REPORT

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Large Power Plant
Flue Gas Desulphurisation
Brief overview of the experience of Tech-wise
and
Consulting Services provided by Tech-wise

1. Tech-wise's Background and Experience

Tech-wise is a consulting engineering company with approx. 200 employees. We are a subsidiary of the Elsam utility group, which operates about 5000 MW_e of power plants of which the majority are equipped with Flue Gas Desulphurisation (FGD) plants. We have engineered power plants from 2 to 600 MW_e, fired mainly with coal, oil and natural gas and, and as required in accordance with the fuel compositions, flue gas cleaning has been integrated in the completed plants. During the last decade four new central power plants with a total capacity of approx. 1600MW_e have been added to our portfolio of projects. All the power plants are with the newest technology of flue gas cleaning at the time of construction, and Tech-wise has followed the stringent rules of Danish environmental rules and regulations.

Tech-wise has a leading role in the development of new technologies, in particular with symbiosis of Spray Dry Absorbtion Product (SDAP) in a wet gypsum producing plants. This process is a new patent pending development by Tech-wise, which eliminate the need to use landfill disposal of the SDAP, increase and improve the quantity and quality of the gypsum, and improve the desulphurisation rate in both processes. The symbiosis has apart from the positive impact on the environmental issues, also a considerable positive impact on operational savings.

Apart from the new central plants a number of rehabilitation, retrofit and optimisation projects have been completed on the existing older power plants, municipal power plants, and international projects for other clients than Elsam.

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1.1 Legal Requirements

The emission of sulphur dioxide (and NO_x) in Denmark is regulated according to a specific law. The requirements for reduction of the SO_2-emissions applicable to the power utilities are based on the 'bubble principle' comprising all power plants. I.e. the sum of emissions from all plants has to be reduced according to the law permitting to install high standard desulphurisation processes in new power units and postponing installations on aged units. This is different from most of other national regulations. The first regulations were laid down in 1984, and the latest revision to date took place in March 1989.

1.2 Utility Policy

Related to the development with still more rigorous regulations it is the policy of the Danish power utilities always to be well ahead of future requirements. This means that already long before the first legal requirements were laid down, the technology and economy connected to the different technical options to fulfil the requirements concerning emission restrictions, were well known in our organisation.

1.3 Feasibility Studies

In order to assure this goal, several feasibility studies have been carried out by Tech-wise A/S.

1.4 Design Experience

The initial situation characterised by research has now strongly been changed into a situation, where real practical engineering in the field of air pollution combat technology is the dominating activity. First of all experience concerning design and construction of commercial of FGD-installations, 10 units with 3 different technologies as mentioned in the following with a total capacity of about 2200 MW_e in the Elsam area and about 2000 MW_e in the ELKRAFT area.

1.5 Project Group Manning

For each specific project a project group manned with qualified engineers and technicians from our technical staff under the leadership of a project manager is established. In some cases a restricted part of the engineering activities are executed by external consultants, depending on location and client requirements, but the basic process, electrical and mechanical engineering services are always completed with our own resources.

1.6 Project Execution

The project group is - under supervision of a steering group - responsible for the execution of all the project activities. The first task is typically to execute a number of prefeasibility studies, preparation of authority applications, followed by tender specifications and evaluations, contracting negotiation and procurement, quality assurance activities and coordination. Finally supervision during construction, testing and final delivery tests are performed.

1.7 Processes Chosen

In the following a brief description is given of the different processes for desulphurisation already chosen by the Danish utilities.

1.8 R&D Activities

Besides full scale projects, Tech-wise A/S masters a broad palette of R&D-activities connected to air pollution combat technologies. These R&D-activities include many features, e.g. support of the development of new/alternative FGD-technology through the installation of pilot plants etc., and the utilisation of by-products from FGD-processes.

In the following the technical features of our most important and successful R&D-activity, the SNOX process, is described.

1.9 Fuel Options

All our boiler installations equipped with FGD-plants are dual-fired, e.g. 100% coal and 100% fuel oil as standard. All the boilers have electrostatic precipitators upstream from the FGD-system. The coal quality is bituminous hard coal with max. 2.5% sulphur originating from all over the world.

2. Selected FGD Technology in Denmark

Introduction

The selected FGD-technologies in Denmark comprise first of all the well-established and well-known lime/limestone processes. A total of 9 installations from different suppliers are in service or under construction.

Then - as a result of a successfully fulfilled R&D-project - the SNOX-process has been chosen for a 300 MW_e station in the Elsam-area.

In attachment A, the tabulated data for the FGD-installations in the Elsam area can be found.

2.1 The Wet Scrubber and Spray Dryer Process

2.1.1 General Introduction

Selection of Process

During the preproject for the first FGD-installation in Denmark in early 1985 it was decided that only two processes had at the time been developed to a stage which made it likely that the power station could build and put the systems into operation with reasonable confidence in their performance. These processes were:

- The wet scrubber process.
- The spray dryer process.

Suppliers of both processes could refer to several operating plants with operating experience. Especially for the wet scrubber process a large number of different suppliers had shown an interest in the Danish market and had started cooperating with various Danish suppliers in the energy engineering field.

The first specific power station under consideration was a new 2 x 350 MW_e twin installation prepared for FGD-retrofit.

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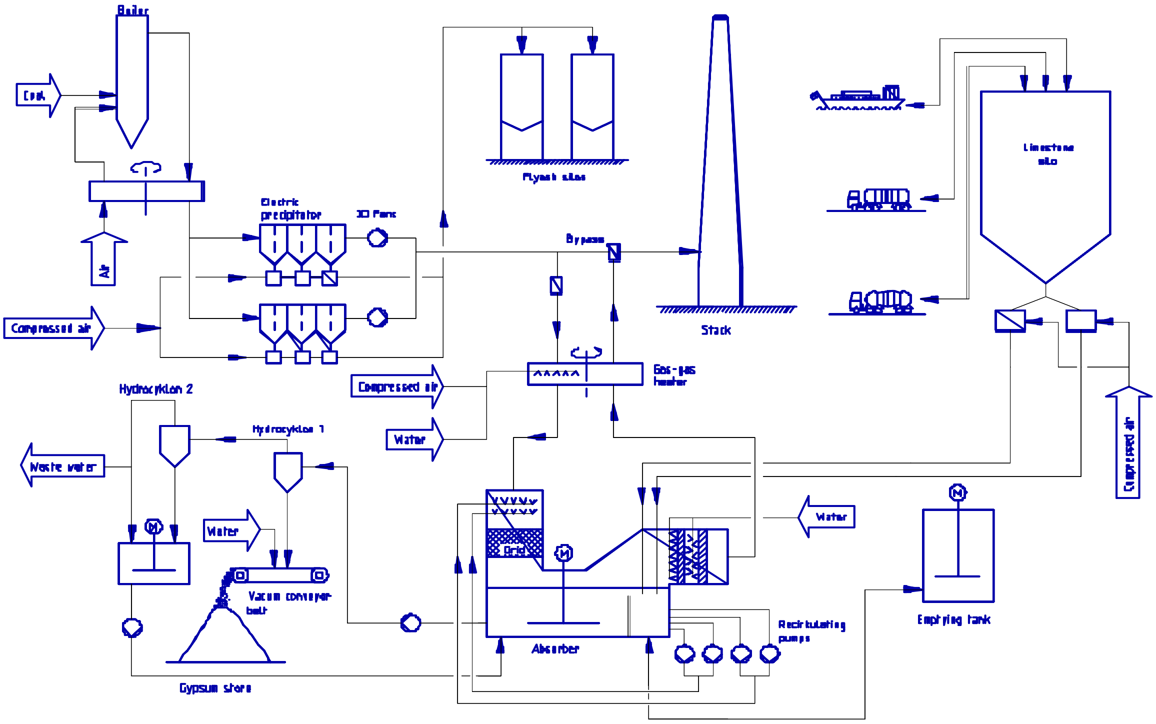
2.1.2 The Wet Scrubber Process

Specification

The wet scrubber is specified as a process using limestone as absorbent and with high-purity gypsum as by-product. Figure 2.1-1 shows a flow diagram of the wet gypsum recovery process.



WET SYSTEM

Figure 2.1-1. The wet gypsum recovery process.

Process Chemistry

The SO_2-absorbtion takes place in the absorber tower in which the flue gas is washed with circulating absorber liquid by means of circulation pumps and spray nozzles.

The oxidation of calcium sulphide to calcium sulphate takes place in the absorber sump.

Gypsum Handling

The gypsum handling system consists of a hydro cyclone thickening the gypsum slurry, followed by a vacuum conveyor belt filter for the final gypsum flushing and dewatering.

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Waste Water
Due to the chloride content in the flue gas it is necessary to bleed from the slurry a certain amount of the process water as waste water. Environmental concerns in Denmark cause the requirements to purification of the water to be very high, and the waste water must therefore pass an elaborate water treatment system before being discharged.

2.1.3 The Spray Dry Absorbtion Process

Specification
The spray dry absorbtion process is as a system using lime as absorbent and producing a stable by-product, disposable in an outdoor disposal site. Figure 2.1-2 shows the flow diagram of the process.

Process System
The heart of the system is the absorber, in which the absorber liquid, a mixture of slaked lime and diluting water, is being atomised by a rotating atomiser. The droplets evaporate in the hot flue gas before reaching the absorber walls, and during the evaporation the droplets absorb SO_2, which together with the lime forms a mixture of calcium sulphide and calcium sulphate that falls down to the bottom of the absorber as dust. Part of the dust follows the gas stream to the bag filter. The flue gas is cooled during the evaporation from 125°C to 70°C. The bag filter cleans the flue gas of remaining dust and acts as an additional zone of SO_2-absorbtion. It is therefore not necessary to protect the steel duct in the stack against corrosion from H_2SO_4, although other but less severe causes for corrosion may require other means of protection. The by-product from absorber and bag filter is collected in the intermediate silo, from where it is routed to either the recycle silo or to the by-product silo.

By-product
Underneath the by-product silo a mixing arrangement is located for mixing the by-product with fly ash and water before discharge into trucks.

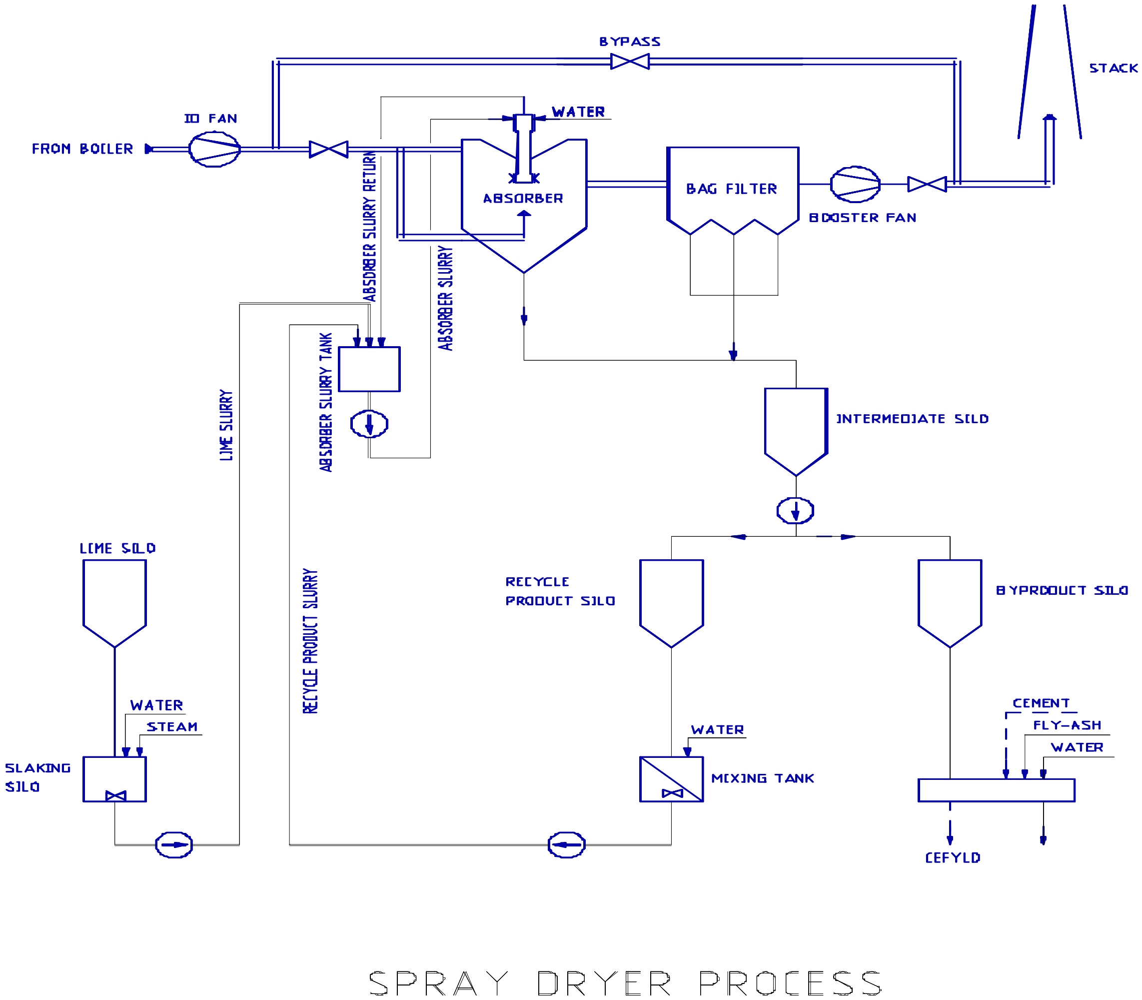

Figure 2.1-2. The spray dry absorbtion process.

1.2 The SNOX Process

1.2.1 The SNOX Process Pilot Plant

The principles of this process for combined removal of SO_2 and NO_x have been developed by a Danish company, Haldor Topsøe A/S. A 10,000 Nm3/hr demonstration unit producing 95% sulphuric acid was operated at Skærbæk Power Plant in the period 1987 - 1992.

The process diagram for the demonstration plant is shown on figure 2.2-1. As the test arrangement in principle includes all the process stages and installations required in a full-scale plant, the specific process diagram describes the process generally.

Basic Process Description

The flue gas is cooled in the SNOX-plant air preheater by means of air from the WSA-condenser (WSA = Wet Sulphuric Acid), so that the flue gas temperature ahead of the bag filter will typically be 190-220°C. The dust content of the flue gas is reduced to less than 5 mg/Nm^3 in the bag filter and boosted by the flue gas fan.

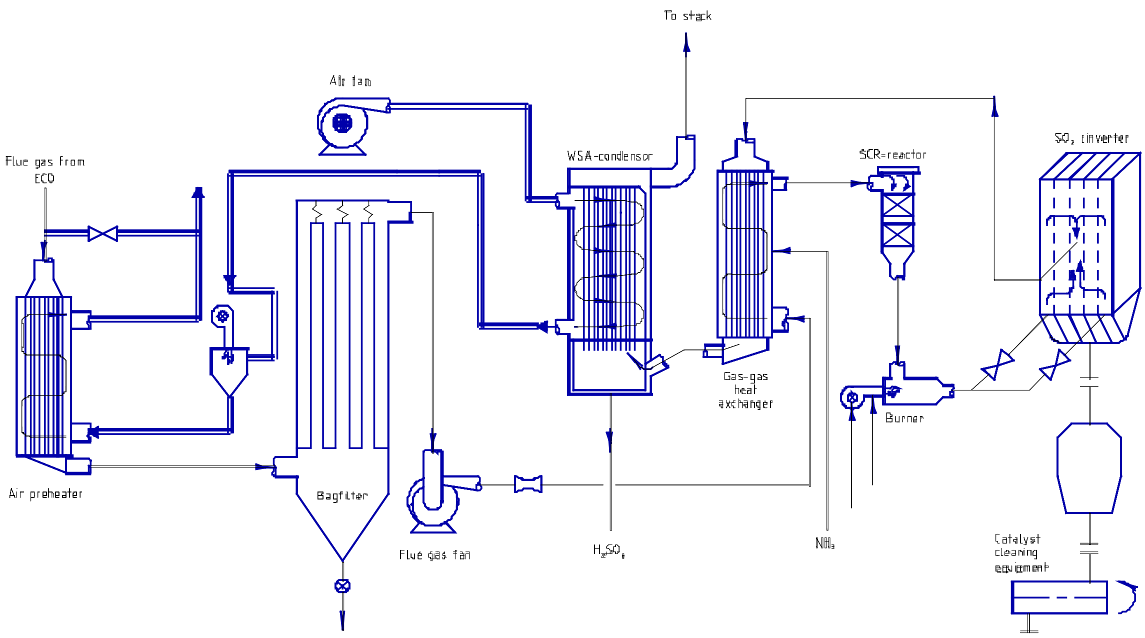

Figure 2.2-1. The SNOX-process.

The flue gas is reheated to approximately 380°C with the flue gas from the SO_2-converter in the heat exchanger, and in the SCR converter the NO_x is removed by means of the SCR-catalyst. The flue gas is further reheated to 400-420°C by burning fuel oil in the combustion chamber. In the full-scale plant, which will be addressed later, it has been chosen to reheat by means of steam from the boiler.

In the SO_2 converter a catalytic oxidation convert 95-97% of the SO_2 to SO_3. After the SO_2 converter the gas is cooled to approximately 250°C, and SO_3 is at the same time hydrated to H_2SO_4 vapour. The flue gas is cooled inside the tubes of the WSA-condenser to approximately 100°C, and the sulphuric acid condenses in a concentration of 93 to 95%. The WSA-condenser is cooled with air from the primary air fan, and the air is reused in the air preheater.

1.1.2 Full-scale SNOX Plant

A full-scale installation after the SNOX-concept with a capacity of 300 MW_e were commissioned in late 1991 and has been in service since then.

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Shortly after commissioning several problems developed, mainly related to uncontrollable sulphuric acid mist, fall out of sulphuric acid droplets, and serious corrosion in particular in the area of the sulphuric acid condensation.

In an optimisation project with a duration over several years, Tech-wise and the operating staff developed improvements, alterations and modifications to the plants which made the operation of the plant reliable.

A new invention cured the important problem of remnant sulphuric acid vapour traces, causing fall out of sulphuric acid droplets. After completion the plant operated with a very high degree of operationally and reliability. The development of droplet of sulphuric acid with the consequential fallout in the vicinity of the stack was stopped completely.

1.1.3 International Experience

Due to the experiences gained with the full scale SNOX plant, Tech-wise assisted as the owner's engineer on a new SNOX plant at a refinery power plant in Italy. The plant was commissioned in October 1999, and has been operating with high availability and reliability from the first day of operation.

3. Optional FGD-Technologies/SO_2-Reduction by Means of Sorbent Injection

Introduction
SO_2-control by sorbent injection is applicable on power plant units, where low investment costs are important and where only moderate reduction is required. The costs of establishing a sorbent injection system are low compared to other desulphurisation systems. The operating costs are mainly dependent on the sorbent price.

Demonstration
From experience obtained during the participation in an international cooperative demonstration project concerning SO_2-reduction in full scale pulverised coal-fired boilers by the use of dry sorbent injections Tech-wise A/S propose that this desulphurisation method could be considered as a possible solution for reducing the SO_2-emission from a lignite-fired thermal power plant.

Method
The method is based on injection of a dry, pulverised sorbent into the upper furnace of the boiler by means of booster air. The sorbent, typically calcium carbonate, $CaCO_3$ or calcium hydroxide, $Ca(OH)_2$, will in the temperature range of 870-1150°C

react with SO_2-molecules in the combustion gases. The sulphur reduction process is dependent on the origin of sorbent and the sorbent particle size. The mean particle diameter of the sorbent used will normally be 5 micron or less to ensure a fast SO_2-capture.

Results
An optimised sorbent injection system will typically result in an SO_2-reduction of about 40% with calcium carbonate or 50% with calcium hydrate as sorbent and with a sorbent ratio similar to a calcium/sulphur molar ratio of 2. The reduction products are calcium, sulphate, unreacted calcium oxide and ash. These dry by-products are precipitated in the filter unit together with the fly ash and can safely be deposited.

Other Projects
Other demonstration projects have indicated that an additional SO_2-reduction is possible by humidification of the outlet gas stream from the boiler. This process takes advantage of the unreacted calcium oxide which, together with the humidification, will reduce SO_2 from the cold gas stream. The total SO_2-reduction from furnace and humidified gas should be 80% or more.

Before finally deciding on installing an sorbent injection system it is recommended to evaluate the boiler and available sorbents to determine whether sorbent injection will be feasible or not.

4. Utilisation of By-products

4.1 SDAP Symbiosis in a Wet Gypsum Producing FGD Plant

Due to the fact that there are three 350-400 MW_e FGD-units in operation with the spray dry absorbtion technique in Denmark, the need for a R&D-program concerning the utilisation of the SDAP by-product was obvious. The R&D-program has been running over several years with the purpose to find solutions to reuse the SDAP in other processes.

The comprehensive R&D-program comprise activities such as:

- research laboratory work
- utilisation trials on a pilot scale
- market research
- full scale trial runs
- additive research
- final commercialisation and patenting

Today one power plant with wet gypsum producing FGD is operating with SDAP as absorbent from another Elsam power plant. Planning has started to upgrade another

SDA-plant for utilisation of the SDAP in another wet FGD plant within the Elsam area.

4.2 Utilisation of Gypsum from the Wet FGD Plants

Today basically all the produced gypsum is sold for the production factories of gypsum boards. All gypsum is produced according to the stringent specifications of quality and limits of impurities.

In connection with commissioning of the patent pending SDAP symbiosis the production and quality of gypsum has increased considerably.

4.3 By-product from Waste Water Treatment Plant

The sludge by-product from the waste water treatment plant mainly consist of gypsum, and other impurities. Some planning has been initiated to improve on the gypsum separation in order to reduce the amount of sludge for landfill disposal, and to reduce the water effluent amount and level of contamination.

5. Emission Measurements

Experience

Due to experience with many unreliable measurements of the installed SO_2 and NO_x gas analysers, e.g. unstable function of the analysers and the substantial costs of overhaul, it was decided to complete a coordinated investigation concerning flue gas analysers.

Test Programme

Experience with already installed equipment were summarised and analysed. New, untested equipment was installed in a coordinated manner, and the operating experiences reported, reviewed and analysed. These efforts have now resulted in general recommendations and requirements for future installations.

Instruments for measuring other emission components, e.g. NH_3 have also been developed, and on-site tests have been completed.

6. Analyses of Disposal Sites

Strategic Considerations

During the last few years the tax burden on landfill disposal in Denmark has been introduced, with considerable impact on the overall operational costs. This means that

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where alternative measures still exist for reutilisation of by-products are possible, the alternatives are investigated in lieu of the landfill disposal.

This also mean that where ever possible and feasible the plant process is optimised in order to reduce any impurities, which cannot be tolerated in the reusable by-product.

Today landfill disposal is limited to waste products which cannot be reutilised in another commercial process.

Areas
The environmental department of Tech-wise is working with all the environmental aspects related to power stations : air pollution, noise, waste water treatment, by-product disposal, etc.

As regards to the disposal of by-products, the environmental department has been engaged in numerous projects at Danish power stations.

Applications
The services provided to the projects have covered applications for environmental approvals for new disposal sites, onshore fillings and remedial investigations of pollution connected with existing by-product disposal sites. As a consequence of this, Tech-wise A/S today possesses comprehensive experience in the field of by-product management.

Old Disposal Sites
The tasks connected with the control of existing disposal sites consist of calculations and evaluations of ground water quality and flow. Additionally, the environmental department has carried out test drilling programs in old disposal sites and analysed the collected samples from the sites.

New Sites
However, the most comprehensive tasks performed have been the environmental investigations and the preparation of applications for new disposal sites.

An environmental application for a new site shall clarify in detail the risk of polluting both ground water and surface recipients.

Investigations
Typically, these investigations take place in two steps: Data collection and model calculations.

The data collected by the environmental department has included ground water investigations, i.e. drilling, pumping tests, etc. to obtain detailed information related to the actual disposal site.

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Based on the collected data the department has used model calculations to estimate the amount of percolate from disposal sites and the resulting dispersion of the percolate into the ground water or to the surface recipient. To this end, Tech-wise A/S has a number of computer models capable of simulating complex conditions and processes in both two and three dimensions.

7. FGD Installations in the Elsam Area

Plant	Size (MWe)	Commissioned year	Project description	Process/absorbent Type of by-product
Studstrupværket	350	1989	Retrofit	Dry/CaO SDAP
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Vendsysselværket	395	1991	Retrofit	SNOX 93% sulphuric acid
Fynsværket	385	1991	New plant	Dry/CaO SDAP
Vestkraft	370	1992	New plant	Wet/$CaCO^3$/SDAP Gypsum
Enstedværket	600	1996	Retrofit	Wet/$CaCO^3$/ Gypsum
Nordjyllandsværket	385	1998	New plant	Wet/$CaCO^3$/ Gypsum
Randers Kommunale Værker	50	1998	Retrofit	Wet/$CaCO^3$/ Gypsum

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