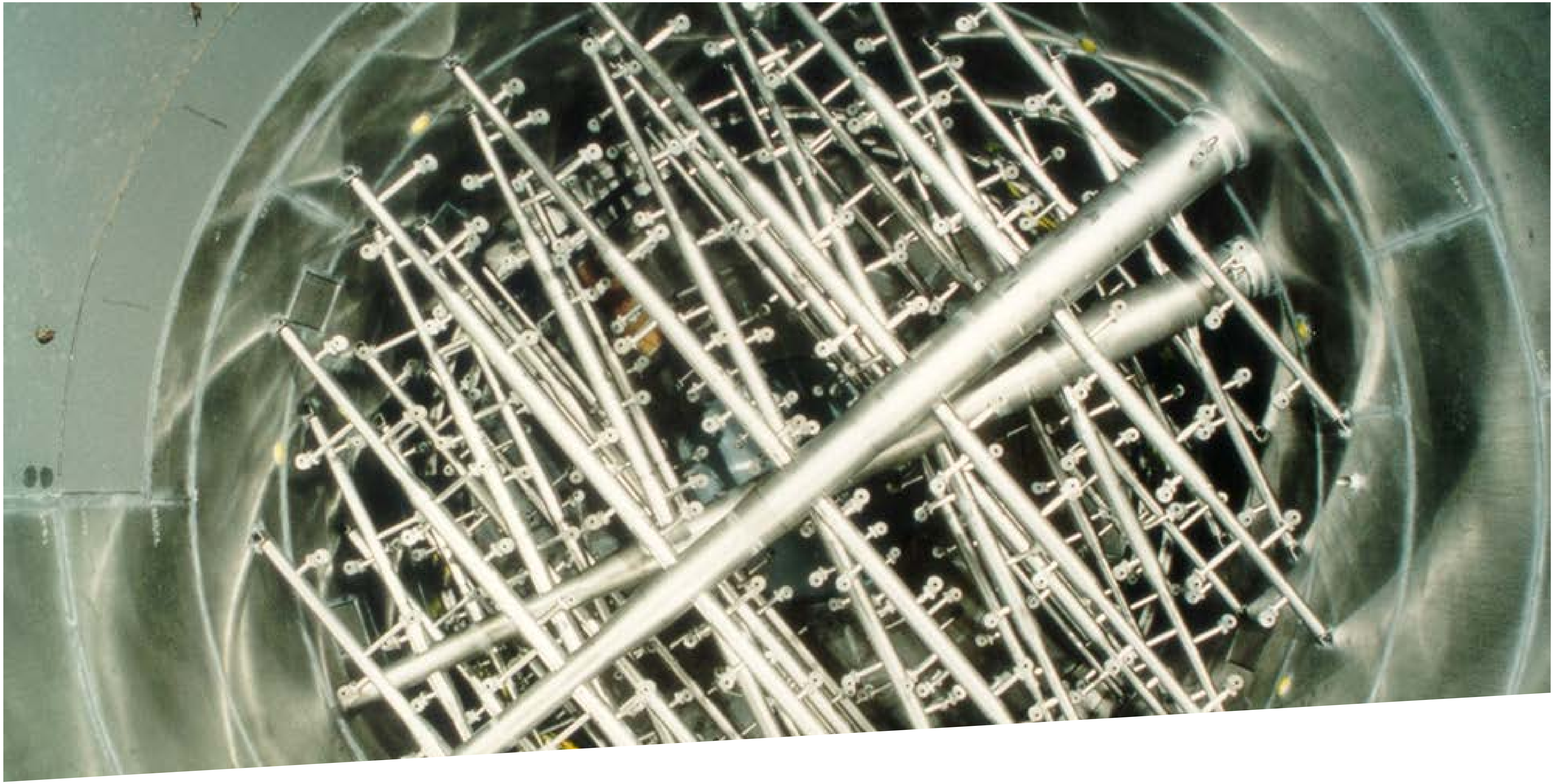


New Indian Environmental Norms: How advanced $DeSO_x$ solutions guarantee a sustainable power generation

Dr. Annette Ziemann-Noethe
Dipl.-Ing. Frank Oberheid
Dipl.-Ing. Christian Demling

Doosan Lentjes

Table of Contents

- New Indian Environmental Norms
- Solutions for Desulphurization Processes
- Requirements of the Indian Market
- Unique Features of the Different Technologies
  - Tailor-made solutions for the different processes:
    - Wet Lime / Limestone FGD
    - Circoclean® FGD / FGC
    - Seawater FGD

Case Study:
Gheco One, Thailand
Contract award: 2009
<u>Project:</u>
Delivery of key
SW FGD technology
Main fuels: Coal
Plant output: 1 x <u>700 MW$_e$</u>
Flue gas flow (wet):
2,158,000 Nm^3/h

Emission Norm India for Thermal Projects installed

	before 31st Dec.2003	between 1st Jan. 2004 – 31st Dec. 2016	from 1st Jan. 2017
SO_2	< 500 MW: 600 mg/Nm^3 > 500 MW: 200 mg/Nm^3	< 500 MW: 600 mg/Nm^3 > 500 MW: 200 mg/Nm^3	100 mg/Nm3
NOx	600 mg/Nm^3	300 mg/Nm3	100 mg/Nm3
PM[2)]	100 mg/Nm^3	50 mg/Nm3	30 mg/Nm3
Hg	> 500 MW 0.03 mg/Nm^3	0.03 mg/Nm^3	0.03 mg/Nm^3

Solutions for Desulphurization Processes:

Doosan Lentjes' APC Products –

- **Wet Lime / Limestone FGD**
  - 205 absorbers installed (110 absorbers in China) (DHI: additional 19 absorbers, 10.7 GW_e installed)
  - 71 GW_e total capacity
  - Maximum absorber size: 1,000 MW_e
- **Seawater FGD**
  - 14 absorbers installed (7 absorbers in cooperation with DHI)
  - 8 GW_e total capacity
  - Maximum absorber size: 700 MW_e
- **Circoclean® FGD / FGC**
  - 88 reactors installed (18 reactors in China, 26 in the USA, 2 in cooperation with DHI)
  - 13 GW_e total capacity
  - Maximum reactor size: 305 MW_e

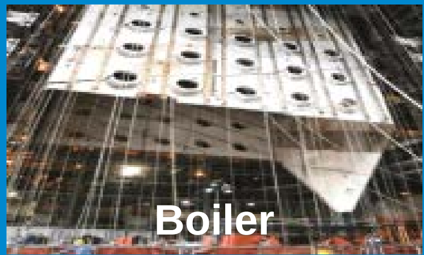
Case Study: Rugeley, United Kingdom

Contract award: 2006
Project: Flue gas desulphurisation plant retrofit
Main fuel: Coal
Plant output: 1 x 500 MW_e
Max. flue gas flow rate (wet): 2,103,000 Nm^3/h

Our Products and Services

Boiler Business Group

Lentjes Business Unit	Boiler Business Unit	Babcock Business Unit	Future Energy Business Unit



Doosan Lentjes is the global center of competence for CFB, WtE and APC in DHI and has its own R&D center for these technologies

Our Product Lines — CFB, WtE and APC

Tisova, $100MW_e$
Czech Republic

CFB
Circulating Fluidised Bed

- ***Top tier level CFB OEM technology***
- *References: 113 units (22 GW_{th}, max. 280 MW_e)*

REC Harlingen, NL
280,000 t/a; 1 line

WtE
Waste-to-Energy

- ***Top tier WtE OEM technology***
- *References: 77 units (9 mill t/a, max. 35 t/h)*
- *Chute-to-stack or full turnkey supply solutions*

Today's Focus

Oroszlany, Hungary
$240MW_e$, Wet Stack

APC
Air Pollution Control

- ***Various APC OEM technologies***
- *References:*
  - *Wet FGD: 205 units (71 GW_e, max. 1,000 MW_e)*
  - *Seawater FGD: 14 units (8 GW_e, max. 700 MW_e)*
  - *Circoclean® FGD / FGC: 88 units (13 GW_e, max. 305 MW_e)*
  - *SCR $DeNO_x$*
  - *Fabric Filters and ESP*

FGD Technology – Origin

2011 – Acquisition by Doosan	Doosan Lentjes GmbH
2007	AE&E Lentjes GmbH
2004	Lentjes GmbH
2004	Lurgi Lentjes AG
2002	Lurgi Energie und Entsorgung GmbH
1998	Lurgi Lentjes Bischoff GmbH
1996	Lentjes Bischoff GmbH
1984 – Acquisition by Lentjes	Gottfried Bischoff GmbH & Co. KG
1910 – Foundation	Gottfried Bischoff GmbH & Co. KG

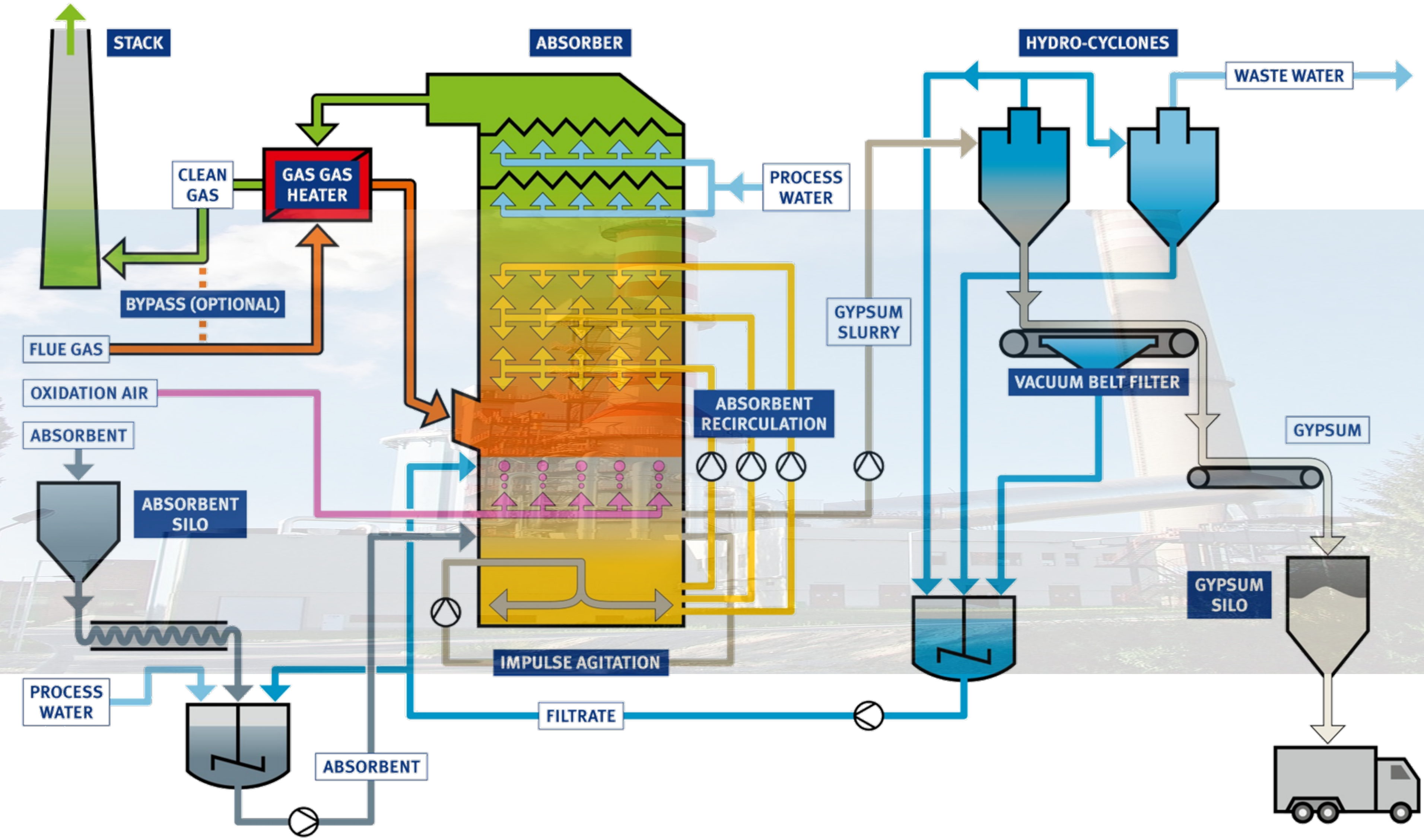
Dry FGD

Wet FGD

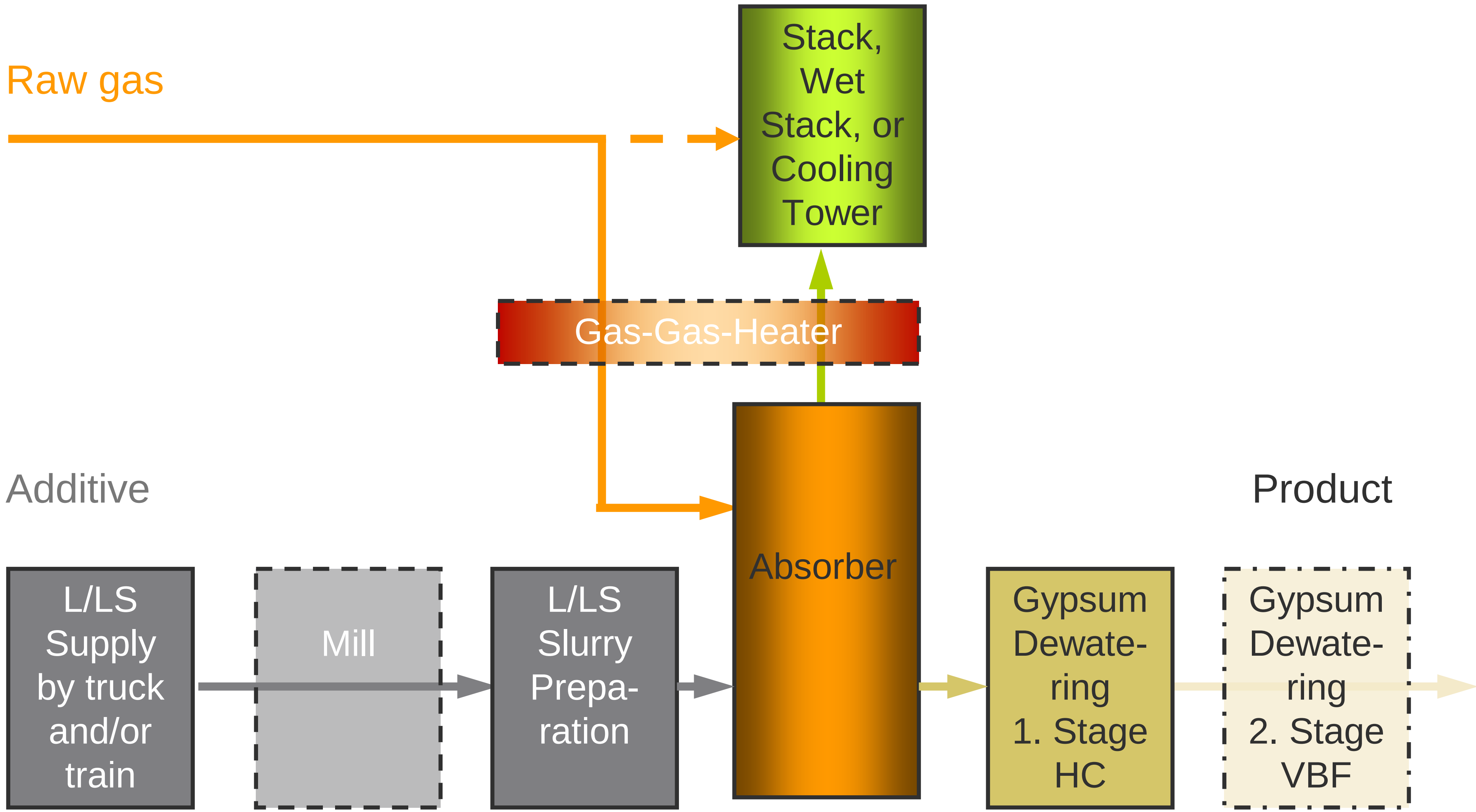
Comparison of FGD processes

Description	Unit	Circoclean® FGD/ FGC	Seawater FGD	Wet Limestone FGD
Suitable for high sulphur	mg/Nm³	Not economic	Only with additional additives or fresh seawater	yes
SO_2 removal efficiency	%	>99	>99	>99
SO_3 removal efficiency	%	>99	approx. 50%	approx. 50%
Absorbents	-	lime	seawater	limestone/lime
Investment cost	%	70-80	70-80	100
Power consumption	% in PP capacity	1-1.5	0.8-1.5	1-2
Maintenance	%	80	30	100
Absorbents costs	%	200	0	100
By- product	-	dry calcium sulfite/ calcium sulfate mixture	sulfate ions (dissolved in seawater)	gypsum
By- product costs	-	high disposal costs	none	saleable (low price)

Basic Flow Sheet



Modules


Raw gas
Stack, Wet Stack, or Cooling Tower
Gas-Gas-Heater
Additive
Product
Absorber
L/LS Supply by truck and/or train
Mill
L/LS Slurry Prepa-ration
Gypsum Dewate-ring 1. Stage HC
Gypsum Dewate-ring 2. Stage VBF

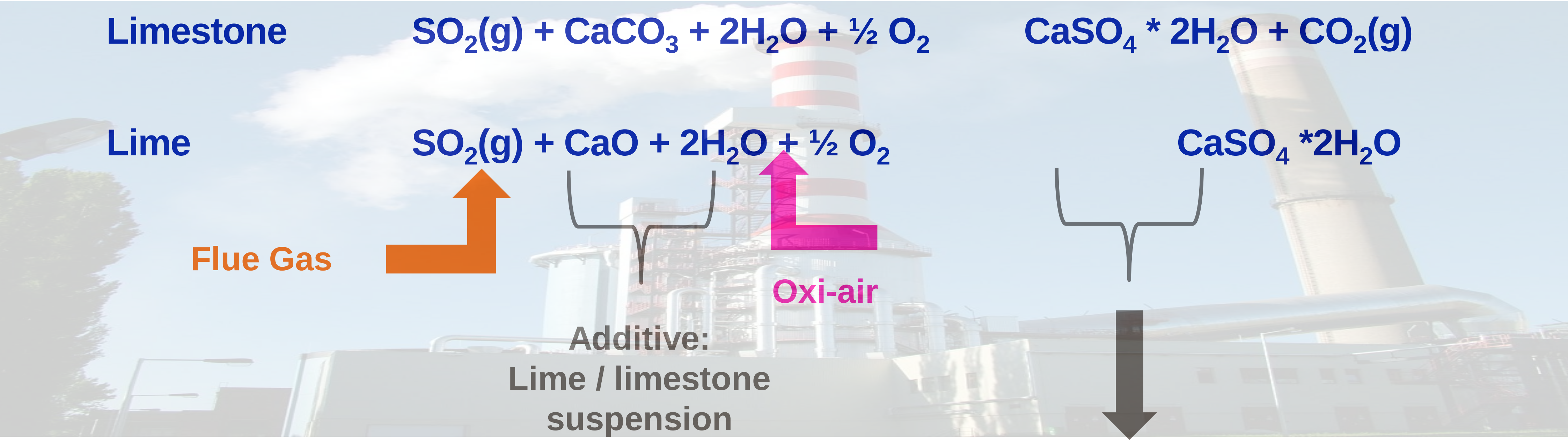
Why to prefer our proven Wet Limestone FGD technology?

- New-build and retrofit
- Size: up to 1,000 MW_e and even more
- Application for a wide range of fuels: coal, lignite, heavy fuel oil
- Suitable for:
  - High sulphur applications
  - Large scale power plants

Case Study: Taichung, Taiwan

Contract award: 1993
Project: Provision of a limestone FGD plant on a turnkey basis
Main fuel: Coal
Plant output (unit 1-4): 4 x 550 MW_e
Max. flue gas flow: 2,150,000 Nm^3/h

Overall Reactions



Limestone $SO_2(g) + CaCO_3 + 2H_2O + ½ O_2$ $CaSO_4 * 2H_2O + CO_2(g)$

Lime $SO_2(g) + CaO + 2H_2O + ½ O_2$ $CaSO_4 *2H_2O$

Flue Gas

Oxi-air

Additive:
Lime / limestone
suspension

Product:
Gypsum

Requirements of the Indian Market

Requirements	
►	Reliable and proven FGD technology ensured by reference plants
►	Optimized design regarding Capex and Opex
►	Minimized water consumption, limited waste water
►	Small and optimized plant footprint especially for retrofit projects
►	Short erection period, short shut down periods
►	Regarding retrofit projects: relining of chimney and installation of booster fan

Key Project Data Rugeley

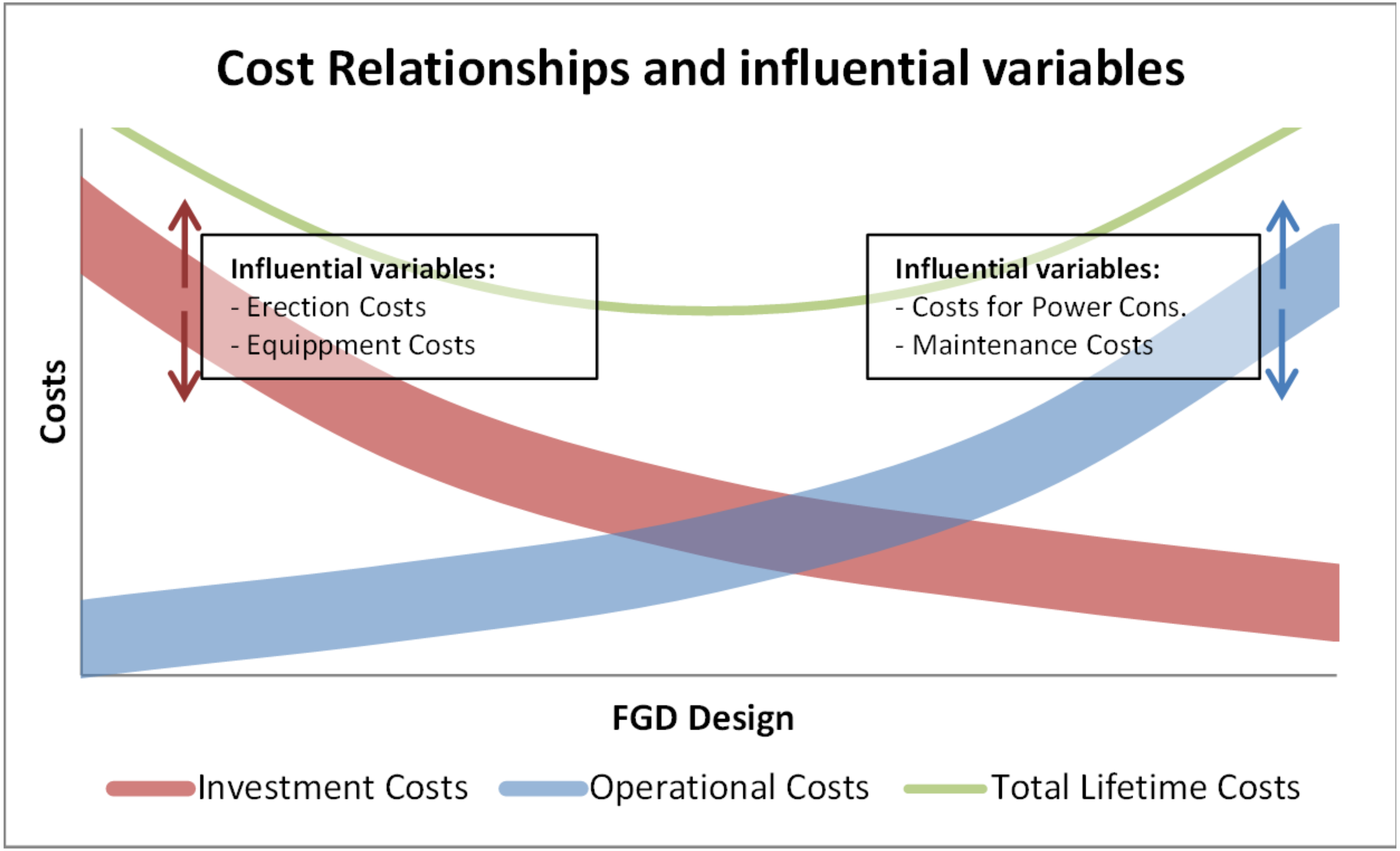
Customer	International Power plc
Location of power station	Rugeley, Staffordshire, UK
Award date	2006
Gross power generation (per unit)	500 MW_e
Number of units	2
Maximum flue gas flow rate (wet)	2,103,000 m^3/h (STP)
Maximum S content in coal	1%
Maximum SO_2 inlet concentration	2,076 mg/m^3
Guaranteed emissions (acc 6% O2, dry)	
So_2 remocal efficiency	94%
Particulate matter	25 mg/m^3 (STP)
Waste water	10.5 m^3/h

EEC 2016: DeSOx Technologies to meet new Indian Environmental Norms – DL Reference Plant in Rugeley

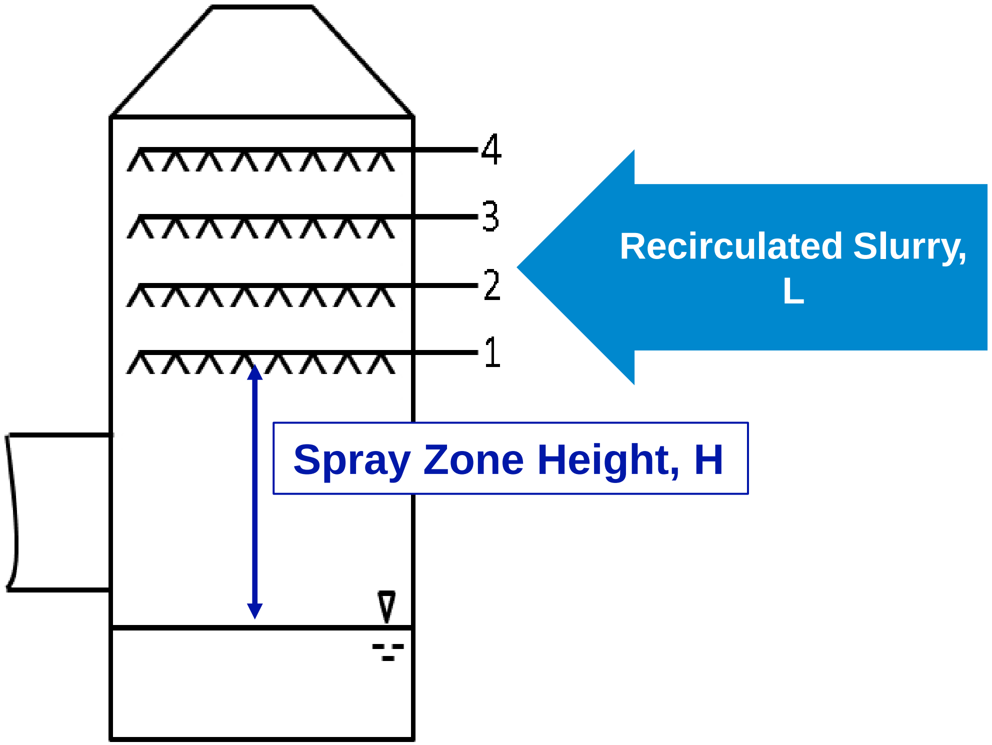
Precise and Accurate Design Calculation: Doosan Lentjes Software Tool

	Consideration of all chemical and physical processes and interactions
►	Validated by all performance data documented in the extensive database for all Doosan Lentjes reference plants
►	Precise calculation of plant dimensions regarding correlation of Capex and Opex
►	Consideration of all key design parameters: • Limestone reactivity • Limestone particle size distribution • Organic acid dosage • Position of spray level in operation • Absorber height • Temperature of suspension • Chloride concentration • Absorbent droplet size • Effect of SO_2 and CO_2 concentration on mass transfer • …

Optimized Design regarding Capex and Opex



Optimized Design regarding Capex and Opex



Reduction of L

→ Reduction of Opex

Reduction of H

→ Reduction of Capex

Optimal design range:

Integral consideration of L and H

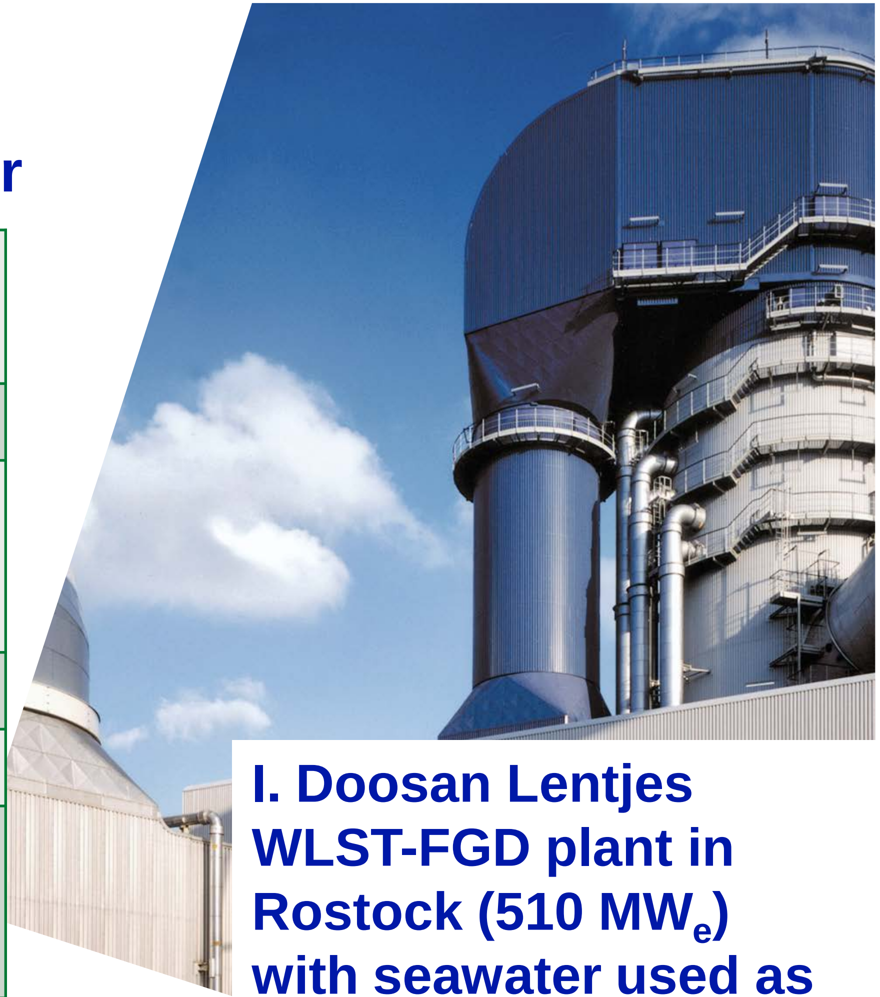
→ Reduction total lifetime costs

Minimized Water Consumption

►	**Minimizing of water evaporation by installing highly efficient gas gas heater and minimizing raw gas temperature before absorber**
►	Use of cooling water (SW) as process water
►	FGD plant operation with no waste water by injection of residual water before ESP
►	Installation of a waste water evaporator – highly expensive
►	For power plants located in coastal areas the installation of SW FGD plants, where no additive or fresh water is used, has advantages.
►	For FGD plants with a capacity of up to 350 MW_e the installation of the dry Circolclean® FGD plants has a lower water consumption

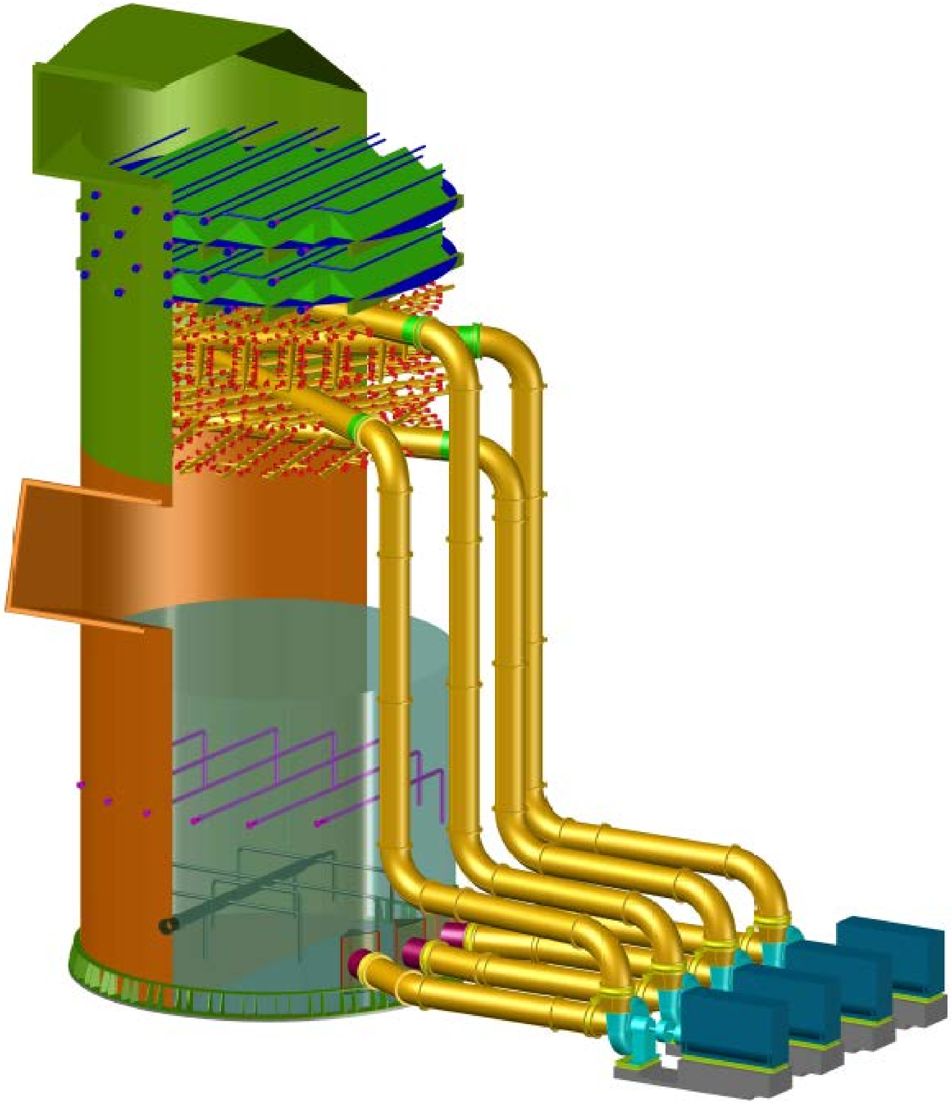
Use of Cooling Water (SW) as Process Water

Challenges by use of seawater as process water
Commercial grade gypsum is produced in all plants.
The chlorine content in the absorber is higher than in the case of using fresh water: 40,000 ppm instead of 20,000 ppm.
Wearing of balls for the wet ball mill is higher.
Amount of bleed waste water is higher.
Chlorine content has a negative impact on removal efficiency (higher L/G to reach the same removal efficiency means higher power consumption).
For saturation of oxidation air and for gypsum washing material selection (absorber, mill, process water system) has to be suitable for the high chlorine content.
Desalinated water is required for gypsum washing. (range: 2-5% of total water consumption)



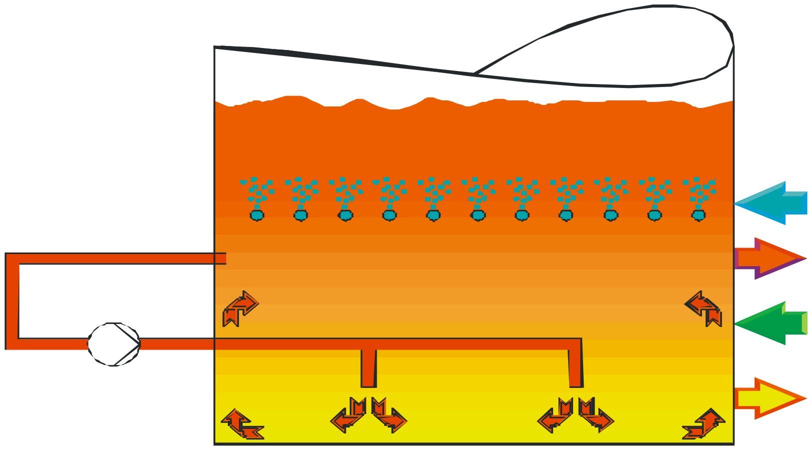
I. Doosan Lentjes WLST-FGD plant in Rostock (510 MW_e) with seawater used as process water.
II. Power Station Almeria, 550 MWe, Spain, Mediterranean Sea
III. Power Station Iskenderun, 2 x 606 MWe, Turkey, Mediterranean Sea

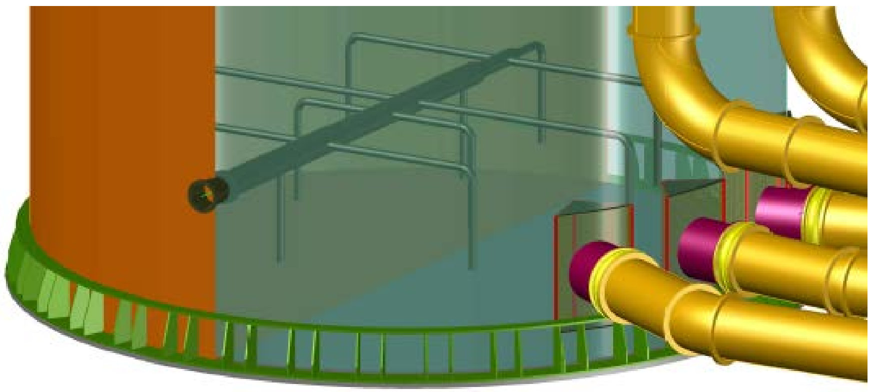
Spray Tower Design



- **Mist Eliminators**
- **Spraying Zone**
- **Sump equipped with Impulse Suspending System**

Sump Design





Special advantages only available with Doosan Lentjes' Sump System

- Suspends the solids without moving parts within the absorber
- Two different zones for oxidation and crystallization
- Better utilization of consumables
- Higher quality of gypsum
- Trouble-free restart of IS-system after FGD shut-down
- No need to operate Impulse Suspension System during shut-down

Aspects Regarding the Choice of Fan for Wet FGD Systems

Combined ID Fan

- State of the art solution for new-build power plants
- References available
- Simpler control loop for flue gas flow
- Reduced danger of flue gas pressure oscillation, smooth operation
- Investment cost saving

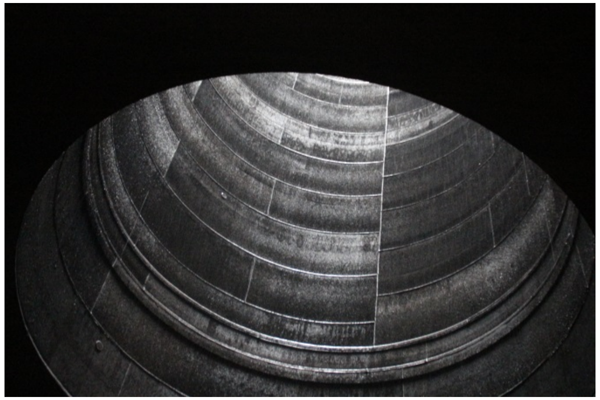
Booster Fan dedicated to FGD

- Preferred for retrofit projects
- No adaption of existing ID fan means reduced tie-in period
- Better efficiency during bypass-operation

Aspects Regarding the Choice of Type of Chimney

■ Chimney Design and Material Selection

- Common stand-alone chimney with one or more flues possible
- Wet stack may also be built on top of absorber
- Existing chimney may be used as FGD by-pass
- In case existing chimney will be modified and reused, stand-still period has to be considered
- Material selection for flue:
  - Carbon steel with flake lining
  - Carbon steel with rubber lining
  - FRP
  - Acid resistant bricks
  - Alloy material



Customer Benefits

- A simple solution to remove SO_2, HCl and HF
- SO_2 removal efficiency up to 99%
- Almost stoichiometric absorbent consumption
- Spray tower absorber not susceptible to clogging due to patented Impulse Suspension System
- Individual spray levels can be switched off during low load or low sulphur fuel operation to reduce power consumption
- Variety of corrosion resistant materials available for absorber design
- A high-quality gypsum is created as a by-product which has manifold uses

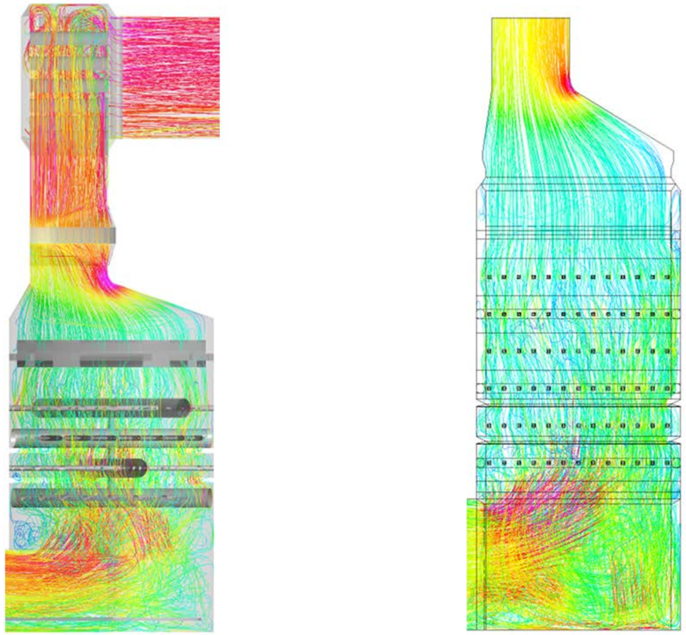
Case Study: Dolna Odra, Poland

Contract award: 1999
Project: Provision of a flue gas cleaning plant for boilers 7+8
Main fuel: Coal
Plant output: 1 x 220 MW_e
Max. flue gas flow (wet): 1,926,000 Nm^3/h

Doosan Lentjes

Doosan Lentjes' Capabilities at a Glance

- More than 40 years of experience with FGD technology
- Three different FGD technologies available
- Worldwide proven technology is own IP of Doosan Lentjes
- High number of references for all FGD technologies
- Experience with seawater as process water (WLST FGD)
- Continuous intensive R&D in own laboratory
- In-house CFB modelling



Wet Lime / Limestone FGD Plant References

Location	Fiddler's Ferry, UK
Customer	Scottish and Southern Energy
Capacity	3 x 500 MW_e
Fuel	Hard coal

Location	Ferrybridge, UK
Customer	Scottish and Southern Energy
Capacity	2 x 500 MW_e
Fuel	Hard coal

Location	Rugeley, UK
Customer	International Power plc
Capacity	2 x 500 MW_e
Fuel	Hard coal

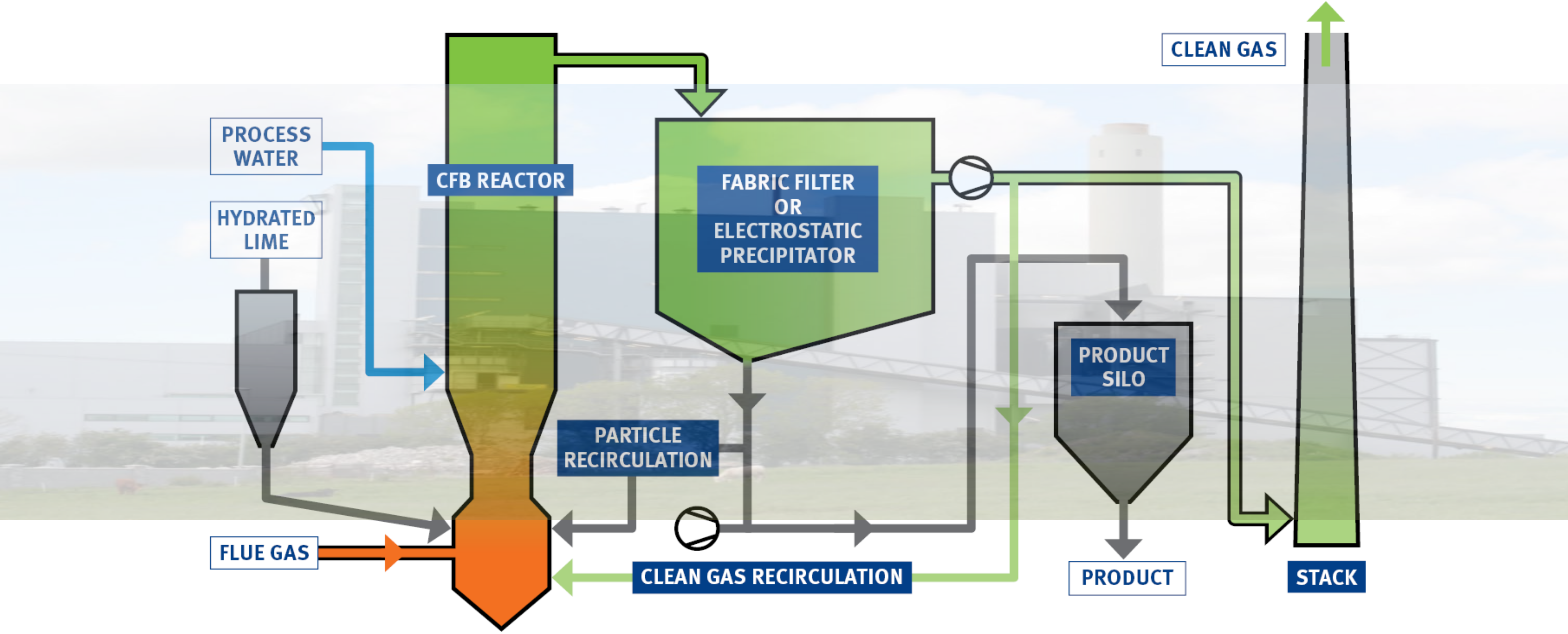
Wet Lime / Limestone FGD Plant References

Location	Oroszlány, Hungary
Customer	Vertes Power Plant Limited
Capacity	1 x 240 MW_e
Fuel	Lignite

Location	Lippendorf, Germany
Customer	Vattenfall / EnBW
Capacity	2 x 933 MW_e, 4 absorbers
Fuel	Lignite

Location	Cayirhan, Turkey
Customer	TEAS
Capacity	2 x 150 MW_e
Fuel	Lignite (extreme high sulphur)

Circoclean® FGD – Basic Flow Sheet



Why to prefer our proven Circoclean® technology?

- New-build and retrofit
- Power stations and waste-to-energy plants
- Size: up to 350 MW_e and even more
- Wide range of fuels: coal, lignite, heavy fuel oil, municipal and industrial waste
- SO_2, SO_3, HCl, HF removal efficiency up to 99% and more
- Usage of hydrated lime as additive
- Hydration of burnt lime on site possible
- Usage of limestone in fuel, calcined in upstream CFB boiler
- Removal of PCDD, PCDF and heavy metals with optional activated carbon injection

Case Study: Cochrane, Chile

Contract award: 2014
Project: Engineering, manufacture and supply of dry FGD system
Main fuel: Hard coal
Plant output: 2 x 250 MW_e
Flue gas flow (wet): 2 x 857,000 Nm^3/h

Overall Reactions

Main reactions, significant for the flue gas desulphurisation in the fluidised bed

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 * ½\ H_2O + ½\ H_2O$$

$$2\ CaSO_3 * ½\ H_2O + O_2 \rightarrow 2\ CaSO_4 * ½\ H_2O$$

$$Ca(OH)_2 + SO_3 \rightarrow CaSO_4 * ½\ H_2O + ½\ H_2O$$

Additional reactions with chlorides and fluorides

$$Ca(OH)_2 + 2\ HCl \rightarrow CaCl_2 * 2\ H_2O$$

$$Ca(OH)_2 + 2\ HF \rightarrow CaF_2 * 2\ H_2O$$

In case of usage of activated carbon adsorption of:
PCDD, PCDF and Heavy Metals

Parallel reaction with CO_2, forming limestone

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

CaO hydrated in a dry hydrating plant on site

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Circoclean® FGD / FGC Plant Design

- Circoclean® Reactor (1)
- Filter (2)
- Venturi Nozzle (3)

Multiple Venturi Nozzle (Flow > 400,000 Nm^3/h)

Outlet View

Inlet View

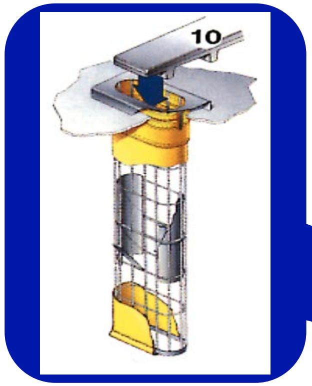
Customer Benefits

- Moderate process water consumption
- Small power consumption
- Small foot print
- No waste water – dry particles only
- High SO_3 removal
- No flue gas re-heating
- Reactor made of carbon steel
- Easy adoption to higher SO_x removal
- Attractive investment costs

Case Study:
Iaşi, Romania
Contract award: 2014
Project: Delivery of key Circoclean® FGD technology Main fuel: Lignite Plant output: 1 x 50 MW_e

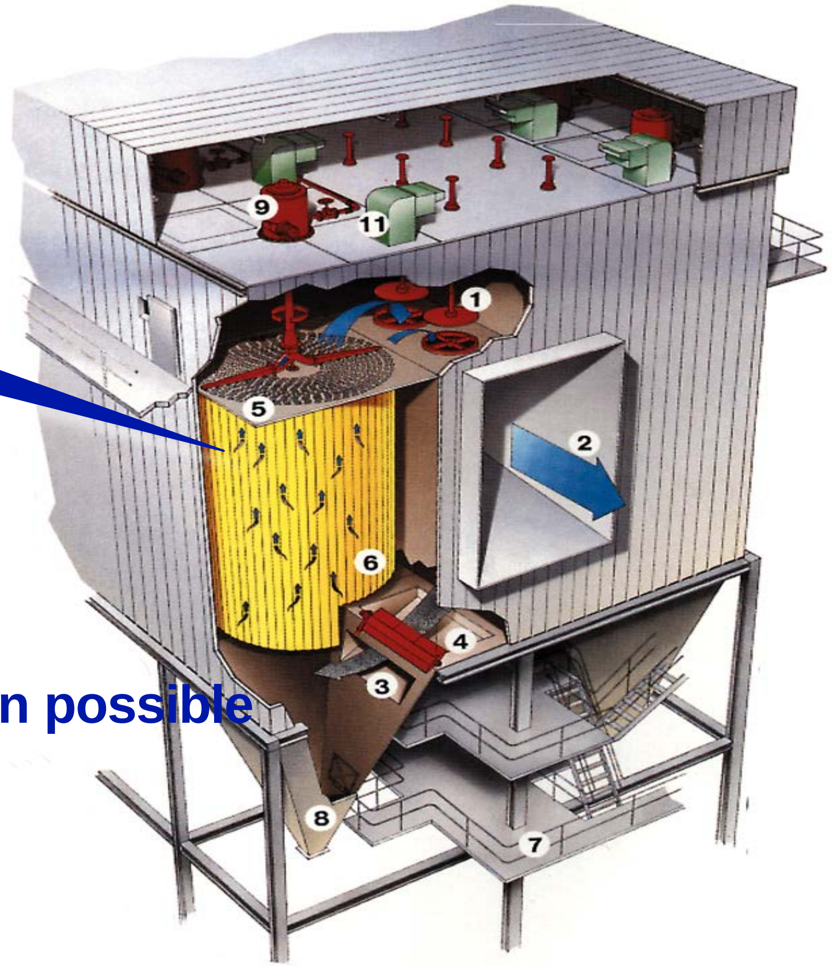
Flue gas flow (wet): 623,500 Nm^3/h

Low Pressure Pulse Jet Fabric Filter downstream Circoclean® FGD / FGC Reactor

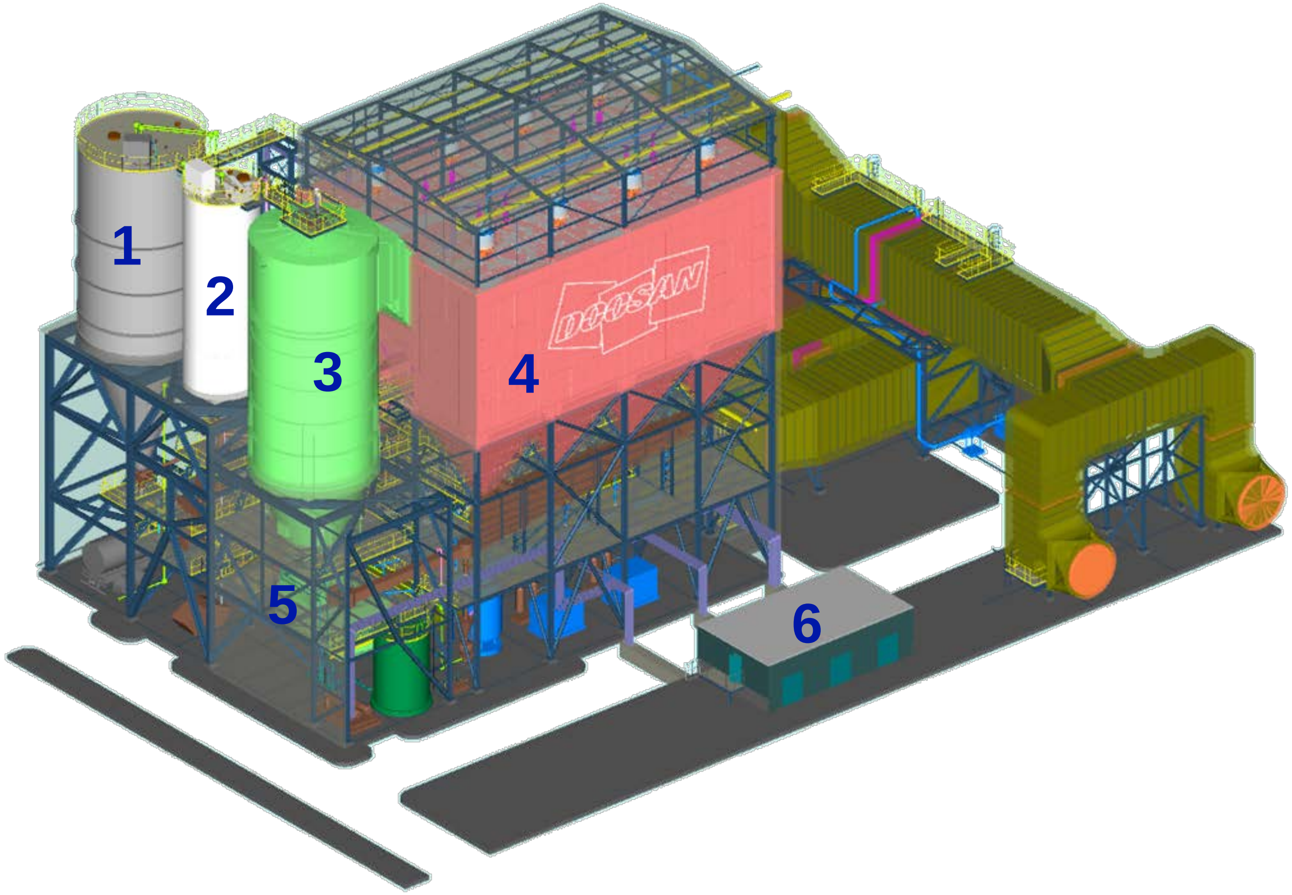


Customer Benefits

- Far less than 10 mg/m^3
- Independent from boiler load
- $DeSO_x$ – effect in ash layer on filter bag
- Furnace sorption injection or CFB installation possible
- Relatively low investment costs
- Higher life time of filter bags



Typical Layout



- Product Silo (1)
- Sorbent (Lime) Silo (2)
- Absorber (3)
- Fabric Filter (4)
- Absorber Inlet (5)
- Electrical Building (6)

Key Project Data Cochrane

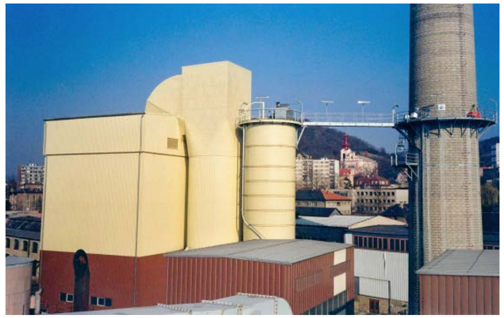
Customer	AES/ Empresa Eléctrica Cochrane (EEC)
Location of power plant	Mejillones, Chile
Award date	2014
Main fuels	hard coal
Gross power generation	2 x 250 MW_e
Flue gas flow rate	2 x 857,000 m³/ h (STP, wet)
$DeSO_x$ - technology Number of lines	Circoclean® FGD 2
SO_2 inlet concentration	1865 mg/ Nm³ dry @ 6% O_2
Dust inlet concentration	21,100 mg/ Nm³ dry @ 6% O_2
Guaranteed emissions SO_2 SO_2 removal efficiency Dust Dust removal efficiency	 200 mg/ Nm³ dry @ 6% O_2 88.6% 30 g/ Nm³ dry @ 6% O_2 99.85%

Circoclean® FGD Plant References

Location	Moneypoint, Ireland
Customer	Electricity Supply Board (ESB)
Capacity	3 x 305 MW_e
Fuel	Hard coal

Location	Plzen, Czech Republic
Customer	Plzeňská Teplárenská a.s.
Capacity	3 x 35 Mw_e – 1 reactor
Fuel	Lignite

Location	Usti nad Labem, Czech Republic
Customer	SETUZA Cinergetika U/L, a.s.
Capacity	1 x 65 MW_e
Fuel	Lignite

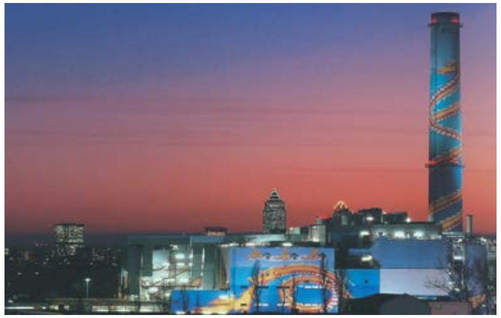


Circoclean® FGC Plant References

Location	Antwerp, Belgium
Customer	Indaver N.V.
Capacity	3 x 105,000 Nm^3 / h
Fuel	Municipal and industrial waste

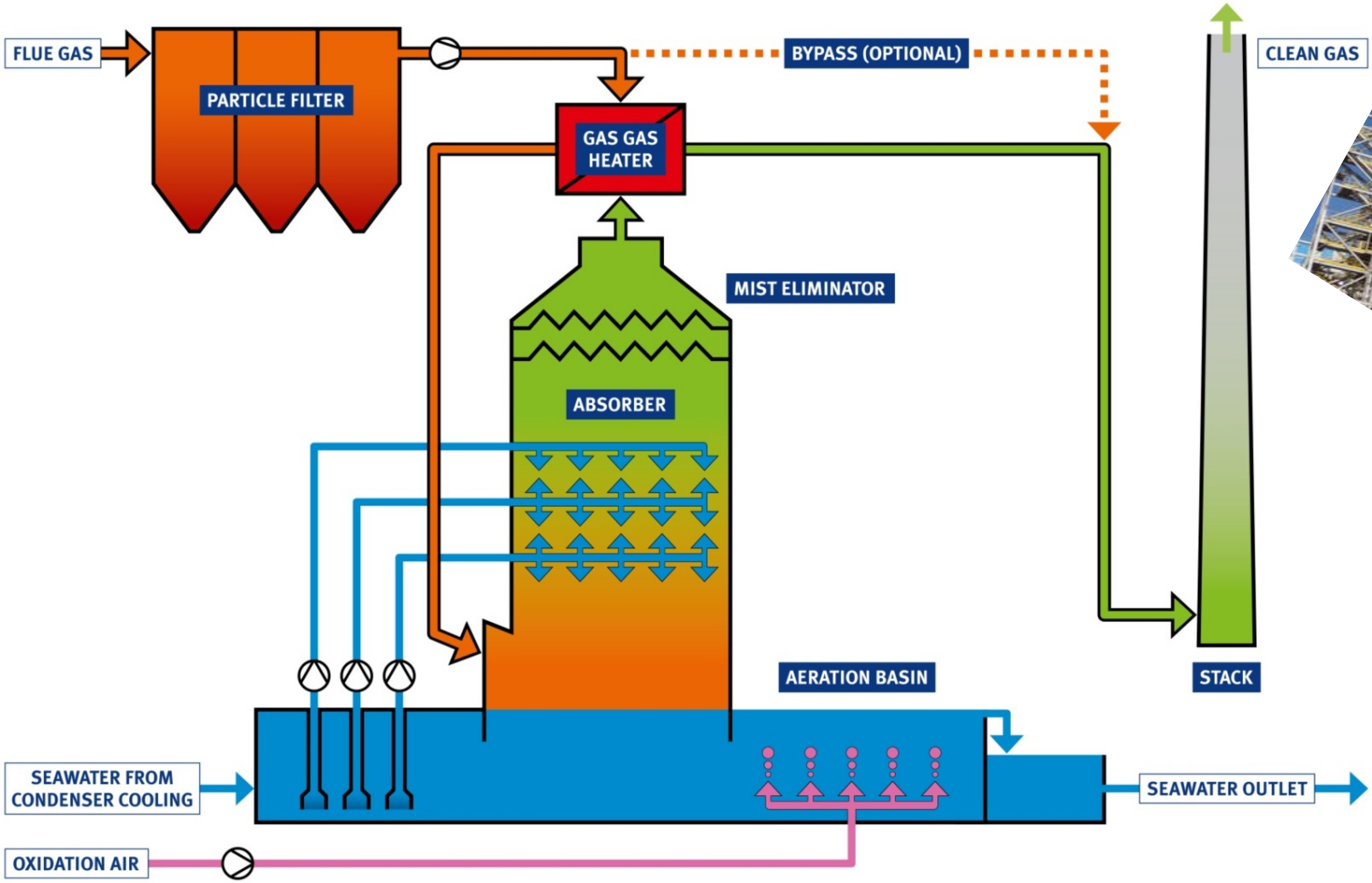
Location	Allington
Customer	Kent Enviropower
Capacity	3 x 100,000 Nm^3 / h
Fuel	Municipal waste

Location	Frankfurt am Main, Germany
Customer	AVA Nordweststadt
Capacity	4 x 114,000 Nm^3 / h
Fuel	Municipal waste



SWFGD - Background

Typical Flow Sheet – Example: Open Spray Tower

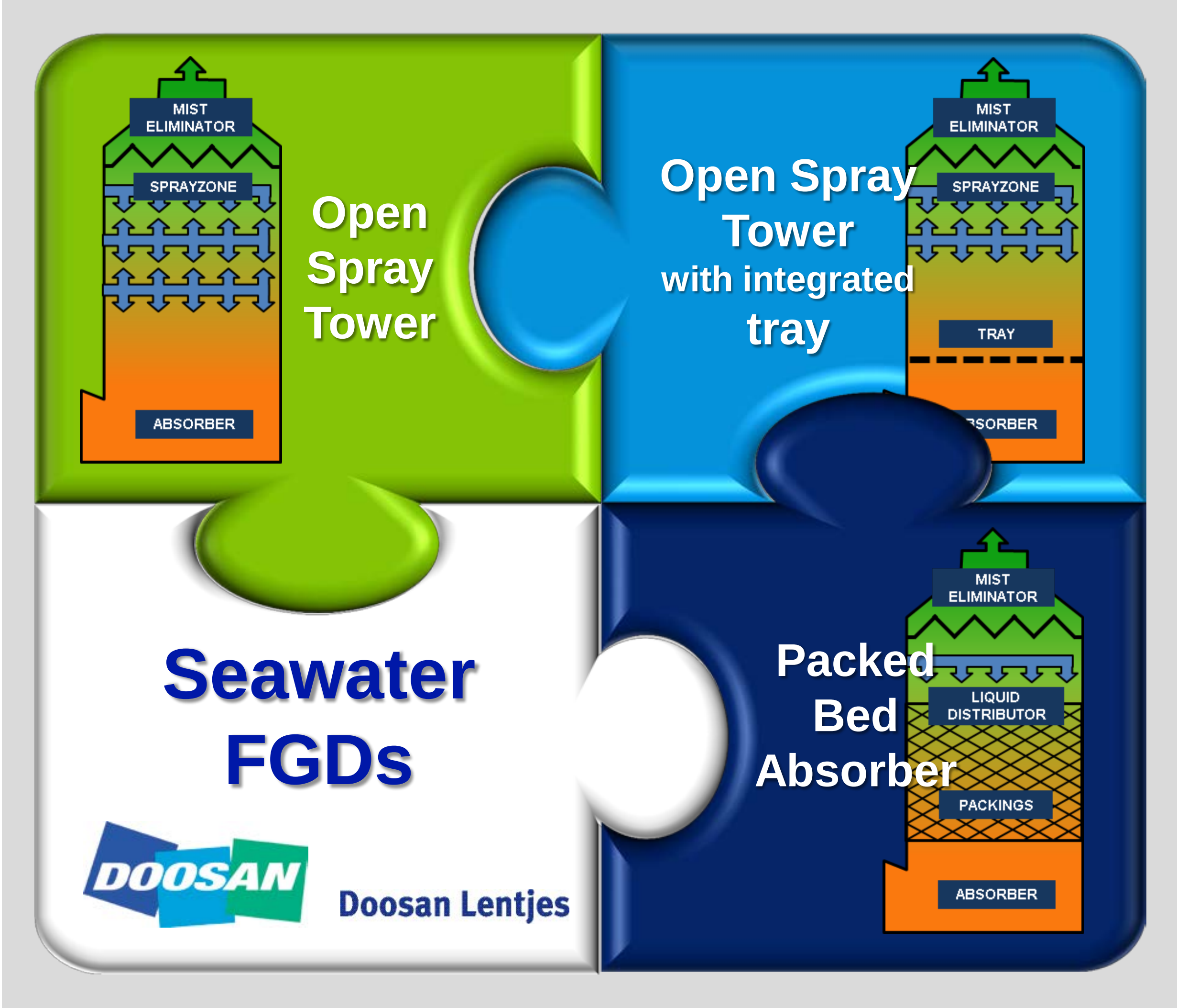


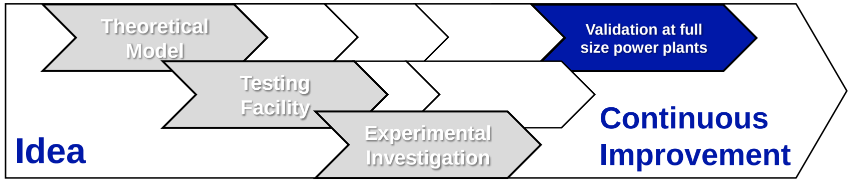

Virtual Tour - 4b_Blick auf Absorber

Types of SWFGD Absorbers

- **Influencing factors on product selection**
  - **SO_2 raw gas content**
  - **Required SO_2 removal efficiency**
  - **Seawater quality , e.g.:**
  - Temperature
  - pH value
  - Alkalinity

  - **Focus on:**
  - Capex
  - Opex
  - Hybrid solution





Field Study at Gheco One Power Plant

Validation at full size Power Plants

- **Verification of models and experimental results**

Absorber Type:
Open Spray Tower

No. of spray levels:
4

No. of oxidation air blowers:
2+1 standby

Maximum SO_2 concentration (Raw Gas):
~2700 mg/Nm³

SO_2 removal in absorber

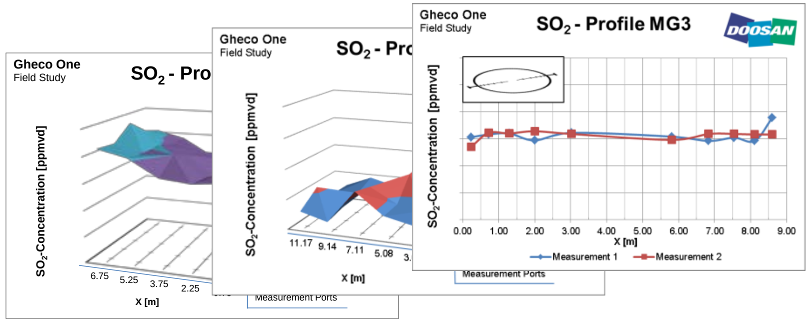
- Flue gas grid measurements under different operating conditions

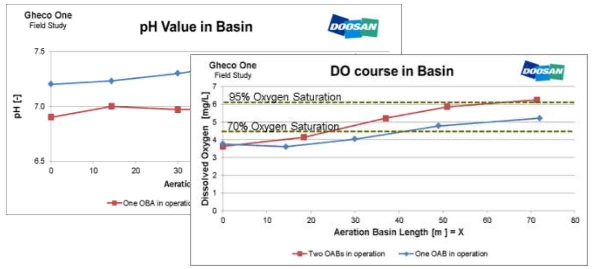
pH increase and oxidation in aeration basin

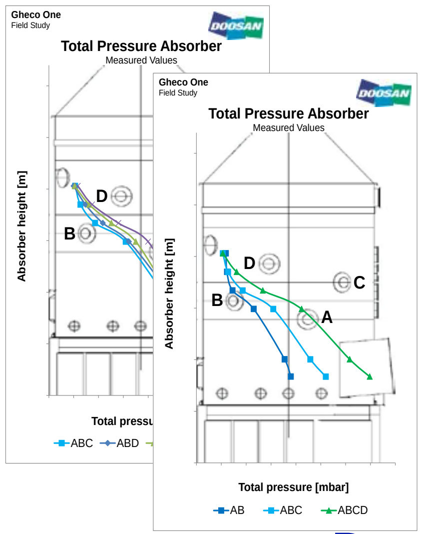
- Seawater measurements under different operating conditions

Flow optimization

- Pressure drop measurements under different operating conditions








Virtual Tour - 4b_Blick auf Absorber

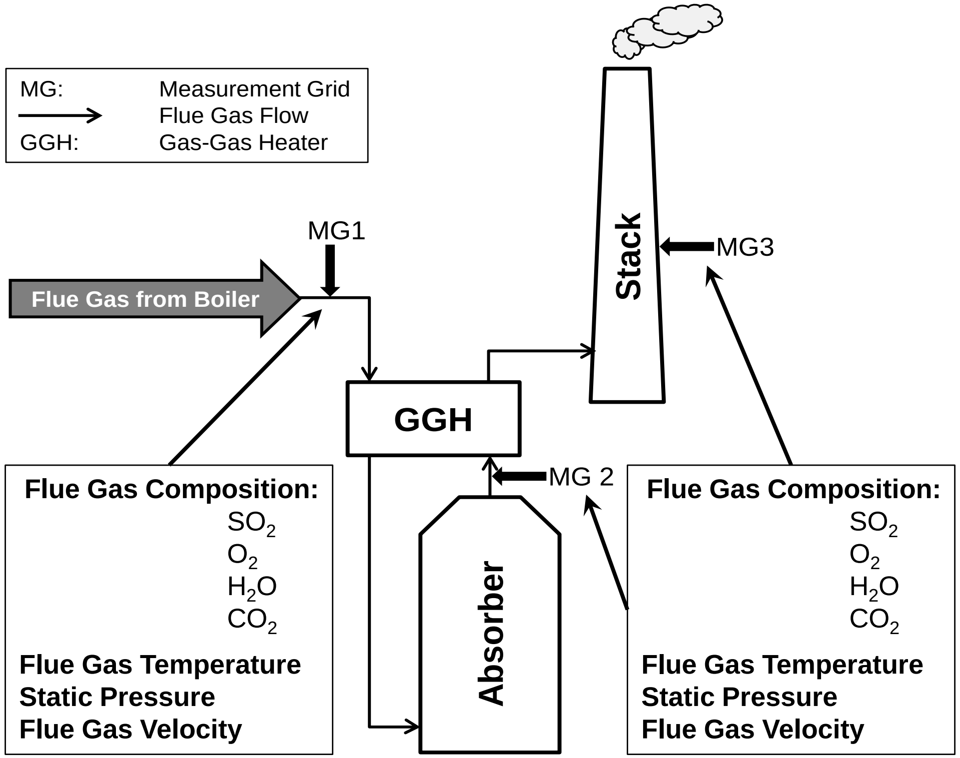
Field Study at Gheco One Power Plant

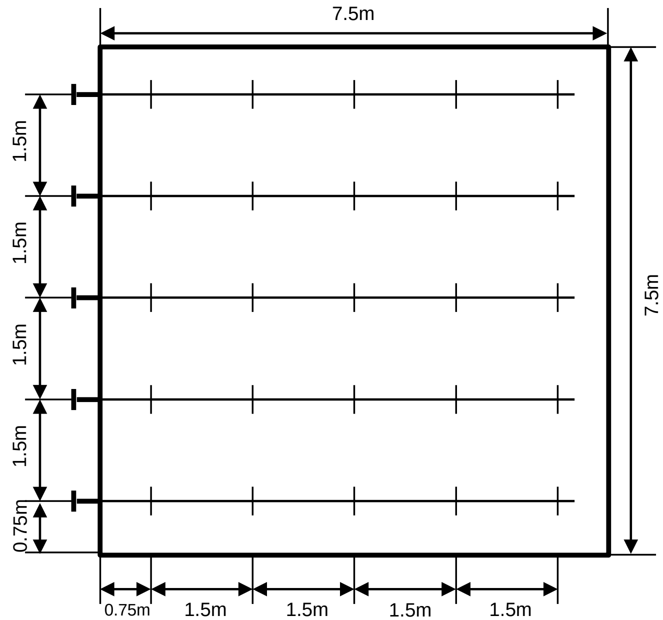
Flue Gas Grid Measurements

- **Measuring grids**
  - Raw gas upstream GGH (25 measuring points)
  - Clean gas upstream GGH (24 measuring points)
  - Clean gas downstream GGH (20 measuring points)

- **Measured values**
  - SO_2-concentration
  - O_2-concentration
  - CO_2-concentration
  - H_2O-concentration
  - Flue gas temperature
  - Static pressure
  - Flue gas velocity

- **A different number of spray pumps (4, 3, 2) were in operation**
  - 6 test runs were executed

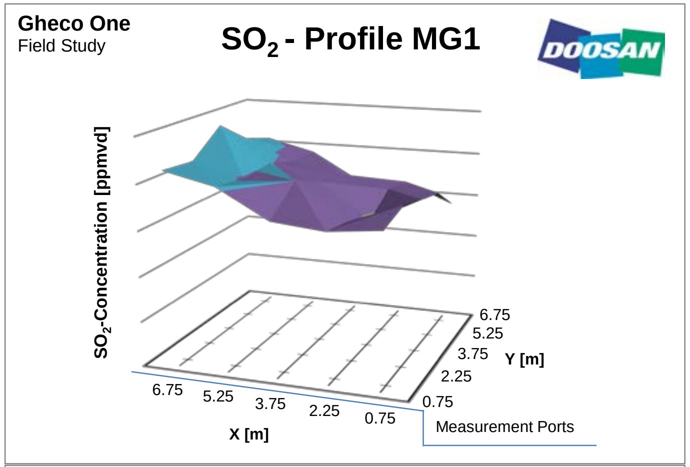


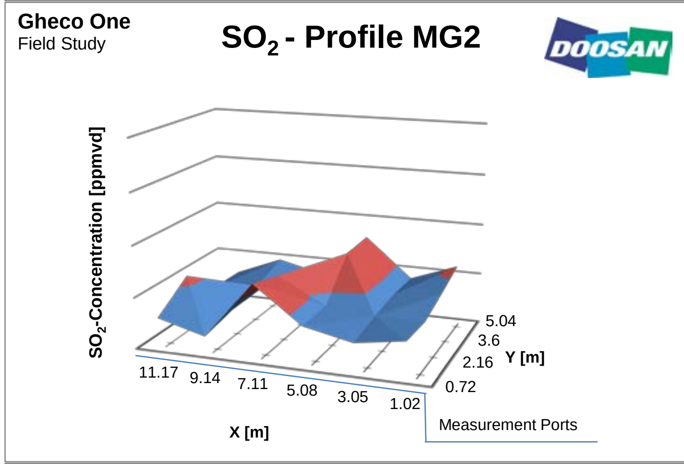


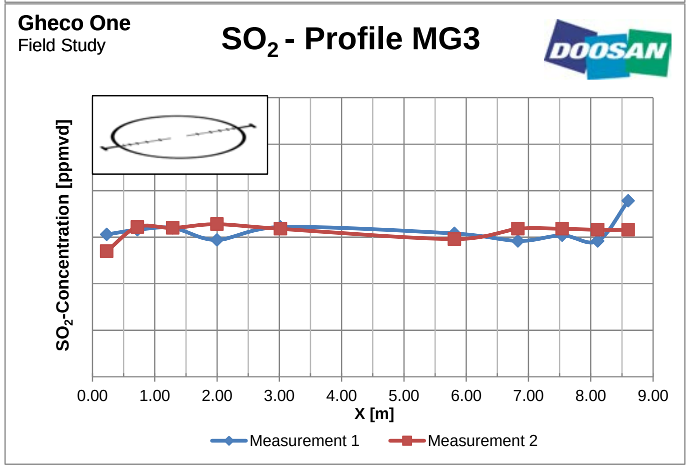
Field Study at Gheco One Power Plant

Flue Gas Grid Measurements

- **Results (selected data)**
  - **Coal with less sulphur content than planned is fired**
  - **SO_2 removal efficiency of ≥99% can be reached**
  - **SO_2 removal efficiency between ≥ 93.5% and ≥99% were measured depending on number of operated spray banks and height of operated spray bank**
  - **The emission limits were upheld under all operating conditions**
  - **Homogeneous distribution of SO_2 at stack**
  - Result of flow optimization
  - **The expected calculated values were reached**
  - Validation of experimental and modelled results successful
  - **New operation concept**
  - Customer benefits: Reduction of power consumption under current operating conditions



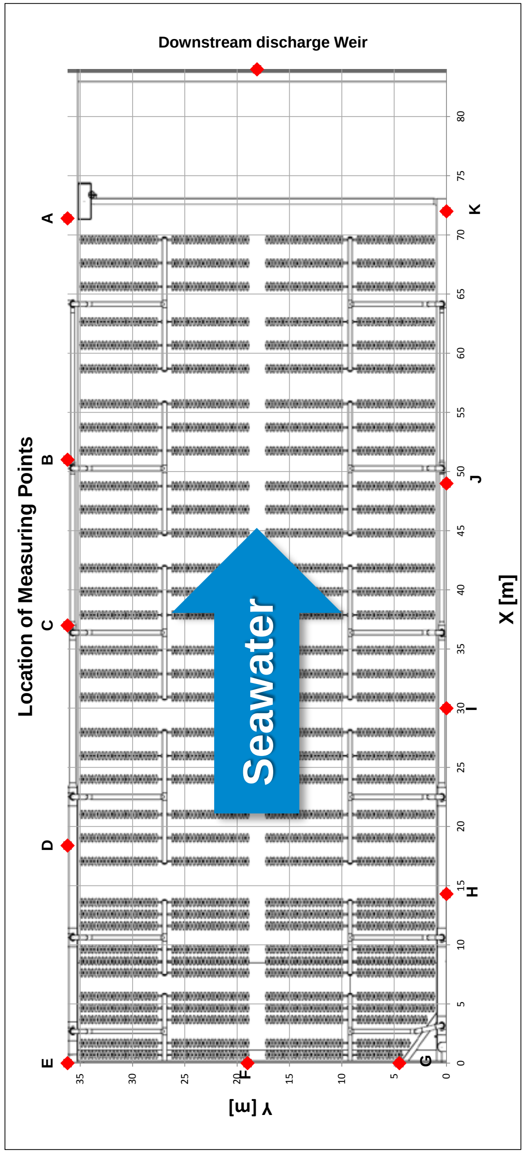




Field Study at Gheco One Power Plant

Seawater Measurements

- **Measurements in aeration basin in parallel to flue gas grid measurements**
- **Measured values at 12 measuring points (selected values)**
  - **pH Value**
  - **Alkalinity**
  - **Dissolved Oxygen [DO]**
  - **SO_3^{2-} concentration**
    - Chemical Oxygen Demand [COD] increase
  - **Salinity**
    - Conductivity
  - **Temperature**
  - **Seawater Velocity**
- **Different number of oxidation air blowers (1, 2) were in operation**
  - **Influence on performance of aeration**
- **Different number of absorber spray pumps (2,3,4) were in operation**
  - **Influence on seawater inlet quality to aeration basin**
- **12 test runs**



Doosan Lentjes

Field Study at Gheco One Power Plant

Seawater Measurements

- **Results (selected data)**

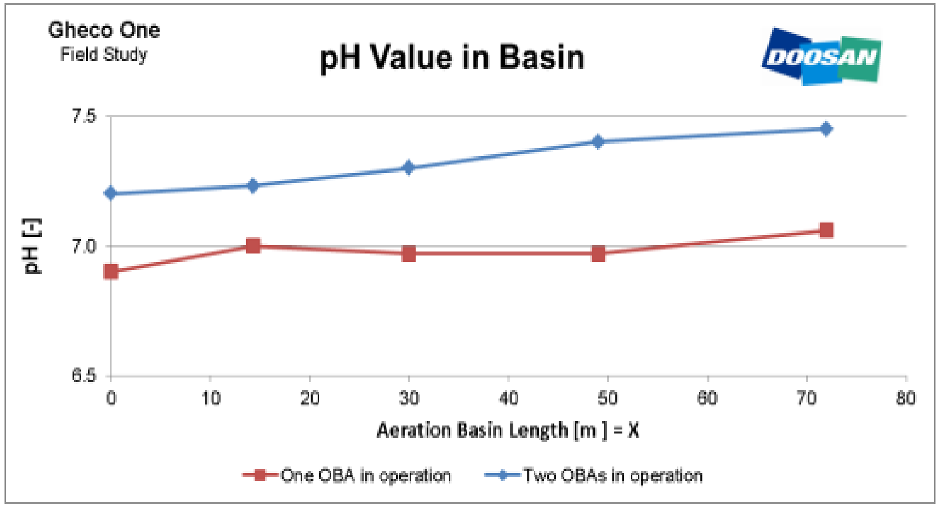
  - **Correlation between pH value and SO_2 removal efficiency (basin Inlet pH value)**
  - Higher SO_2 removal efficiency → Lower aeration basin inlet pH value

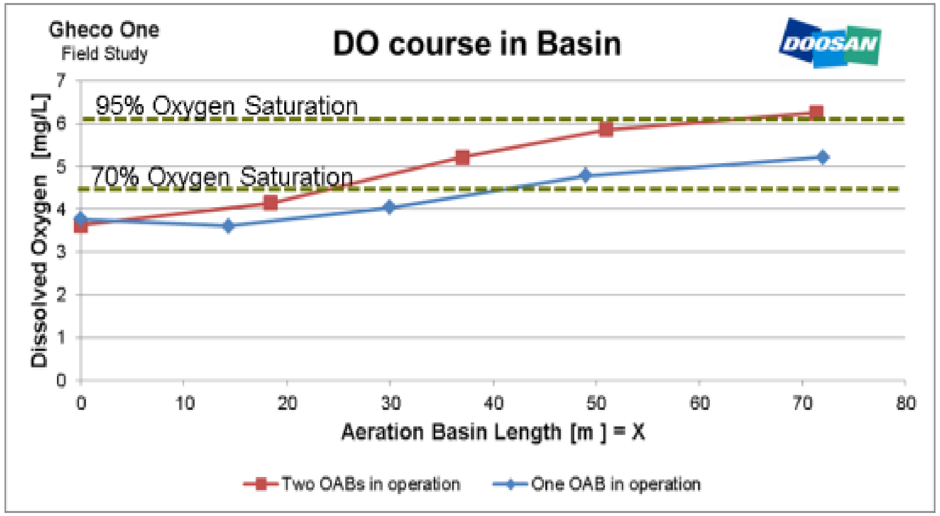
  - **All emission limits are kept under all operating conditions**

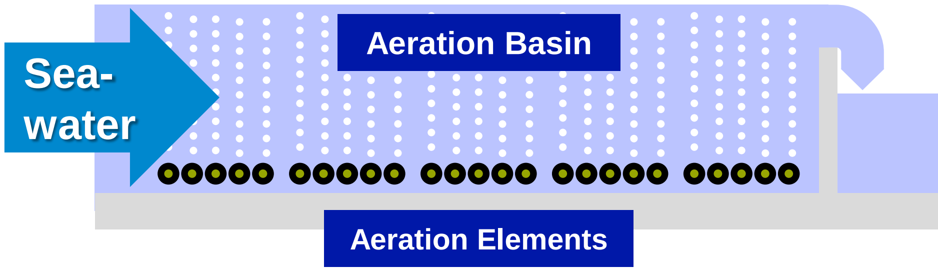
  - **pH-value and DO increase faster, when more air is brought into aeration system**

  - **The expected calculated values were reached**
  - Validation of experimental and modelled results successful

  - **New operation concept**
  - Customer benefits: Reduction of power consumption under current operating conditions







Why to prefer proven SWFGD technology?

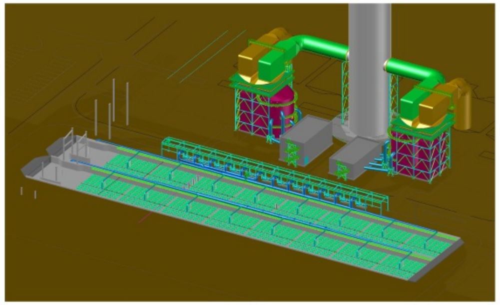
- **Cost effective solution for plants in coastal regions:**
  - Seawater is used as an absorbent
  - Seawater typically taken from the power plants cooling circuit
- **Size: up to 1,000 MW_e and higher**
- **Application for a wide range of different fuels:**
  - coal
  - lignite
  - heavy fuel oil
- **Applicable for a wide range of SO_2 raw gas concentrations**
- **High level of removal efficiency, ≥ 99% possible**
- **No by-product and no additional absorbents necessary**
- **Low operating and capital costs**


Rabigh, Saudi Arabia
4 x 700 MW_e , heavy fuel oil


Gheco One, Thailand
1 x 660 MW_e , coal


Paiton, Indonesia
2 x 660 MW_e , coal

SWFGD Plant References



Location	Vinh Tan
Customer	Vietnam National Coal – Mineral Industries Holding Corp. Ltd.
Capacity	2 x 620 MW_e
Fuel	Hard coal

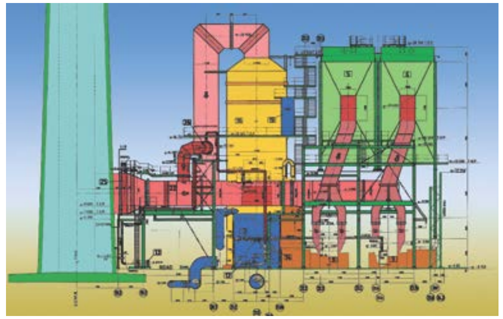
Location	Rabigh, KSA
Customer	Doosan Heavy Industries & Construction
Capacity	4 x 700 MW_e
Fuel	HFO

Location	Gheco One, Thailand
Customer	Doosan Heavy Industries & Construction
Capacity	1 x 700 MW_e
Fuel	Hard coal

SWFGD Plant References

Location	Qatalum, Qatar
Customer	SNC Lavalin
Capacity	4 units
Fuel	Aluminium smelter gas

Location	Madinat Yanbu, KSA
Customer	Enel Power
Capacity	1 x 130 MW_e
Fuel	HFO



Location	Paiton, Indonesia
Customer	Siemens
Capacity	2 x 660 MW_e
Fuel	Hard coal

Thank you धन्यवाद ! Danke

Doosan Lentjes

Excellence in Power

Backup

- Save flue gas desulphurization processes reduce SO_2 emissions to a minimum according to new Indian environmental norms
- Provision of complete clean gas packages from boiler to stack (SO_x, NO_x, PM, Hg)
- Clean and efficient power generation from coal and biomass support a sustainable long-term growth of the Indian economy
- Reliable waste-to-energy solutions help India reduce its waste volumes (>90%) while recovering valuable energy

Indian's Powerful German Engineering and Technology Partner - for Protection of the Environment