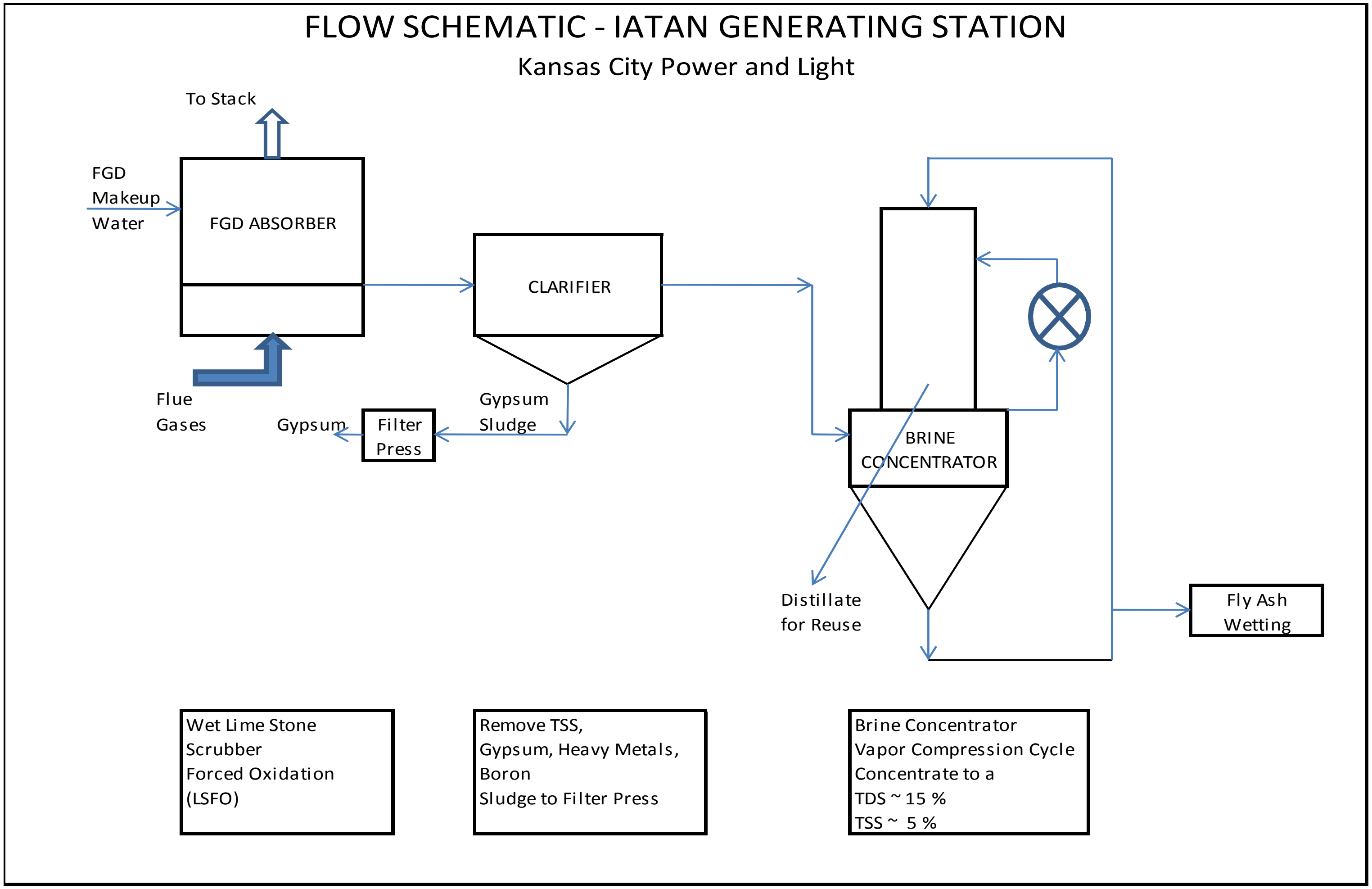


Figure 5-1
Iatan Generating Station - FGD Treatment System Flow Schematic

Kusile Power Station, South Africa

At the time of this writing, a new FGD treatment system is in work for the 4,000 MW Kusile Power Station. The plant is located in the Delmas Municipal area of the Mpumalanga Province, South Africa.

It is anticipated that the FGD wastewater treatment system will be commissioned in 2012.

The design calls for the FGD blowdown to be fed to a 1 x 200% softener-clarifier where lime and soda ash will be added. The clarifier sludge will then be dewatered via a plate and frame filter press. The clarifier effluent is fed to a 2 x 100% train consisting of a brine concentrator followed by a crystallizer.

Each train has a brine concentrator and crystallizer with feed capacities of 25 m^3/h (110 gpm) and 2.5 m^3/h (11 gpm) respectively.

The crystallizers are powered by plant steam and employ thermal compression to enhance the energy efficiency. The crystallizer solids end product consists of mainly sodium chloride with some calcium and sodium sulfate.

A flow schematic of the thermal FGD ZLD system is presented in Figure 5-2. The significant FGD blowdown characteristics are listed in Table 5-1.

Table 5-1
Design FGD Blowdown Characteristics
Kusile Power Station

PARAMETER	*CONCENTRATION*
Chloride	~30,000 mg/l
TDS	~50,000 mg/l
TSS	<10,000 mg/l
B	20 - 40 mg/l
As	< 3 mg/l
Hg	< 0.8 mg/l
pH	4 - 7

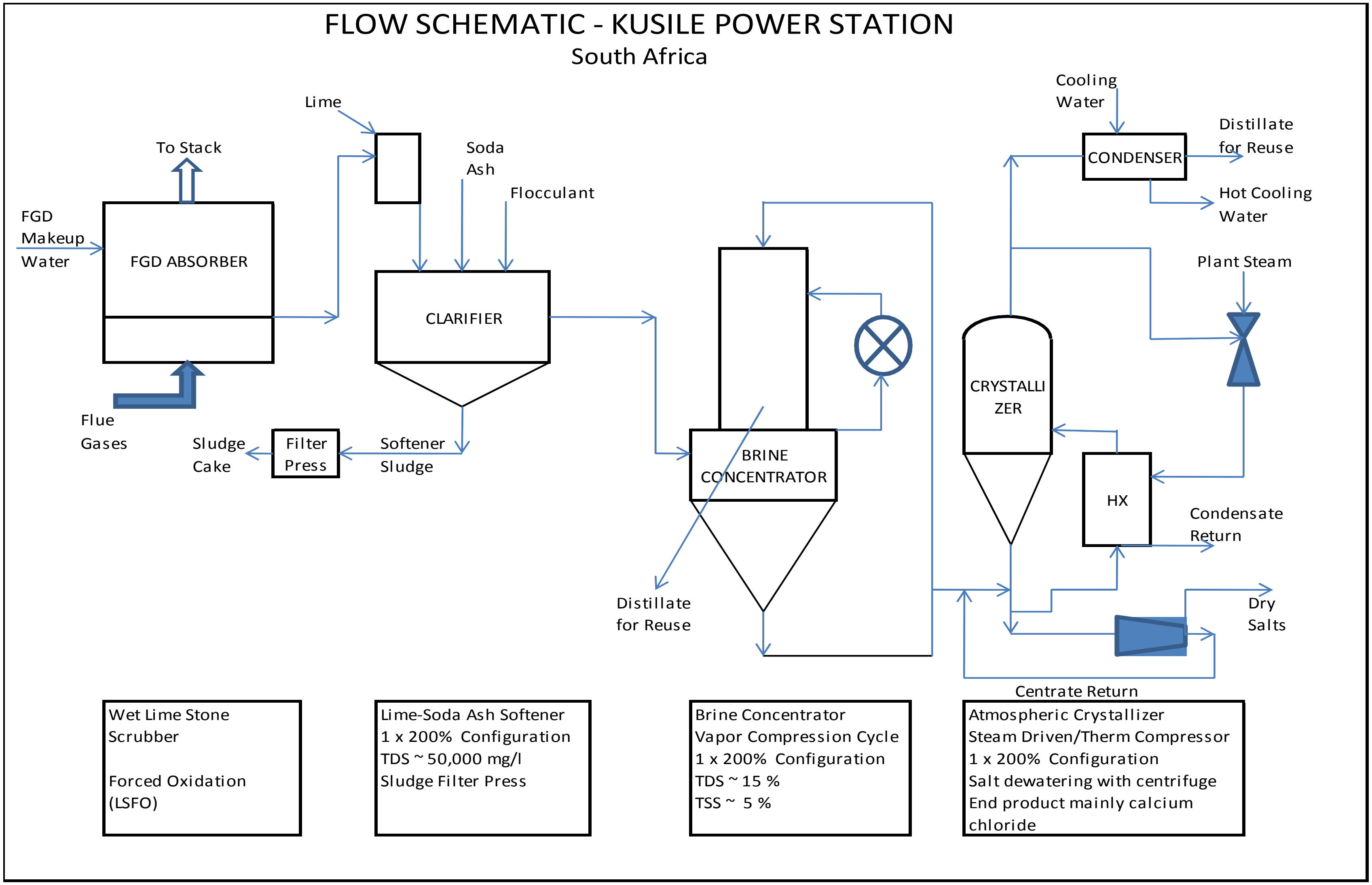


Figure 5-2
Kusile Power Station - FGD Treatment System Flow Schematic

Nordjyllandsværket Unit 3

Overview

The Nordjyllandsværket Unit 3, owned and operated by Vattenfall A/S, is a pulverized coal-fired power plant, located in Vodskov (near Aalborg), Denmark. It generates 410 MW of electric power and provides a maximum of 420 MJ/s (1,433 MBTU/hr) of heating to the surrounding towns.

Unit 3, commissioned in 1998, is equipped with a limestone-based Mitsubishi Heavy Industries (MHI) FGD system. Recovered gypsum and fly ash are sold to the local cement industry, which in turn supplies the plant with limestone for the FGD. Although purchased from various sources, the coal is typically less than 1% sulfur and has a chloride content ranging from 0.02 to 0.18 percent (200 to 1,800 ppm).

Due to stricter environmental laws, an evaporative FGD wastewater treatment system was installed as part of a major, corrosion instigated FGD refurbishing program. The modifications were completed and commissioned in 2005.

The end product of the FGD wastewater treatment is a concentrated calcium chloride solution, which is sold as a liquid de-icer. The production of brine concentrate and the thermodynamic coupling with the power plant are covered by a PCT patent application (international "Patent Cooperation Treaty").

Technical Summary

The technical highlights of the FGD wastewater treatment system of this Danish generating station are listed below. A flow schematic of the system is shown in Figure 5-3.

- The FGD wastewater treatment system consists of a spray dryer, which receives the purge water directly from the FGD without pretreatment.
- The spray dryer was supplied by Anhydro A/S, a Danish company.
- Heat for evaporation is provided by hot air drawn as a side stream from the combustion air pre-heater.
- At full load approximately 18 kg/s (39.6 lbs/sec) of hot air is delivered to the dryer to evaporate 5-6 m^3/h (22 to 26 gpm) of the FGD blowdown.
- The spray dryer product is a mixture of dry powder and air at 140°C.
- The dry solids are removed in a bag house, located downstream from the dryer.
- The 140°C outlet air is mixed with the flue gas and discharged to the stack.
- The dry powder consisting mainly of calcium chloride, gypsum and fly ash with some sodium chloride and sulfate in the mix.

- The dryer solids are sent to a contact basin where the salts are redissolved, resulting in a brine solution strength of 25 – 30 %, which consists of mainly calcium chloride.
- The reconstituted salt solution from the basin is now a salable product and is used for local road de-icing needs.
- Vattenfall estimates that the energy penalty for the dryer hot air extraction from the combustion preheater plus the additional heating needed to compensate for the decreased flue gas temperature in the stack, translates to an increased coal consumption of approximately 850 tons per year.

It must be noted that the FGD purge water does not contain significant levels of heavy metals or boron.

Specifications for the de-icer fluid, generated by the plant, are shown in Table 5-2.

Table 5-2
De-Icer Solids Properties

PARAMETER	***CONCENTRATION***
Density	1.25 kg/m3
TDS	25%
Chloride	15 – 16%
Calcium	2-8%
Sodium, Magnesium, Potassium	< 7%
Total Nitrogen	< 0.25%
Heavy Metals (Cd, Hg, Cu, Ni, Zn, Cr, Pb)	<5 mg/l

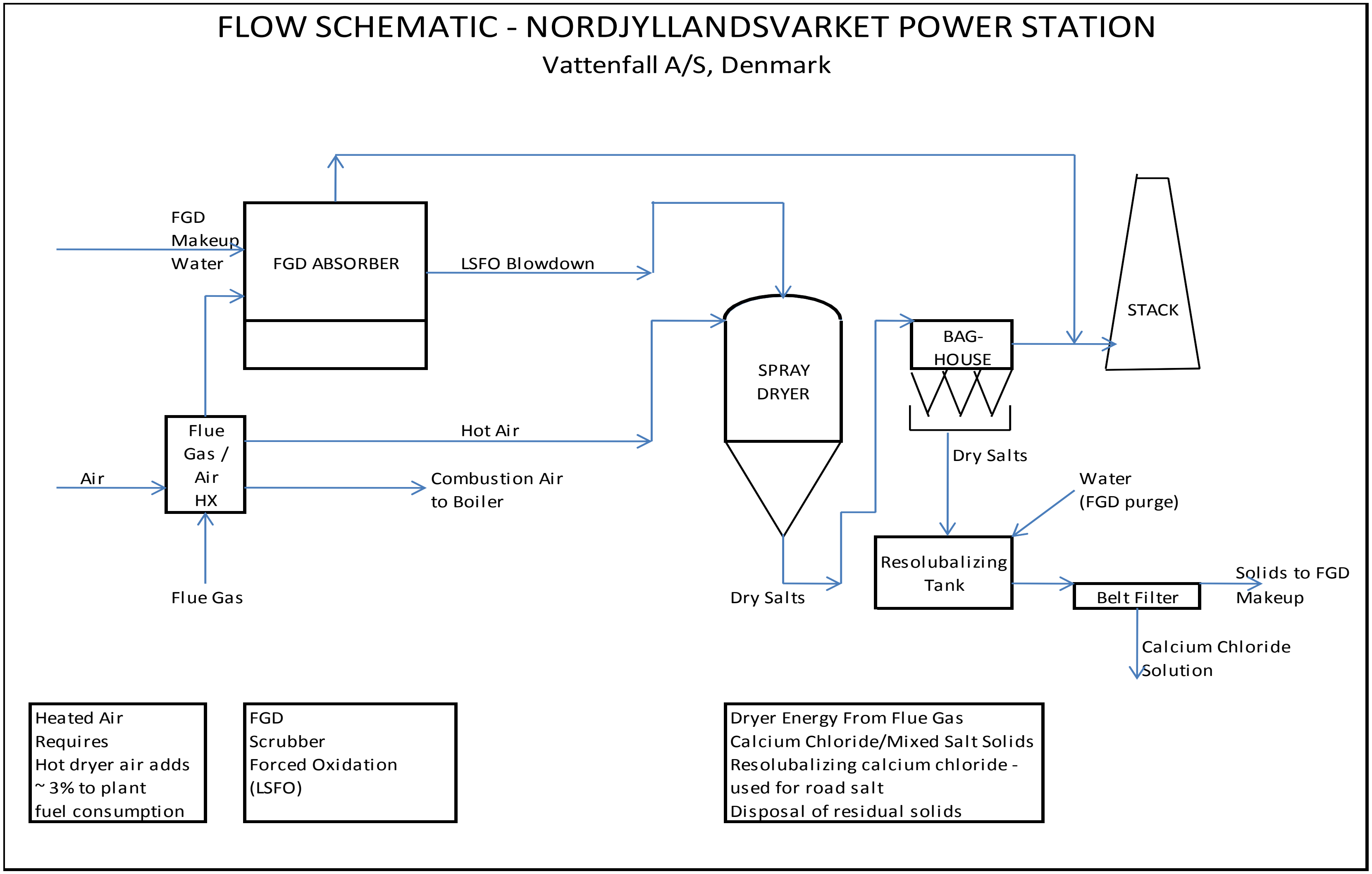


Figure 5-3
Nordjyllandsvaerket Power Station - FGD Treatment System Flow Schematic

6

OTHER COAL POWER PLANT, NON-OPERATING ZLD TREATMENT SYSTEMS

Milliken Generating Station

The Milliken FGD wastewater treatment system was part of a Department of Energy funded Clean Coal Technology Demonstration Project (MCCTD), originally funded in Round IV of the Clean Coal Technology Program (CCTP) in 1992. The treatment process consisted of an initial clarification step followed by a brine concentrator for volume reduction. The project goal was to achieve ZLD for the FGD water and generating road salt as a usable end product. It must be noted that this was the first brine concentrator to be used for an FGD treatment application. It was commissioned in 1995 and operated in this service until 1997.

The pre-treatment for the brine concentrator consisted of solids settling, but no chemical precipitation.

The brine concentrator was of a design typically used for power plant applications, operating with a "seed slurry" process. What differentiated this system, however, was that the design boiling point rise was 17°C (30°F) compared to the 2°C to 3°C (3°F to 5°F) usually encountered in conventional power plant cooling tower applications. Furthermore, due to the high boiling point rise the system was operated at a low concentration factor, which makes the critical heat balance of an MVR system more precarious. MVR energy requirements are strongly dependent on the temperature rise or compression ratio needed. The feed composition was mainly calcium chloride ($CaCl_2$) at 5% with a design boron feed level of 40 mg/l.

The metallurgy was typical for a brine concentrator of that era, consisted of titanium (Ti-12) evaporator tubes and 316SS vapor ducts.

The initial operation was plagued by two main and some minor issues, with the latter typical for the startup in new applications:

- The 316 SS vapor ducts were failing due to corrosion.
- Although the design boron level was 40 mg/l, in reality 800 mg/l was encountered, representing a 20 fold increase.
- The high boron caused the heavy precipitation of the very "sticky" calcium borate, which interfered with the seed slurry process and resulted in plugging.
- The salt quality generated was not of sufficient purity to allow its use as road salt.

- Some minor design and operational issues, including compressor problems, were encountered. (Due to the high boiling point rise, a new compressor type and vendor had been selected.)

To address these issues, the vapor ducts were replaced with a higher grade alloy. The pH of the recirculating brine slurry was lowered, which kept the boron in solution and prevented the sticky calcium borate from precipitating and the compressor issues were resolved.

The treatment plant was eventually shut down before these remedies could be proven during long term operation. The Milliken plant is now using a chemical treat-and-discharge approach for their FGD wastewater management.

Dallman Generating Station

Dallman Station, owned by Springfield City Water, Light and Power, consists of four power blocks with a total of 440 MW output.

- 2 X 80 MW - used as peaking units (old units)
- 1 x 200 MW - base load unit (old unit)
- 1 x 240 MW - base load unit, commissioned in 2009

The fuel source for all four units is Illinois bituminous coal, which has a sulfur content of about 3.2% and a high chloride level. The plant had been using coal from a nearby strip mine to supplement the fuel, but this mine was shut down. The latter coal had a much lower sulfur content of about 1%.

The FGD systems at Dallman consist of:

- The 200 MW unit FGD is a dual loop system that has been operating since 1978.
- Both 2x 80 MW units are served by one, single tower Lurgi Lentjes Bischoff (LLB) FGD, which was commissioned in 2000.
- The 240 MW unit has a Siemens-Wheelabrator FGD, commissioned in 2009.

Plant water treatment is handled via a surface water cooling lake, which receives plant return water that had been subjected to lime treatment. The other plant water treatment is for the ash pond and the FGD systems.

The initial FGD blowdown treatment approach was to feed the chemically pretreated wastewater to the ash pond, which ultimately ends up in a discharge to a nearby creek. With the 250 to 500 ppm boron level in the FGD blowdown, however, the ash pond effluent would no longer meet the NPDES discharge limit so that an alternate means of treatment was sought.

This alternate treatment plan consisted of two 120 gpm (2 x 60%) brine concentrators followed by 2 x 60% gas fired spray dryers. The brine concentrators were intended to be operated in a "seeded" mode. The dual treatment trains were delivered to the site for an intended startup in

2007. Due to operational uncertainties and significant increases in waste disposal costs, the systems were never commissioned.

The reasons why the ZLD system was never put into service were as follows:

- During the preliminary design decisions, the spray dryers were determined to be cheaper to operate compared to crystallization. It was later discovered that, due to changing operating parameters, the cost for the drying process increased significantly.
- The plant could not be assured that the dryer solids could meet the necessary disposal standards. The initial plan was to bag the dryer cake and deposit it to landfill. But, during pilot testing, the dryer cake was found to be of a pasty consistency so that its acceptance at the intended landfill was questionable and the cost of disposal would potentially increase significantly.

With the high operating and installation cost exceeding expectations, the plant looked for alternatives to ZLD in the form of stream separation. The FGD blowdown is now taken to a solids clarifier where polymers are used to settle the suspended solids, which also results in an approximately 10% reduction in boron. The clarifier effluent is then piped directly to sewage treatment plant, which is capable of accepting the FGD wastewater pollutants, including the boron. A flow schematic of the Dallman Station FGD ZLD treatment system is presented in Figure 6-1.

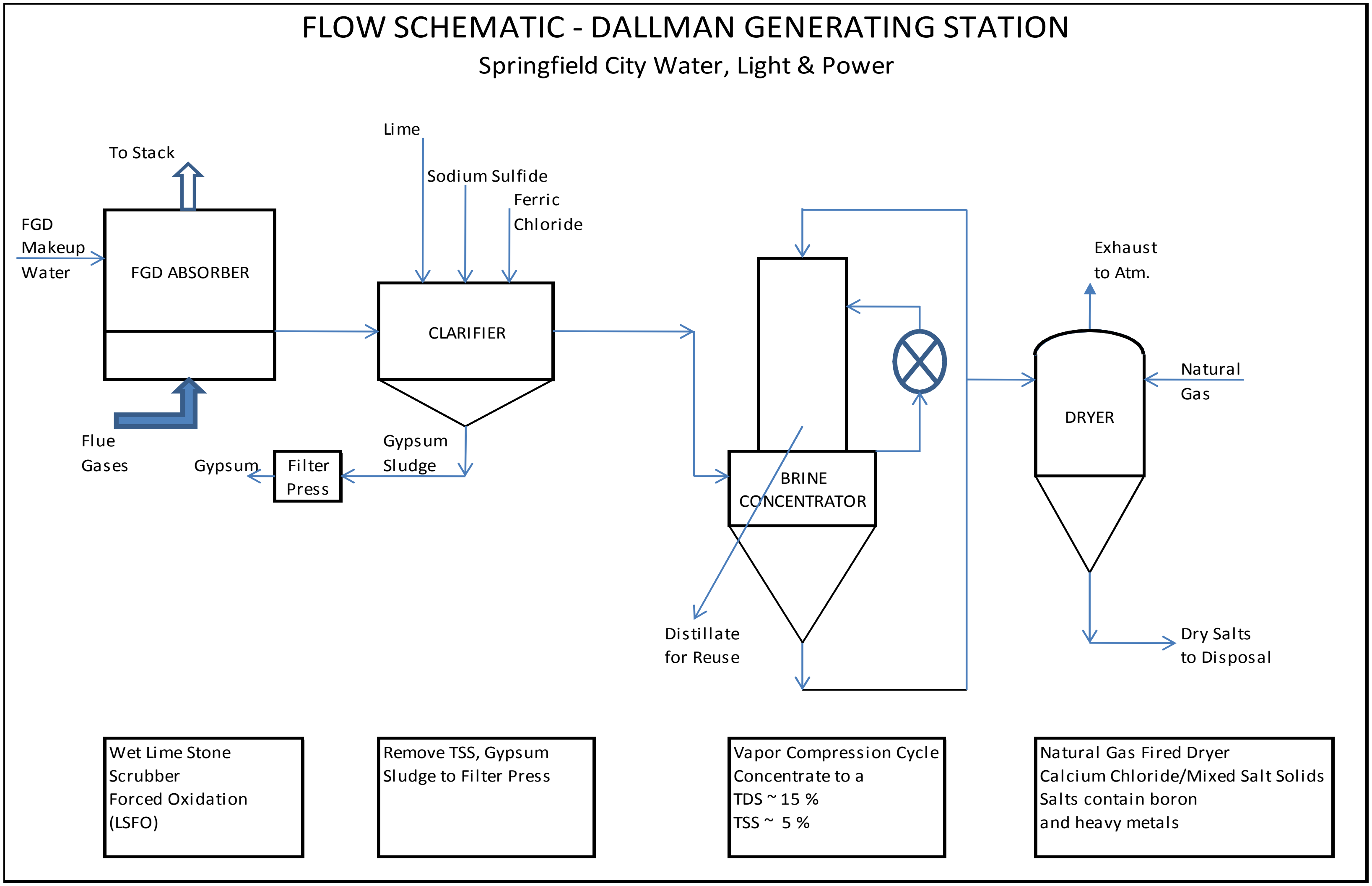


Figure 6-1
Dallman Generating Station - FGD Treatment System Flow Schematic

Other details about the Dallman FGD system are:

- The limestone to the FGD is relatively pure, consisting of more than 95% $CaCO_3$ and less than 3% $MgCO_3$.
- About 95% of the gypsum is harvested from the FGD water using both hydrocyclones and cloth vacuum filters. The gypsum is sold for use in a cement plant, agricultural supplements and mine stabilization.
- The FGD blowdown from all 4 units goes to a holding tank and then to a single clarifier.
- While the flow from the 200 MW and 240 MW FGDs is relatively constant, the peaking units add fluctuations.
- The FGD blowdown rate is typically 225 gpm and has a pH of about 6.0 to 6.5.
- Cooling tower blowdown (from the new power block) is used for FGD makeup.
- All reagents are added directly to the reaction clarifier.
- The chemicals added to the clarifier consist of:
    - Lime to raise pH to about 7.0 to 7.5
    - Organo-sulfide for mercury removal
    - Cationic polymer
    - Anionic polymer
- All clarifier sludge is returned to FGD to supplement the virgin limestone makeup.
- The chloride level in the FGD blowdown is about 10,000 mg/l.
- The clarifier performance is:
    - The influent TSS of 350 to 750 ppm is reduced to about 5 ppm
    - The influent mercury of 35 to 50 ppb is reduced to about 200 ppt, which is far below the allowable limit.
    - The influent boron of 150 to 250 ppm is reduced by about 10%

Centralia Generation Station

The 1,376 MW Centralia Generating Station LLC, owned by Transalta and located in Centralia, Washington, installed a crystallizer to treat the pretreated FGD blowdown. The effluent from the clarifier, used to remove suspended solids, was fed to a forced circulation crystallizer. The boron in the feed water precipitated in the crystallizer as the sticky calcium borate (encountered by other FGD evaporators) and caused processing problems, which the plant never resolved. The crystallizer was consequently shut down and mothballed and an alternate means of FGD wastewater disposal sought.

The plant uses coal that contains 1.1% sulfur and some Powder River coal containing 0.3% sulfur. Based on their unsuccessful attempt of achieving ZLD for the 40 gpm of FGD blowdown using the crystallizer, the plant was able to return to a chemical treat-and-discharge method via a variance in their NPDES permit.

The treatment now consists of lime addition to a reaction clarifier, which is operated at a pH of about 10.2. In this environment the 30 to 40 mg/l of boron in the feed precipitates as calcium borate. The clarifier sludge is dewatered in a vacuum filter and disposed of in a landfill.

Long Term Pilot Demonstration Systems

Matsushima Electric Generating Station – Japan

In 1996, a 12 month brine concentrator pilot demonstration test on FGD wastewater was performed at the 1000 MW (2 x 500 MW) Matsushima Electric Generating Station, which is located on the tip of the West Coast in Japan.

The general design of the 5 gpm test unit was similar to that used at the Milliken evaporator plant except that materials and processing lessons learned at the Milliken facility were incorporated into the pilot unit.

This evaporator was operated in a "seeded" mode, processing FGD wastewater containing:

Boron	~ 200 mg/l
Calcium	~ 700 mg/l
TDS	~ 200,000 mg/l
Operating pH	acidic

With an operation at the relatively low pH, no calcium borate precipitation problems were noted. The unit ran well for the intended 12 month duration. After the completion of a generally successful demonstration, the power station opted to continue the treat-and-discharge approach to dealing with the FGD wastewater.

7
DESIGN CONSIDERATIONS

Pretreatment vs. Crystallization Options

As previously stated, the number of thermal treatment systems for FGD wastewaters are few, limited to only a handful of plants worldwide.

To date, the most commonly used thermal treatment approach is to employ water softening ahead of the brine concentrator to avoid the extremely high boiling point and the very corrosive environment (due to the high chloride levels and high operating temperatures) resulting from the crystallization of calcium chloride. The addition of soda ash in a softener transforms the calcium chloride to the much more amenable sodium chloride. At the same time the calcium hardness precipitates as calcium carbonate, which can be used as FGD makeup reagent. Further, the softened water can be used as FGD makeup water.

$$Ca^{+2} + 2Cl^{-1} + 2Na^{+1} + CO_3^{-2} \Rightarrow 2Na^{+1} + 2Cl^{-1} + CaCO_3\downarrow$$

As an alternative to softening, vacuum crystallization can be considered to minimize the above described issues. The advantage of vacuum compared to atmospheric crystallization is that:

- The brine boiling temperature is decreased
- The boiling point rise of the less concentrated brine is reduced by approximately 50%

The combination of these two factors in a vacuum system results in a significantly less corrosive environment and reduces the steam pressure needed to drive the process (plant steam or MVR). In the case of MVR systems the lowered boiling point rise is offset by the lower overall pressure of the system, which means the compression ratio required in the compressor system is not reduced by the same percentage as the BPR. Nevertheless, the MVR energy requirement is generally lower for vacuum systems.

The downside of vacuum crystallization is that the steam volumes per kg (lb) evaporated are much greater. This translates to overall larger system and component sizes, which increases the capital costs and also forces the energy cycle away from vapor compression to plant steam. Other disadvantages include the operating and maintenance complexity associated with vacuum systems and that the heat transfer value is somewhat reduced (compared to an atmospheric operation). Distillate carryover might be higher in vacuum systems, especially volatile metals like Hg. Vacuum operations are also more prone to foaming.

Another approach for consideration is the use of a multi-effect or a split crystallizer design utilizing a forward feed approach. By having the larger 1st step crystallizer carrying most of the evaporation load, the majority of the work is done at lower concentrations and thus under less severe process conditions. This way only the much smaller 2nd step crystallizer at the back end is exposed to the high concentration issues of the final crystallization process, i.e. high boiling point rise and highly corrosive conditions.

An father disadvantage of not converting from calcium to sodium chloride lies in the solid treatment. The solids produced in the crystallizer in either of the above processes are mainly $CaCl_2$ or $MgCl_2$. Calcium chloride is very hygroscopic, which makes containment, packing, shipping and landfill more problematic.

From a chemical point of view, aside from the conversion of calcium chloride to sodium chloride, water softening does have the benefit of precipitating some undesirable species like calcium borate (which reduces boric acid in the evaporator).

A block diagram of the above described options is presented in Figure 7-1.

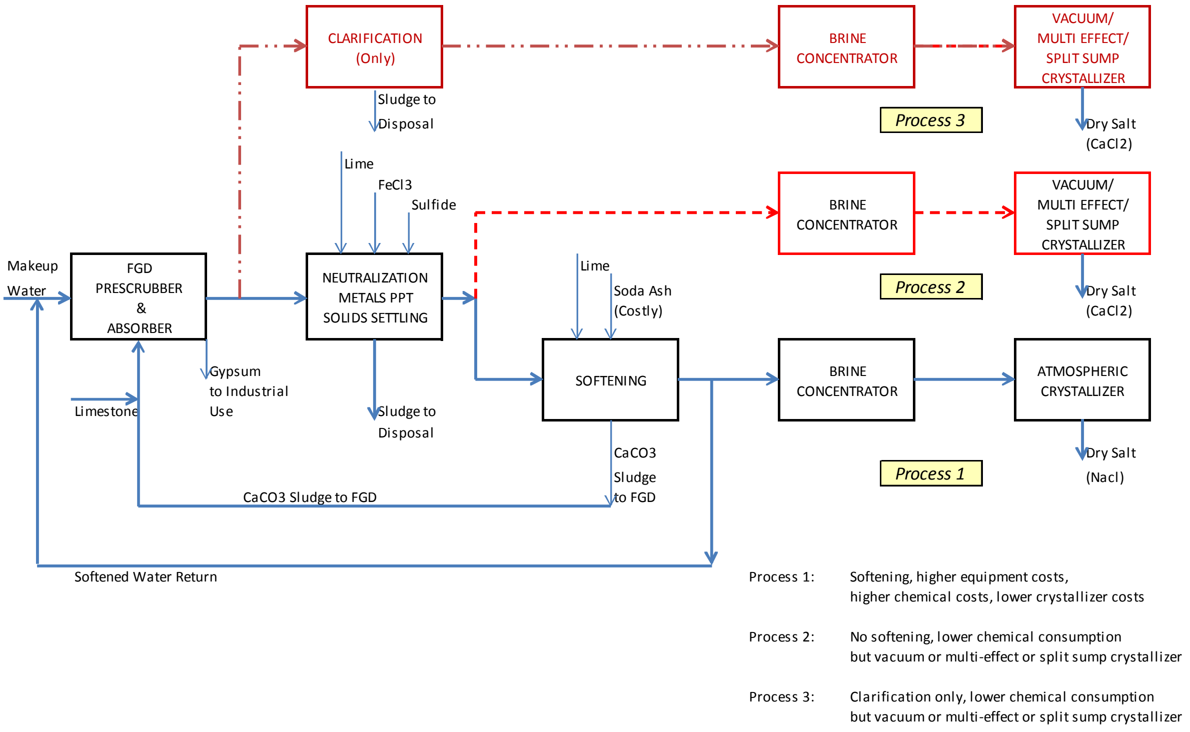


Figure 7-1
Pretreatment Options Affecting the Crystallization Process

The decision of softening vs. vacuum or multi-effect crystallization is not clear cut, each offering advantages and disadvantages. The influencing factors to be considered include:

- Pretreatment system size and crystallizer feed rate.

- Cost of soda ash.
- Is the brine concentrator operated in a “seeded” or “unseeded” mode? If it is an “unseeded” operation, then softening is mandatory.
- Is some of the clarifier FGD purge water returned to the FGD as makeup? If yes, does the water have to be softened to prevent scaling of the FGD system components?
- Will the calcium carbonate sludge from the softener be used as part of the lime stone makeup in the FGD?
- Availability of sufficient plant steam to drive a vacuum crystallizer (verses a MVR crystallizer
- Physical plant size considerations for the softening and chemical storage systems.
- Staffing for the softening operation.
- Skill and expertise requirements for operators and maintenance staff of a softener vs. the more complex vacuum crystallizer system.

The above enumerated factors are plant specific and have to be weighed against their economic and operational impact on the process selection. As of this writing, most of the operating installations employ softening. The Monfalcone ZLD, which is relatively small, uses softening and vacuum crystallization.

System Redundancy

Most of the thermal FGD treatment systems identified for coal fired plants consisted of a mix of 1 x 100%, 2 x 50% or other redundancy arrangements.

Table 7-1
Design Arrangements of Coal Fired Power Plant - Thermal FGD Treatment Systems

Plant	Clarifier / Dealkalization	Softening	Evaporators	Crystallizers	Dryer
La Spezia	1 x 100%	1 x 100%	1 x 100%	1 x 100%	n/a
Brindisi	1 x 100%	2 x 50%	2 x 50%	1 x 100%	n/a
Torrevadaliga	1 x 100%	1 x 100%	1 x 100%	1 x 100%	n/a
Fusina	1 x 100%	1 x 100%	2 x 50%	1 x 100%	n/a
Sulcis	1 x 100%	1 x 100%	1 x 100%	1 x 100%	n/a
Monfalcone	1 x 100%	1 x 100%	1 x 100%	1 x 100%	n/a
Iatan	1 x 100%	n/a	2 x 50%	1 x 100%	n/a
Kusile	1 x 100%	1 x 100%	1 x 100%	1 x 100%	n/a
Dallman	1 x 100%	n/a	2 x 60%	n/a	2 x 60%

As can be seen in Table 7-1, crystallizers, which are by far the most costly equipment items (per unit capacity), are typically supplied as 1 x 100% systems.

Brine concentrators, which are also costly equipment items and normally require significantly less cleaning compared to crystallizers, are also mostly in a 1 x 100% arrangement. 2 x 50% or other configurations may, however, be dictated by turn-down requirements or process performance uncertainties at the design stage.

Turn-down for centrifugal compressors is limited to about 60% of maximum capacity. If higher turndown is desired, the only realistic option is to recycle the distillate, which adversely impacts the energy consumption. Turn-down for positive displacement (PD) compressors, such as normally used in crystallizers, is not an issue and can be accomplished by reducing the compressor speed (by use of a VFD).

Conversely, thermal compressors, as are used as energy saving devices on crystallizers, have essentially no turn-down capacity. To achieve process flexibility, two thermal compressors can be supplied, one to be used for 50% crystallizer capacity and the other for 100% capacity. Thermal compressors, which require high pressure steam, typically achieve an energy savings of a maximum of 1.5 times over a single effect steam driven systems (which is less than that realized from a two effect crystallizer system previously discussed).

As described in the evaporator technical technology discussion of Section 2, the feed/distillate heat exchanger (HX) is a critical system component. The heat exchanger captures the distillate heat for the incoming feed, which is necessary for the thermal balance of the MVR process. If the feed is at a saturated level with respect to calcium sulfate or other components, it poses a danger of precipitation as the brine temperature is increased. This problem is commonly addressed by providing a redundant HX system. One heat exchanger is on line, while the second is subjected to cleaning and subsequent placement into stand-by. Flat plate heat exchanger typically takes eight (8) hours or more, pending on severity of scaling and the need for disassembly.

Materials of Construction

Materials of construction (MOC) is an important parameter in the process design of the various treatment components. Since MOC translates to equipment costs there is an obvious tendency not to “overdesign”. This is juxtapositioned against the need for process integrity since “in-field” repair or replacement is many times more costly compared to the proper material selection to begin with.

Most of the FGD treatment systems investigated had only minor material issues. As has been previously described, the SeaCure tubes in the ENEL crystallizer heat exchangers were replaced with titanium when some of the ENEL systems were showing corrosion issues. Another example of process incompatibility was the use of 316L in the Milliken brine concentrator vapor ducts, which is the material usually used in cooling tower evaporators. The 316L was subsequently changed to a more corrosion resistant alloy, which seemed to resolve the corrosion issue encountered.

In general, with respect to MOC, a main difference between normal power plant ZLD (cooling tower) and FGD operations is the high chloride level encountered. Vendors typically have a chloride level and pH threshold, which trigger an upgrade of alloys such a change from 316L or 317L to 2205 or 6%moly alloy or even Hastelloy C, or upgrades in titanium from Ti-2 to Ti-12 or Ti-16. The chloride tolerance of various metals and alloys is also a function of pH, where a higher pH makes the specific alloy significantly more tolerant to chlorides.

Since this threshold of material selection is not an absolute rule but is based more on vendor experience and design philosophy, especially in gray cross-over concentrations and pHs, it behooves the end user to make sure that the materials selection of each process component and sub component will provide the necessary corrosion resistance under the specific process environment(s). Since the end user will own the system for the duration, after the vendor is gone, it behooves him to pay due diligence to the selection of the proper materials, possibly from a conservative view point.

Process Variables

In establishing a viable design and cost estimate for a FGD ZLD treatment plant, there are many influences and variables to consider. Each plant is different with respect to equipment selections, makeup water chemistry, waste disposal options and costs, regulatory requirements, esthetics and public relations, geographic location, vendor and A&E relationships as well as operational and managerial preferences and financial policies.

The influencing, technical parameters that will guide the design of the FGD treatment system include:

- Coal quality
    - Sulfur in coal
    - Chlorides in coal
    - Trace element constituents in the coal
- Goals fuel flexibility
- FGD system type as it relates to FGD blowdown rate and quality
- Plant makeup water availability and quality
- Limestone quality
- FGD makeup water quality
- Plant makeup water
- Cooling tower blowdown
- FGD purge water quality
- Internal plant water recycling needs
- Use of distillate from evaporative treatment systems (usually for plant service water)
- Availability and pressure of plant steam
- Solids (or hazardous) waste disposal

Any or all of the above parameters and variables can have a significant effect on the treatment process and costs. Careful consideration of the impact of these factors must be given in selecting the best suited treatment system concept for each plant.

Many power plants that are considering thermal ZLD are concerned with system reliability and the potential downtime required to modify and to replace equipment. Since the trade-offs of materials and equipment can translate significantly the capital cost, future work is needed to better understand materials of construction selections.

8

MUNICIPAL WASTE INCINERATOR FGD SYSTEMS

The primary objective and focus of this study was thermal ZLD applications on coal power plants using wet FGD systems. Three municipal solid waste (MSW) ZLD systems operating on wet FGD wastewaters were identified during this project, and a limited effort was conducted to summarize these MSW/FGD applications.

Herten, Germany

In order to meet the stricter wastewater discharge regulations, the Herten Waste Incineration Plant, located in Herten, Germany has switched from the previous chemical treat-and-discharge to a thermal ZLD system consisting of chemical pretreatment followed by a multiple-effect, forced circulation (FC) crystallizer. The ZLD system produces saleable salt and the condensate is returned for reuse in the scrubber.

The scrubber blowdown contains chlorides, sulfates, fluorides, free acids, bromide, iodide and nitrogen, as well as heavy metals and sulfur and sulfur compounds.

A flow schematic of the Herten system is shown in Figure 8-1. The technical highlights of FGD wastewater treatment system are:

- Heavy metals are removed from the FGD wastewater via physical/chemical pre-treatment consisting of three stages
    - Stage 1: Lime is added to raise the pH
    - Stage 2: A sodium sulfide solution is added for the effective precipitation of heavy metals
    - Stage 3: Ferric chloride was added as an adsorbent and flocculation aid.
- The precipitated solids are dewatered in a filter press.
- The filter cake is shipped offsite for disposal.
- The filtrate is fed to the two-effect, forced circulation crystallizer.
- The first effect is operated in a “seeded” mode.
- The seed density in the first effect is artificially maintained at a high level by use of “seed recycling” system consisting of static thickener, with the underflow returned to the crystallizer.
- The thickener supernatant is fed to the second effect, where calcium chloride is crystallized.

- The calcium chloride is recovered as a saleable product.
- The nature of the fuel burned influences the quality of the end product. As an incinerator, the fuel can vary widely and rapidly over a short period of time, depending on the source of the waste material.
- The operation of the industrial waste incinerator has an influence on the particle size in the crystallizer.

SNB NV Power Plant – Moerdijk, Netherlands

The waste-to-energy SNB NV Power Plant was constructed in 1996 near Moerdijk, Netherlands to burn sewage sludge. The plant has a ZLD system consisting of a two-effect crystallizer. The crystalline end product is shipped to Germany for the stabilization of salt mines. As a sewage burner, the feed stock remains relatively stable compared to the Herten waste incinerator previously described.

The flow schematic of this system is similar to that depicted in Figure 8-1. The typical FGD blowdown composition is presented in Table 8-1. The technical highlights of FGD wastewater treatment system are:

- The 3 m^3/h (13.5 gpm) of FGD scrubber blow-down from the equalization tank is fed to a forced circulation (FC) crystallizer system in a 2 x 100% configuration.
- The crystallizer feed temperature ranges from 30°C to 80°C (85°F to 175°F).
- The crystallizer solids are mainly sodium sulfate, which are harvested by use of a centrifuge.
- The centrate is returned for further concentration, while the solids are dewatered and removed.
- Since sodium sulfate picks up waters of hydration, the end product is a dry salt.
- The sodium sulfate (Na_2SO_4) amounts to about 1,500 tons/year.
- The crystals are dewatered by use of a centrifuge.
- The evaporation rate is approximately 70 tons/day.
- The crystallizer system consumes approximately 2.8 tons/h of steam.

Table 8-1
SNB NV Power Plant FGD Blowdown Composition - Moerdijk, Netherlands

Cation Component	*(mg/l)*	Anion Component	*(mg/l)*
Calcium	410	Chloride	7,490
Sodium	19,550	Sulfite	3,080
Ammonia	1,730	Sulfate	34,300
		Fluoride	700

Table 8-1 illustrates that the composition consists of mainly sodium sulfate. This is in contrast to the typical coal fired power plants, where the FGD blowdown contains predominantly calcium or sodium chloride.

GMVA Oberhausen-Buschhausen Power Plant

The Oberhausen-Buschhausen Power Plant is the second 25 MW plant located in Duisburg, Germany and burns municipal solid waste. The first was commissioned in 1982 and the second in 1998. Both facilities have thermal ZLD systems to treat the FGD wastewaters.

A flow schematic of the system is shown in Figure 8-2. The technical highlights of FGD wastewater treatment system are:

- The FGD blow down is at a temperature of approximately 30°C (86°F) and has a TDS level ranging from 10 – 12 %, consisting of mainly calcium chloride plus some calcium sulfate and sodium chloride.
- The 15.3 m^3/h (67 gpm) of FGD blowdown is fed to a two-effect, forced circulation (FC) crystallizer.
- Due to the uncertainty of the feed water quality (i.e. concentration level of the major components) an in-line third effect was installed to serve as a stand-by unit in case the boiling point rise (BPR) rose beyond the capacity of the first two effects to handle.
- To date, the third effect has not been used in this service.
- About 0.6 m^3/h (2.6 gpm) of crystallizer concentrate is generated consisting of approximately 40% of calcium chloride.
- This product solution is shipped to various salt mines in Germany, where it is used as a stabilizing agent.
- The steam consumption is 8.3 tons/h.
- The staff consists of one inside and one outside operator for each of the three shifts.

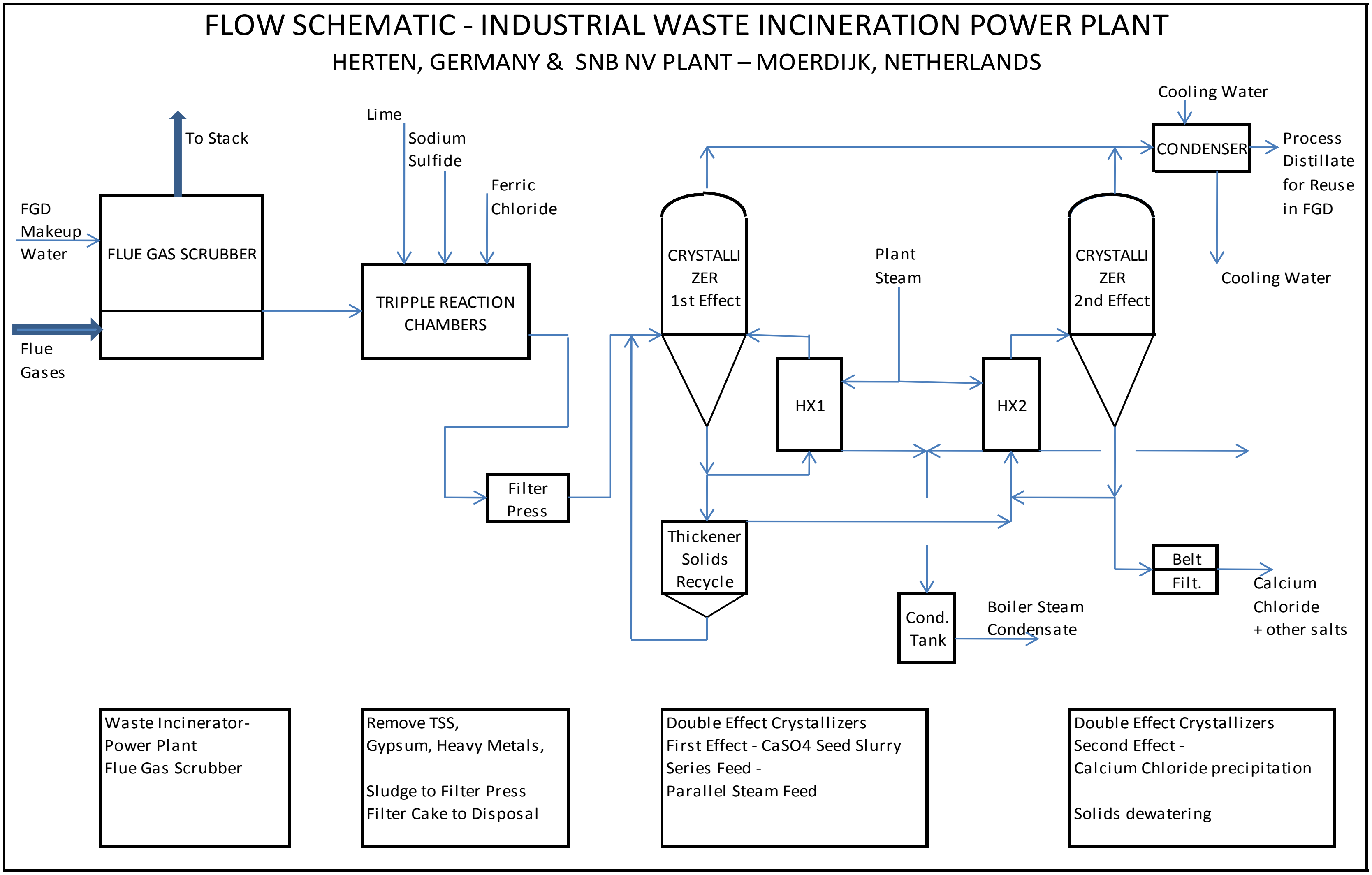


Figure 8-1
Herten & SNB NV Waste Incinerator - FGD Treatment System Flow Schematic

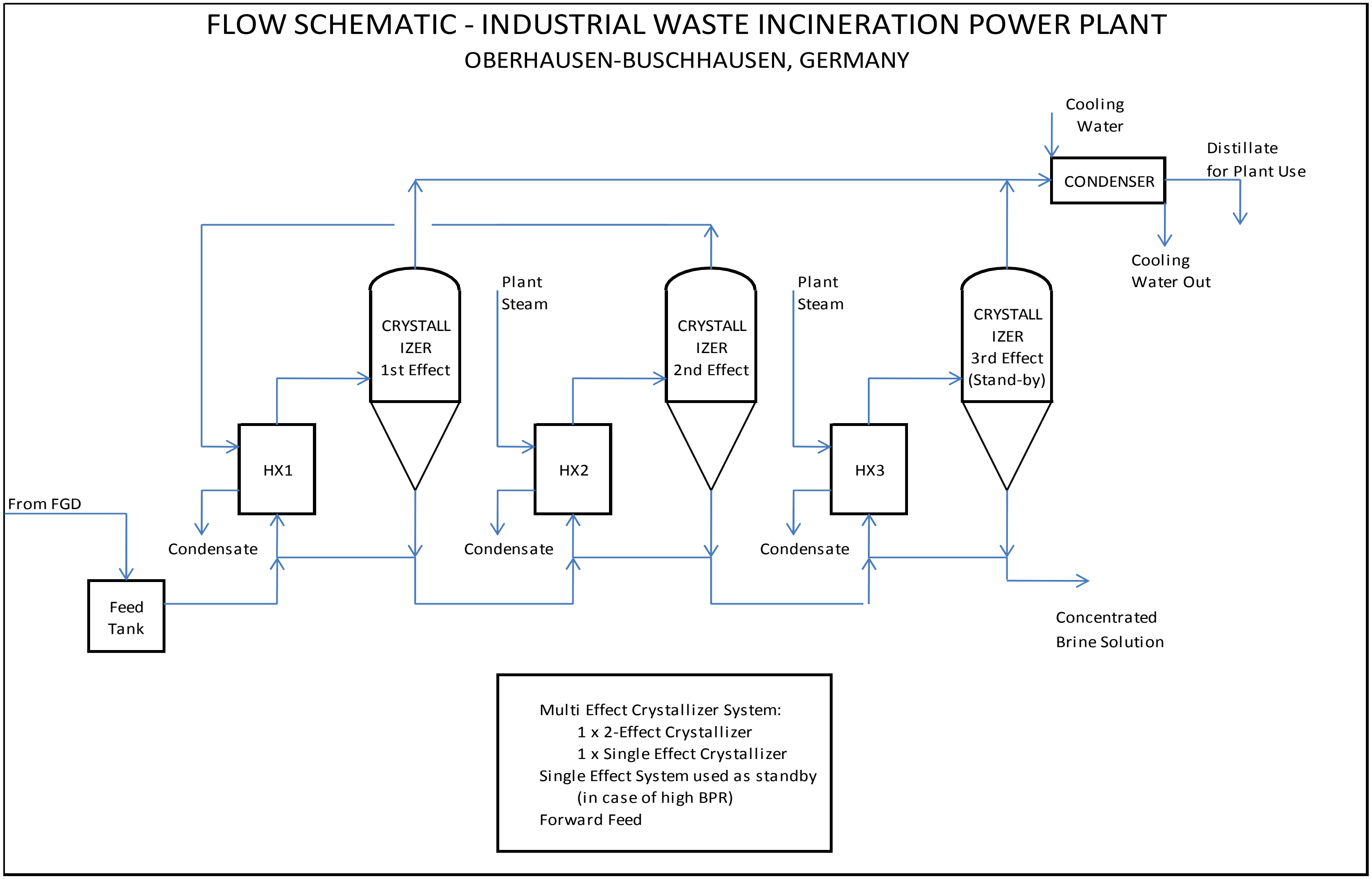


Figure 8-2
Oberhausen Waste Incinerator Power Station - FGD Treatment System Flow Schematic

9

DISCUSSION AND CONCLUSION

Although the thermal treatment of FGD wastewaters has not been widely used in power plant applications to date, the technology is successfully employed at several generating stations around the world. The majority of the installations identified in this study are relatively new, having only been commissioned in the past few years.

At the presently operating FGD ZLD facilities, most of the technical challenges seem to have stemmed from material selections that were not well suited for the corrosive environments encountered. System reliability and the potential power plant downtime to modify and replace equipment are significant concerns. As the capital cost-considerations can be substantial, future work is needed to better understand materials of construction selection.

Other problems in earlier brine concentrator operations may be attributed to the peculiarities of FGD wastewaters and the lack of experience in dealing with them in comparison to treating cooling tower blowdown. Another source of difficulty has been the discrepancies encountered between the design vs. the actual FGD blowdown compositions, especially with respect to calcium, TDS and boron. Process adjustments for the evaporators as well as the implementation of pretreatment have remedied many of the earlier difficulties. After one or more years of experience, today's operating plants, including the ones visited as part of this study, appear to be satisfied with their respective systems.

Due to the relatively high operating costs for energy and chemical reagents, several of the stations have opted to mothball their thermal treatment systems in favor of employing the chemically treat-and-discharge approach when this allowed by their NPDES or other (international) discharge regulations.

The plants that are using spray dryers or crystallizers (only) appear to be successful operations. Regarding the end product use of the residual salts for deicing fluid or mine stabilization, it is unclear what the allowable heavy metal and/or boron contamination levels are. Before considering such an approach for new systems, a more thorough study of the removal efficiency of contaminants (by re-solubilization in holding ponds) to meet regulatory requirements would be in order.

The cost comparisons, which are not included in the scope of this study effort, of softening vs. non-softening in the pretreatment seem to favor the latter, especially for larger plants. In such a trade-off, the downsides of a more complex system and the hygroscopic nature of the salt residual product must be considered.

Future work is needed to characterize and manage solid waste disposal, as well as potentially co-management of the brine concentrate discharge with fly ash in a landfill.

With so many variables relating to baseline costs, ZLD size, plant circumstances and many others, each application is unique and will result in its own cost-benefit trade-off. There are not enough thermal FGD ZLD systems in operation today to truly point in one direction or another.

In future work, it is planned to conduct a detailed cost analysis, which lists the cost of the variously sized equipment components and process approaches.

A

APPENDIX A. SUMMARY OF SITE VISITS

La Spezia Eugenio Montale Generating Station

The power plant in La Spezia, officially named *Eugenio Montale Generating Station* (named after an Italian poet), consists of:

- 2 x 300 MW Gas Combustion Turbine Units
- 1 x 600 MW Coal fired Unit

The FGD system, installed in the 1990s, is a "Double Loop" technology, which is licensed by Babcock (formerly Noell-KRC) and was manufactured by Termokimik. The scrubber consists of two stacked vessels, with the bottom one serving as the quencher. It is a double contact unit where the lime stone slurry contacts the gas as it is sprayed upward and then provides more contact when it falls back down.

One interesting thing to note is that the lime stone for the FGD is supplied in the form of marble dust, which is delivered from the nearby marble quarry and manufacturing operations. (La Spezia is one of Italy's marble mining and stone working centers.)

Compared to the other ENEL FGD wastewater treatment systems, the La Spezia plant is relatively small.

A flow diagram of the La Spezia FGD wastewater treatment system is presented in Figure 4-3. The following is a listing of information that is supplementary to that given in Section 4.

La Spezia power station burns low-sulfur imported coal (<1%S) from world-wide markets.

PRETREATMENT

- It is sized for 30 m^3/h (133 gpm) with a feed TSS of ~ 1.5%.
- System consist of 3 reaction tanks in series:
    - 1st tank: Lime for ppt
    - 2nd tank: Lime for pH control plus Na_2S for settling and metals ppt
    - 3rd tank: Designed to provide additional holdup time. Ferric chloride is dosed to the tank outlet.

- Due to the relatively high pH of ~ 5 from the FGD, metals are not dissolved to a high degree. The metal concentration is lower than anticipated so that sodium sulfide treatment is used on an "as needed" basis.
- The effluent from the last reaction tank goes to a clarifier, where anionic polymer is added.
- The sludge is fed to a conventional filter press for disposal as a "special" i.e. industrial waste.
- 15 m^3/h (66 gpm) of clarate plus other water are returned to the FGD feed holding tank.
- The remaining 15 m^3/h (66 gpm) is passed on to the softener for further pretreatment.
- Soda ash is added to reaction clarifier/softener.
- Soda ash is made up using softened water or alternately using industrial water from the general plant wastewater treatment system.
- Relatively high levels of hardness reduction are achieved in the softener.
- The original design called for the softener sludge to go to disposal, but it is now use as supplement to the lime stone makeup slurry to FGD.
- Some primary clarifier effluent water bypasses the softener and goes directly to the brine concentrator feed tank. The amount of by-pass is adjusted to ensure the brine concentrator feed blend has the required chemistry required for the seed slurry process.
- The target Ca level for the BC feed ranges from 500 to 1000 mg/l.

BRINE CONCENTRATOR (BC)

- The brine concentrator operates with a "seed slurry" process, which includes "seed recycling".
- The significant operating parameters are:
    - CF = 6 – 10
    - TSS ~ 6%
    - TDS ~ 5%
    - TS < 15%
- The feed pH is at first lowered using HCl (typically used in Europe instead of H_2SO_4) for deaeration and then increased to slightly above neutral with caustic for corrosion protection.
- The BC uses a single stage, mechanical compressor (manufactured by ABB).
- Two small flat plate heat exchangers are used in the front end of the BC:
    - One for the BC feed/BC distillate heat transfer
    - One for the BC feed/crystallizer distillate heat transfer
- The distribution system consists of two stacked perforated sieve plates with off-set holes.
- The BC tube bundle is typically cleaned once per year. Other system components have been cleaned 3 to 4 times per year. This cleaning consists of shutdown and the mechanical removal of solids buildup.

- BC and crystallizer distillates are used for general plant industrial water use. The distillates contain some ammonia and boron.
- BC blowdown goes to the blow down tank, which is the feed to the crystallizer.
- The BC feed chemistry is analyzed 1 to 2 times per day.

CRYSTALLIZER

- The driving energy for the crystallizer is provided by plant steam.
- The thermal compressor usage is optional and based on cost optimization criteria.
- When steam is available, it is used to improve the energy efficiency of the crystallizer.
- The plant steam pressure varies between 5 to 9 bar.
- The SeaCure tubes in the condenser were replaced with titanium since some corrosion was experienced at the steam inlet section.
- The condenser is seawater cooled.
- Caustic is added as needed to raise the crystallizer operating pH to 8.0 - 8.5 for corrosion protection.
- The crystallizer is washed with dilute distillate about once month to remove solids buildup.
- The distillate is routed to the brine concentrator heat exchanger for heat recovery and then discharged to general plant industrial water use.
- The FGD blowdown shows some seasonal variations, which affect the relative $NaCl/Na_2SO_4$ salt ratio precipitated in the crystallizer.
-

BELT FILTER - DEWATERING

- The crystallizer slurry goes to two Oberlin belt filters for dewatering. The filters are in a 2 x 100% configuration. They are operated on an alternating basis: one in service the other in standby.
- The dewatering pressure belt filter operation is affected by the feed chemistry.
- The filter cloth has a higher tendency to plug when dewatering sodium sulfate rich slurries. This is due to the nature of this salt, which takes up water as it cools.
- The Oberlin system was designed for 0.5 t/h, but is typically operated at ½ that capacity.
- Brindisi was designed with 2 t/h salt generation, but is typically operated at ½ that value.
- Salt is collected in 1 m3 (35ft3) bags and shipped off site.

PLANT OPERATIONS

- The thermal treatment portion of the ZLD was added to the original treat-and-discharge system in 2008/09.
- The FGD is operated by the power block operations:
    - The ZLD has its own, dedicated staff
    - The staff consist of a total 1 supervisor and 5 operators
    - A single operator is in charge of control, field and sampling
    - Operators are responsible for the chemical analyses
    - There is a separate staff for maintenance
- Sampling for the ZLD is done 1 x per shift
- Computer trending of the treatment system includes calculation of the on-going U-values in the brine concentrator.

Brindisi Generating Station

GENERAL

- FGDs are sized for 1% sulfur in the coal, but the presently used coal has lower a sulfur content.
- Each of the four power blocks has a FGD with a dual train of prescrubber and absorber configuration.
- The flue gas stream is first split 50/50 and then fed to each of the prescrubber – absorber trains.
- The FGD system was commissioned in the 1990's (i.e. it is about three years older than the La Spezia FGD).
- The Brindisi FGD system consists of:
    - Unit 1 & 2: GEA Bischoff units consisting of 2 separate vessels for each block
    - Unit 3 & 4: Mitsubishi units consisting of 2 stacked vessels for each block.
- Makeup to the absorber is 40% fresh and 60% recycled water.
- The blowdown from the prescrubbers accounts for most of the FGD wastewater.
- The first step of the wastewater treatment system consists of two parallel lines each of a capacity of a 250 m^3/h (1,100 gpm).
    - The wastewater goes to two 600 m3 (160,000 gallon), parallel, rectangular settling basins equipped with weir overflows.
    - No chemicals are added to the settling basins.
    - The two settling basins are used alternately, i.e. one on-line while the other is dredged.
    - The sediments from the basins are pumped to a belt filter system for dewatering.
    - The clarate goes to a concrete storage tank for chemical pre-treatment. Pre-treated water is reused in the FGD or feeds the softening stage.

CLARIFIERS/SOFTENERS

- There are two wastewater treatment systems in series.
- The dewatered sludges form these operations go to an industrial waste landfill.
- System 1 consists of two stages:
    - Each system is designed to process 250 m^3/h (1,100 gpm)
    - 1st Stage: Lime is added to the reaction tank to precipitate $Mg(OH)_2$
    - 2nd Stage: Lime and $FeCl_3$ are added to precipitate metals

    - The 2^{nd} Stage effluent goes to a 8,000 m3 (2.1 Mgal) storage tank, which feeds the prescrubbers.

- System 2 consists of only one stage:
    - The system is designed to process 250 m^3/h (1,100 gpm)
    - Some of the treated water is returned to the FGD as makeup and some is subjected to a pre-softening stage
    - The effluent from the Lamella clarifier goes to a clear well for subsequent pumping to either the ZLD or return to the prescrubbers as needed.
- Softening system:
    - The total softener design feed rate is 140 m^3/h (616 gpm)
    - The feed is split onto two parallel trains designed as 2 x 100%
    - The operating is pH ~ 10.
    - Calcium level in the effluent is about 50 ppm (as ion)
    - Calcium carbonate sludge goes to FGD to supplement the limestone makeup
    - The clarifier effluent is directed to a holding tank
    - Up to 70 m^3/h (308 gpm) of the softened water goes to the ZLD with the remainder used as FGD makeup water

BRINE CONCENTRATOR and CRYSTALLIZER

- The ZLD system was initially started in 2008.
- The system consists of 2 x 50% BCs, each unit is designed for 35 m^3/h (154 gpm).
- Due to the unique makeup water chemistry, glauberite ($Na_2Ca(SO_4)$) is easily formed at higher concentrations.
- Glauberite is a large crystal, which interferes with the seed slurry process.
- The concentration factor in the BC is, therefore, limited to ensure operation below the glauberite precipitation point.
- The concentration factor is held to about 9-10.
- The BC’s vapor compressor is in the form of a two stage blower.
- The BC’s demisters are located in the vapor duct outside of the vapor body.
- The total solids content of the concentrate is about 18 – 20%.
- Due to corrosion concerns, the operating pH is maintained at about 7.5 by caustic addition after the deaerator.
- Also due to corrosion concerns, the crystallizer is operated in a pH range of about 8.5 – 9.0.
- The combined distillate from the BC and crystallizer has a TDS < 100 mg/l.

- Some of the distillate is used for demister wash, startup steam and steam temperature reduction.
- Hydro blasting and EDTA cleaning of the BC is done at least once per year.
- The crystallizer is typically operated at 34% to 40% total solids, which is composed of mainly NaCl.
- The crystallizer has two thermal compressors:
    - One is designed for use at 50% operation
    - The other is designed for use at 100% operation
- The crystallizer condenser has-an additional condensate hot-well for ammonia rich distillate blow-down. This hot-well is located at the cold condenser end (the cooling water inlet side).
- One of the crystallizer design requirements was that • 40% of the boron in the feed would be carried over to the distillate. This condition was met during the performance test.

PLANT OPERATIONS

- Sampling:
    - TDS/TSS, pH and Ca are sampled 2 x per shift
    - Chloride is sampled 1 x per day
- Staffing:
    - There are 3 shifts per day
    - Two operators for each shift
    - One operator is stationed in the control room, the other in the field
    - Operators are responsible for the routine sample analysis, which is conducted once per day
- The performance parameters are trended on the HMI, including the U-values.

CO$_2$ CAPTURE

- The Brindisi plant has a 15M-Euro CO$_2$ capture pilot plant, which uses MEA as the absorbent.

Monfalcone Generating Station

GENERAL

- Plant Information:
    - The 2 x 160 MW coal fired power blocks were built in 1965.
    - The 2 X 320 MW oil fired power blocks were built in 1982.
    - Total output plant output is 1,000 MW.
    - Once through seawater cooling is used.
- Fuel:
    - See description in Section 4.
- FGD information:
    - FGD consists of only an absorber and uses Mitsubishi technology
    - FGD efficiency is 95 to 96%
    - FGD makeup water is industrial water, mainly city water
    - Gypsum solids go to a belt filter for dewatering
    - Gypsum is relatively high quality. It is sold for construction material use
    - Filtrate goes to a storage tank for 8 hour retention
    - It is then fed to the ZLD system
- Plant water management:
    - The industrial water is generated by use of RO desalination
    - General plant wastewater is treated separately from the FGD and is discharged to the sea

SOFTENER SYSTEM

- The softener system consists of 2 reaction tanks and one reaction clarifier.
    - 1st vessel: Lime addition for a pH of about 11
    - 2nd vessel: Designed for soda ash addition, but no chemicals are added now. This tank is used for additional retention time
    - Soda ash, ferric chloride and polymer are added directly to the reaction clarifier
    - The clarifier sludge goes to a sludge tank and then to a filter press
    - The clarate is stored in a holding tank and is then fed to the BC
    - The calcium level in the softener effluent is about 70 mg/l
- The softener system produces about 700 t/yr of $CaCO_3$.

  - Due to high metals, the filter cake is disposed of as an industrial waste and not recycled

BRINE CONCENTRATOR

- The BC is designed for about 10 m^3/h (44 gpm), but typically is operated at only 80% of this capacity.
- It is operated at a slightly above atmospheric pressure.
- The BC has a twin HX setup, i.e. one is in standby (for cleaning).
- Heat exchangers are usually cleaned by disassembly.
- BC feed is acidified for deaeration. No caustic is added to the BC so that the sump pH is about neutral.
- The BC has an internal recirc pipe design, where the discharge from the recirc pump enters the sump and then goes up the center of the condenser to the flood box. This is done to reduce heat losses in the recirc line.
- BC distillate normally has a conductivity of < 40 µS/cm.

CRYSTALLIZER

- The crystallizer is operated at a moderate vacuum condition.
- The sump temperature is < 100°C, commensurate with the vapor body operating pressure and boiling point rise.
- The total solids are controlled at about 45%.
- Crystallizer conductivity is typically < 20 µS/cm, but can have high excursions if there is carryover due to foaming.
- The crystallizer uses plant steam for heating and has an air cooled condenser (AAC)
- The ACC has sufficient capacity without water spray for cooling even during the summer months.
- The HPD brine concentrator and crystallizer were fabricated in northern Spain.

CRYSTALLIZER SLURRY DEWATERING

- The crystallizer TS level is monitored by the recirculation pump energy draw. When the maximum pump energy draw is encountered, the slurry is dewatered.
- The salts are harvested and dewatered using a belt pressure filter.
- The filtrate is collected in a batch tank and then returned to the crystallizer
- Salt is collected for disposal in 250 kg bags.

- The residual salt is transported to Germany for salt mine restitution.
- The total salt production about 300 - 400 t/yr.

GENERAL OPERATION

- The control room is located a little distance from the ZLD system.
- FGD blowdown water is analyzed for Ca, Mg and Cl.
- Calcium from softener is tested 1 x / shift.
- The BC feed composition and flow are found to be relatively stable.
- The BC is operated only on level control, not on a sp.g. or TDS basis.
- The maximum chloride level in the FGD blowdown has been 30,000 mg/l but is typical in the 10,000 – 20,000 mg/l range.

STAFFING AND MAINTENANCE

- There are two operators per shift for the total plant water treatment system, one in the control room and one in the field.
- The two operators are responsible for :
    - ZLD
    - Wastewater treatment
    - Boiler
    - Seawater RO for makeup water
- The BC has not required cleaning in the 1 ½ years of operation.
- There has been no system shut-down for maintenance during this time.

B

APPENDIX B. GLOSSARY

Term	Description
ACC	Air Cooled Condenser
BC	Brine Concentrator
BPR	Boiling Point Rise
CF	Concentration Factor (cooling tower or brine concentrator)
EPRI	Electric Power Research Institute
ENEL	Ente Nationale Energia Electrica
FGD	Flue Gas Desulfurization; treatment process and/or equipment
HX	Heat exchanger
MOC	Materials of construction
MVR	Mechanical Vapor Compression
NPDES	National Pollutant Discharge Elimination System, the permit which regulates discharges to a surface water body.
PCT	Patent Cooperation Treaty
RO	Reverse Osmosis
SpA	"Società per Azioni" (term for a joint-stock company in Italy)
TDS	Total Dissolved Solids; the amount of organic and inorganic substances dissolved in solution expressed as mg/l, ppm or percent
TSS	Total Suspended Solids; the amount of organic and inorganic substances suspended in water, typically expressed as mg/l, ppm or percent

TS	Total Solids; the amount of dissolved and suspended solids contained in the liquid body expressed as mg/l, ppm or percent
TVC	Thermal Vapor Compression
U-Value	Heat Transfer Coefficient
VTE	Vertical Tube Evaporator
WW	Wastewater
ZLD	Zero Liquid Discharge

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