REINHOLD ENVIRONMENTAL Ltd.

2013 APC Round Table & Expo Presentation

July 8-9, 2013, in St. Louis, MO / Hosted by Ameren

Wet Limestone Scrubber Technical Overview

July 8, 2013,

Reinhold Environmental APC Roundtable

John F. Van Woy, Regional Manager After Market Services

Bruce C. Studley, Vice-President After Market Services

Steve Mosch, Director , Engineering WFGD Systems

Hitachi Power Systems America, Ltd.

Agenda

- Introduction
- Major Process Equipment
  - Absorber Inlet
  - Spray Zone
  - Mist Eliminator
  - Reagent Preparation
  - Dewatering
- Secondary Emissions
- Summary

Wet Flue Gas Desulfurization (WFGD)

- The first major FGD unit was installed in 1931 at Battersea Power Station owned by London Power Company.
- An additional two were built but abandoned during WWII
- With the Clean Air Act of 1970 the FGD became the process of choice because it was the only option that had been developed.

Environmental Protection

- Fossil fuels such as coal and oil contain significant amounts of sulfur
- 95 percent or more of the sulfur is generally converted to sulfur dioxide (SO_2) when burned
- SO_2 is then released into the atmosphere to combine with particulate water in the air to form Acid Rain

Hitachi Experience

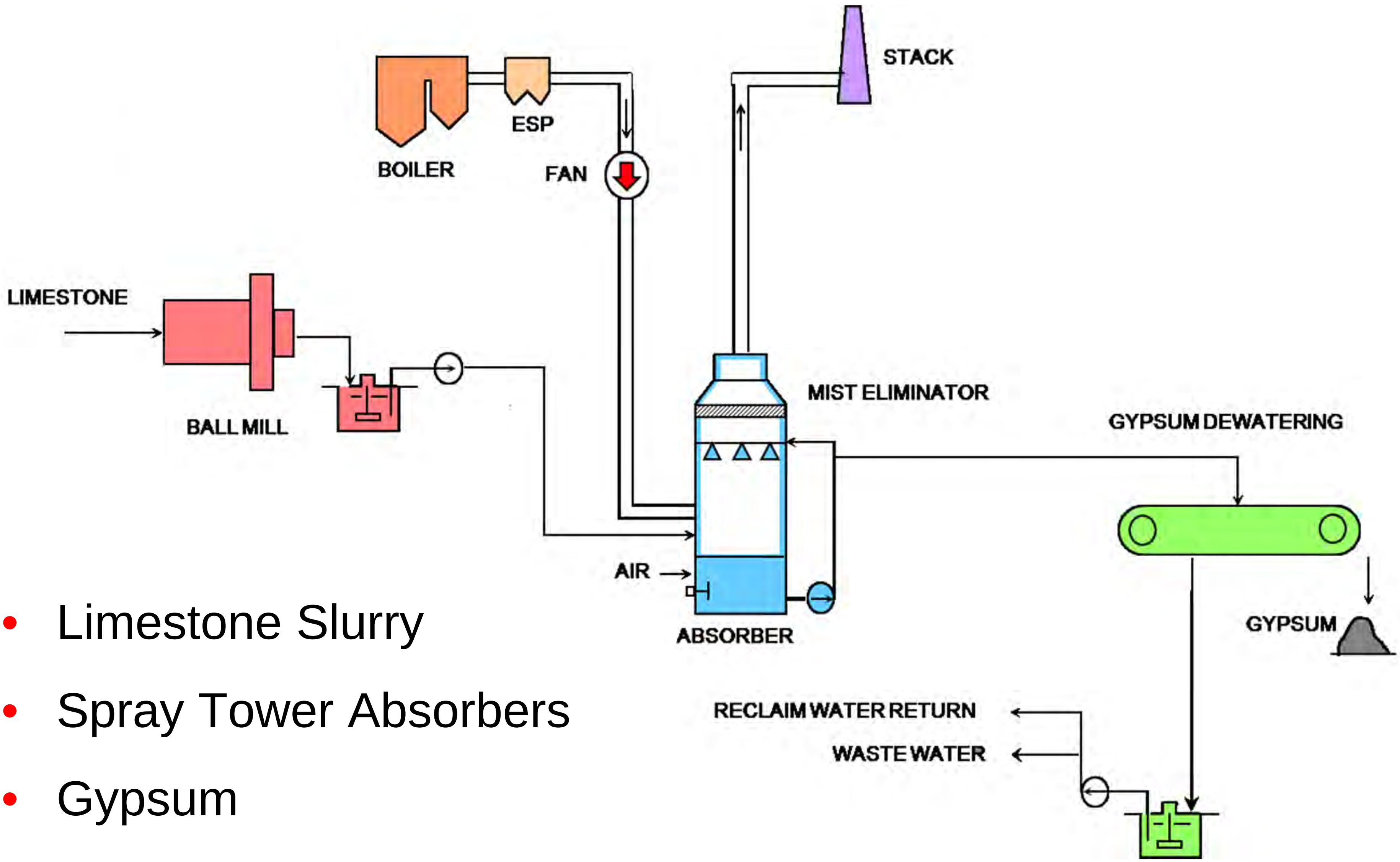
- 73 Installations
- Over 29,000 MW of Installed Capacity
- All Common Utility Fuels
- Inlet SO_2 Concentrations from 300 to 4,000ppm
- Single Absorber Capacity up to 1,050 MW
- Absorber Sizes to 69 ft
- All Common Absorber Materials
- 30 Years of Commercial Grade Gypsum
- U.S. Projects – extremely successful
  - Minnesota Power (PRB) - 98% SO2 Removal
  - Ameren (Bit/PRB Blend) - >99% SO2 Removal

Minnesota Power Boswell 3

Tachibanawan 2

40 Years of Wet Limestone FGD Technology

HITACHI
Inspire the Next



- Limestone Slurry
- Spray Tower Absorbers
- Gypsum

40 Years of Hitachi FGD

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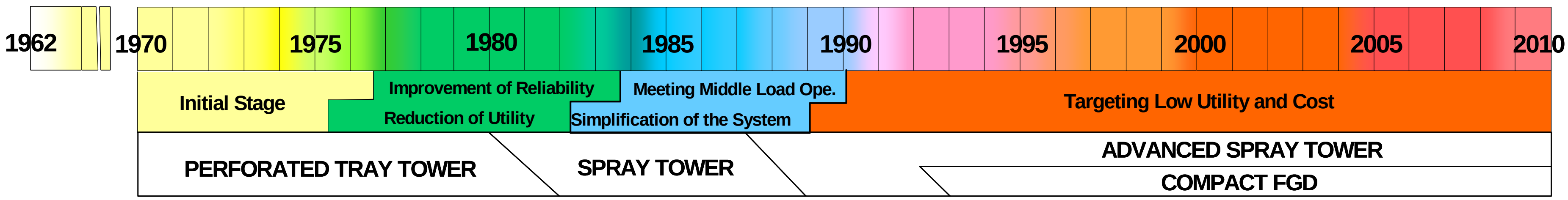

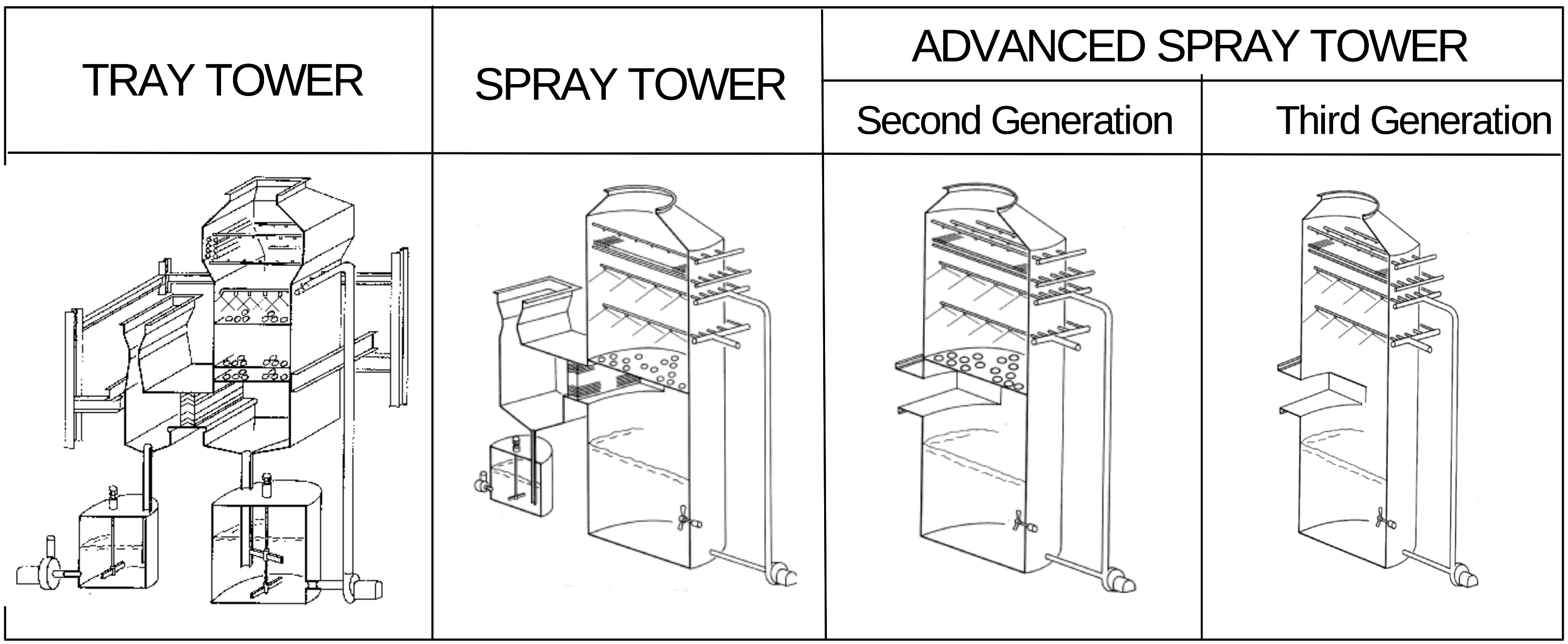

Streamlined design for high efficiency and low power consumption

History of HITACHI Single Tower Absorber

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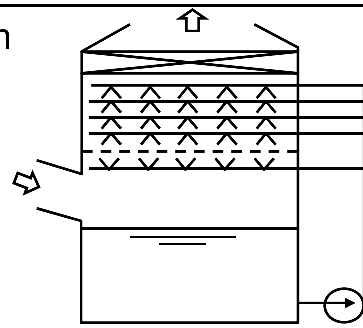
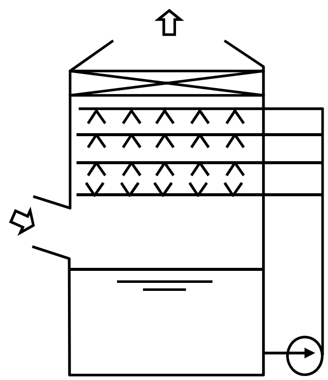
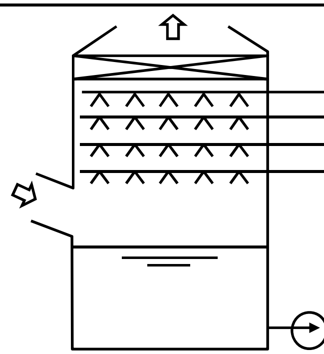
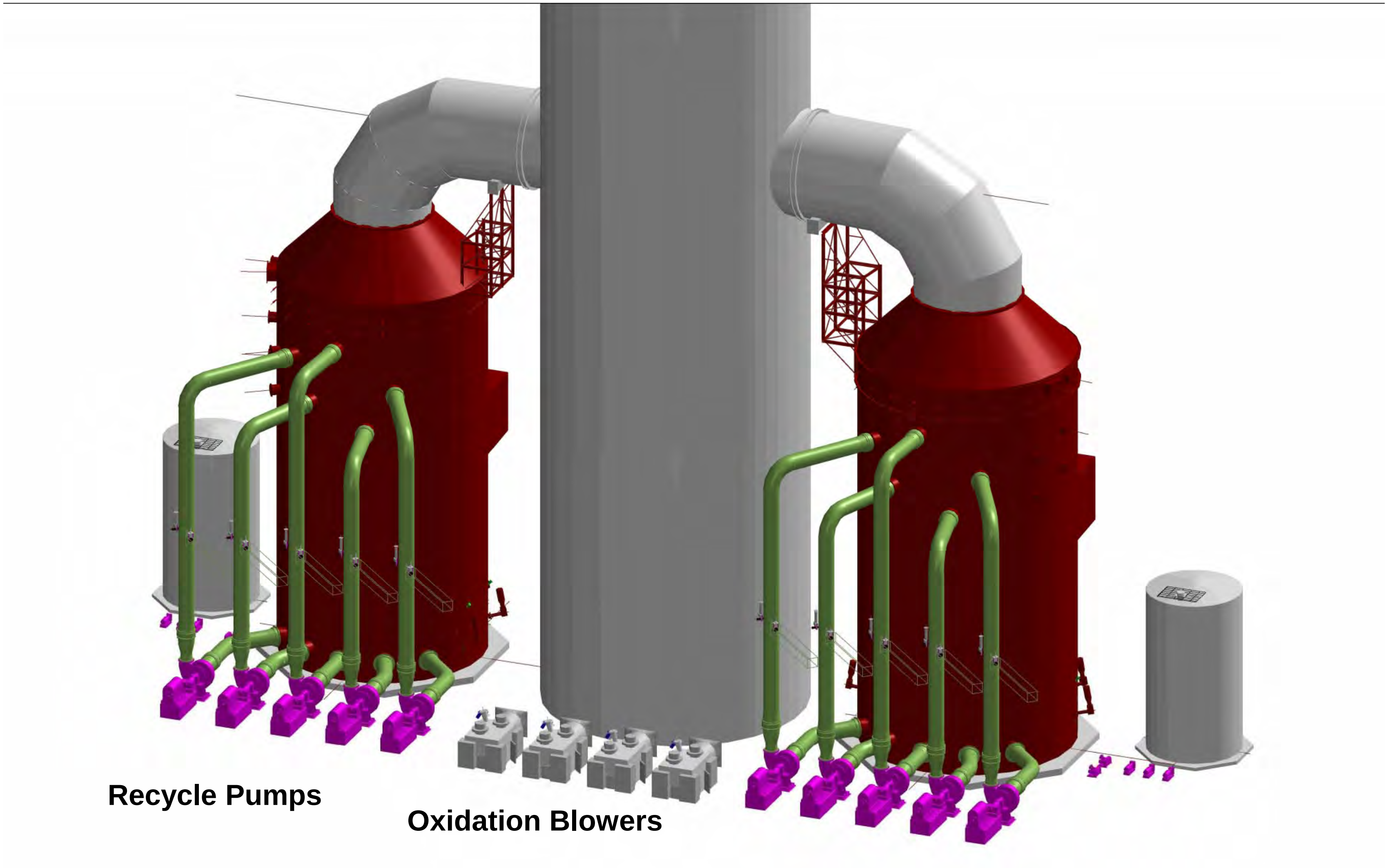
Year	Absorber Type	Remarks
1990 - 1996	·With gas distribution screen ·Upper spray for lowest spray level 	·Uniform gas distribution. ·First stage nozzles is used for washing gas distribution plate. ·**Increasing gas velocity is limited** because of high pressure loss.
1997 – 2007	· No gas distribution screen ·Upper spray for lowest spray level ·High Gas Velocity (3-4m/s) ·High Density Spray 	·Prevention of sprayed slurry entering to the inlet duct during off-line operation. ·**Lower pressure loss.**
2000 -	· No gas distribution screen · All downward Spray · High gas velocity (4-5m/s) · High density spray 	·**Better gas distribution.** ·**Higher SO2 removal, dust removal.**

Absorber Island



Absorber Unit Operations – Design Consideration

- SPRAY TOWER TECHNOLOGY
  - Inlet Gas Distribution
  - Excellent Spray Zone – gas/liquid contact
  - Mist Eliminator Zone – liquid/gas separation
  - Reaction Tank –
    - High forced oxidation
  - Maximum turndown and unrestricted ramp rate
- Design Considerations
  - Optimized For
    - Small footprint
    - Low operating and maintenance cost
    - Wide range of different fuels
    - Single use absorber up to 1300MW

Chemical Reaction Steps in the FGD Process

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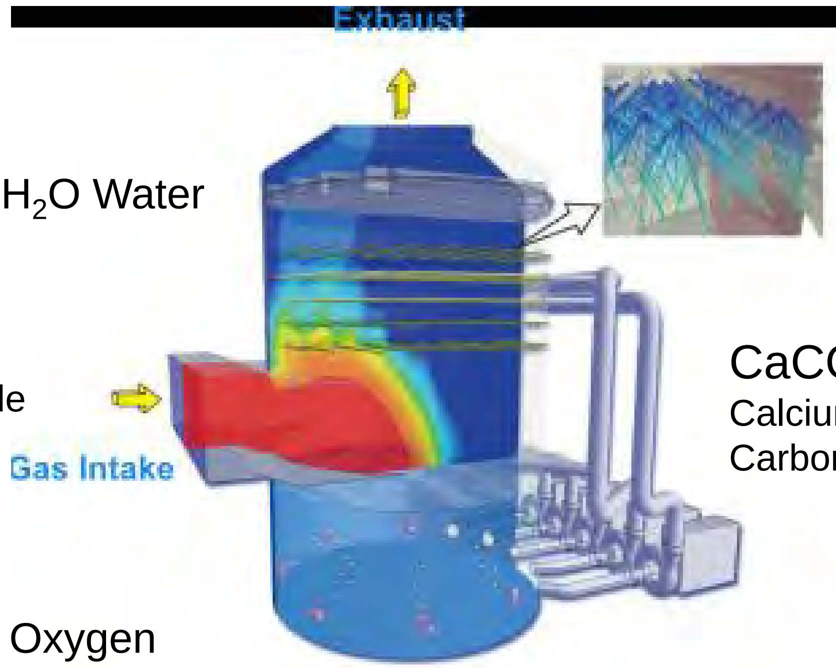
Sulfur Dioxide	Limestone	Oxygen	Water	Gypsum	Carbon Dioxide
SO2 +	CaCO3+	O2 +	H20→	CaSO4*2H20 +	CO2
Gas	Solid	Gas	Liquid	Solid	Gas

- SO2 Absorption
  - SO2 absorbed in absorber
  - Neutralization of the absorber SO2 to keep the SO2 vapor pressure low allowing more SO2 to be absorbed
- Limestone Dissolution
  - Provides alkalinity for neutralization and calcium ion for precipitation
- Oxidation
  - Absorbed SO2 with forced oxidation forms sulfate
- Precipitation
  - Precipitation of calcium and sulfite or sulfate forms byproduct

Limestone/Forced Oxidation

CO_2 Carbon Dioxide



H_2O Water

SO_2Sulfur Dioxide

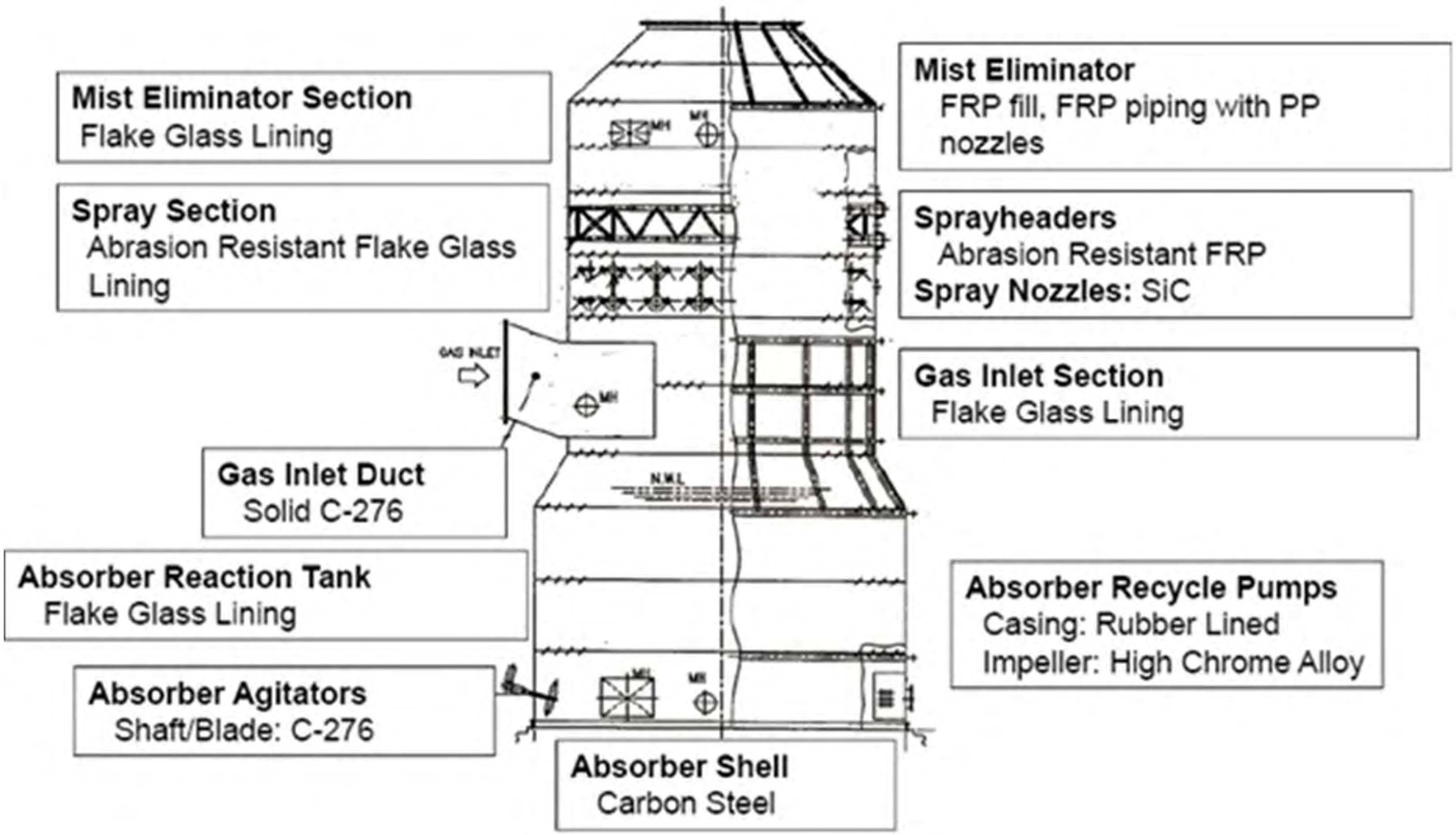
$CaCO_3$
Calcium
Carbonate

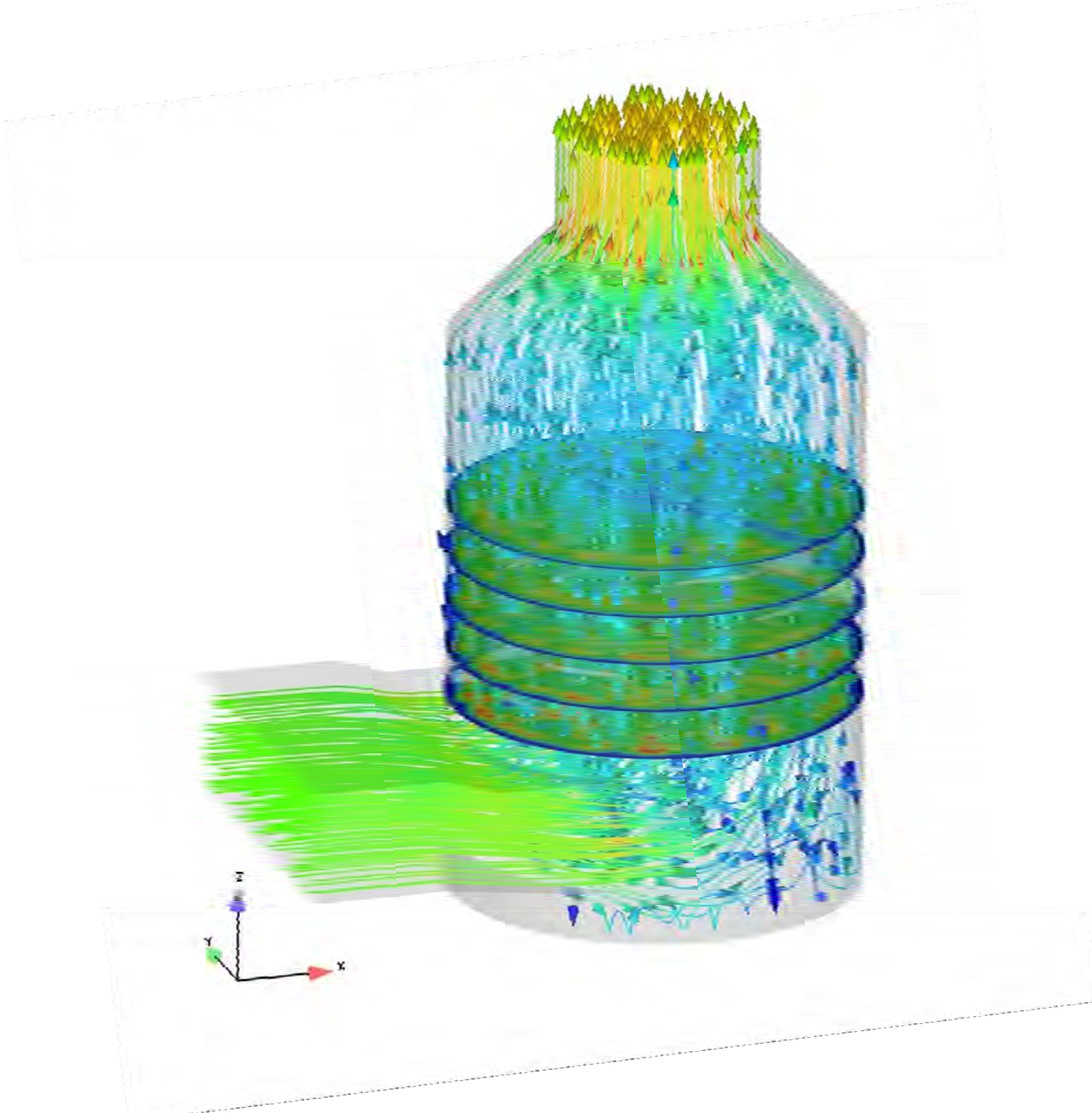
O_2 Oxygen

$CaSO_4$*$2H_2O$ – Calcium Sulfate

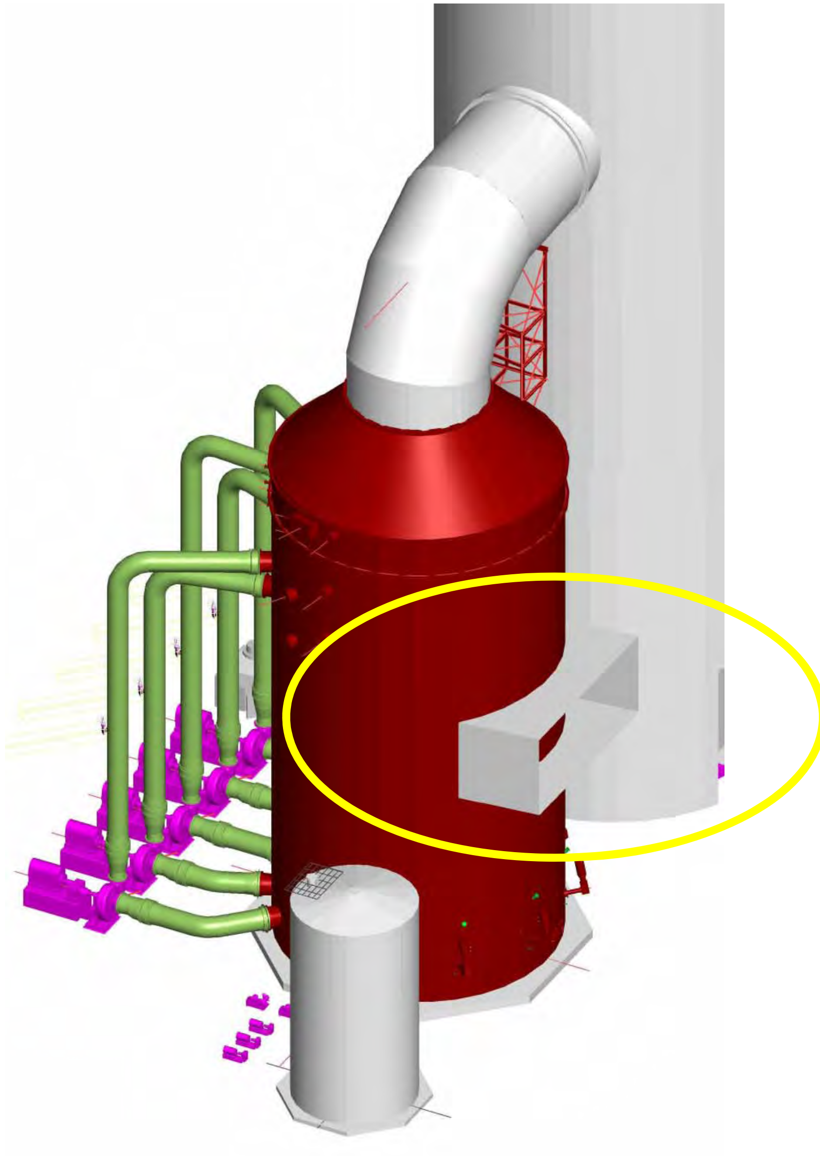
$$\mathbf{SO2 + CaCO3 + \frac{1}{2}O2 + H2O \rightarrow CaSO4 \bullet 2H2O + CO2}$$

Absorber – Typical Materials of Construction




Z
Y
X

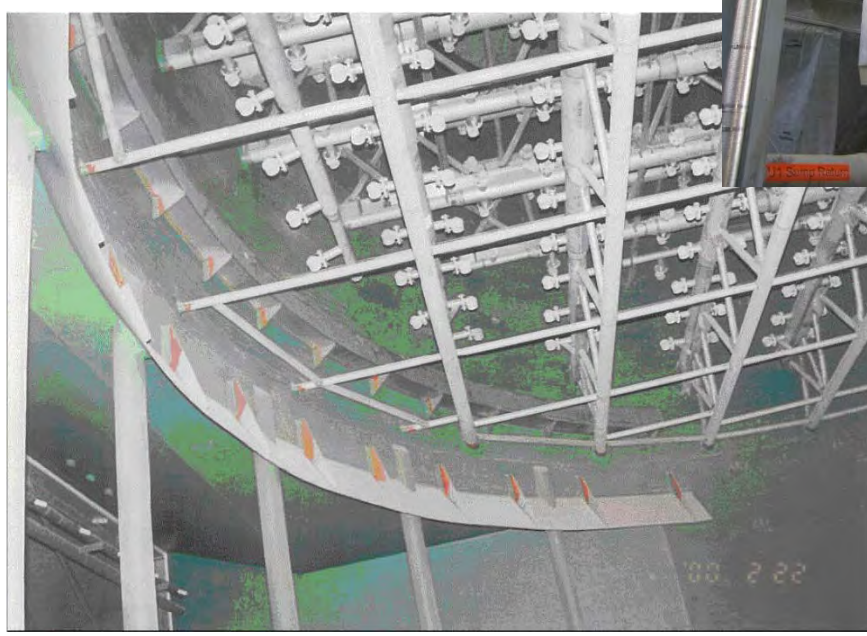
Absorber Inlet



- Solid Alloy (C-276) to Eliminate Wet/Dry Interface Corrosion
- High Velocity Inlet Ensures Gas Flow to Opposite Wall
- Maintain Duct Proportion to Eliminate Side Swirls and Backflow
- Optimum "Cutout" for Gas Distribution and Shell Strength
- Alloy Posts for Additional Strength

Absorber Inlet

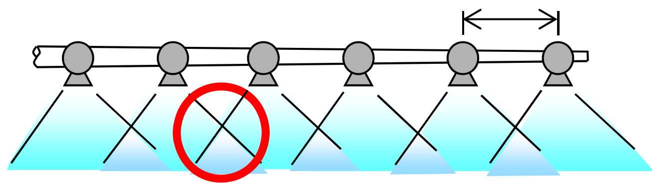
- Solid Alloy to Eliminate Wet/Dry Interface Corrosion
- High Velocity Ensures Gas Flow to Opposite Wall
- Inlet Geometry Eliminates Side Swirls and Backflow

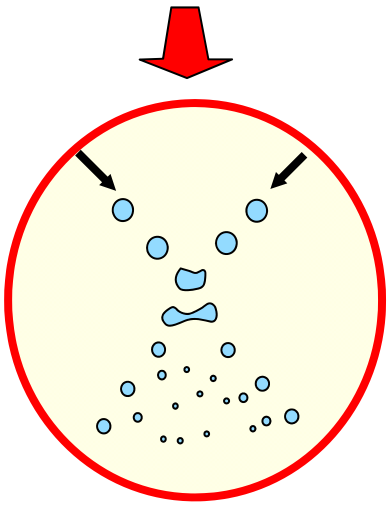


Consideration for Collision of Droplets

High Density Spray

2.5'~4.0' **← 5' (Conventional)**

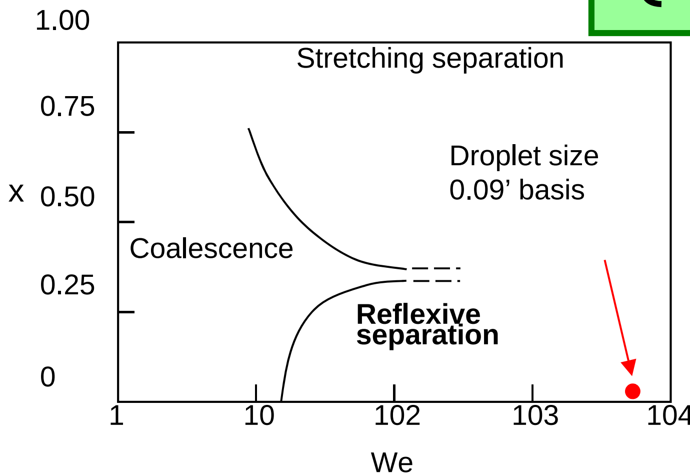




Weber Number

$$We = \frac{\rho d_s u^2}{\sigma}$$

σ : Surface tension force [N/m]
ds : Diameter of spray droplet[m]
u : Relative velocity[m/s]
ρ : Density[kg/m3]



(x : Spray Angle Factor.)

1) Fine droplets are produced by collision of droplets at high Weber number
2) Generation of fine droplets are enhanced by high density spray

High Gas Velocity Design

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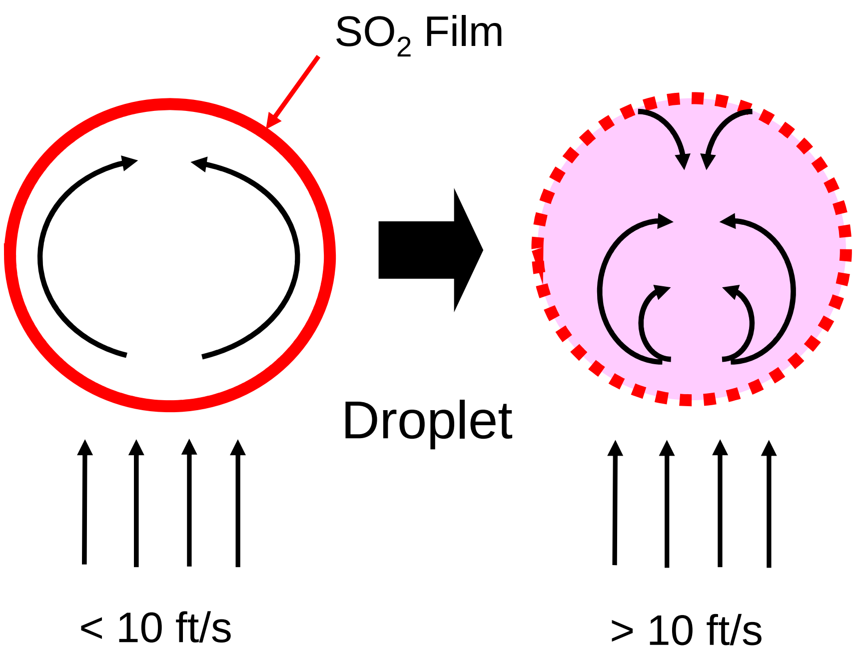
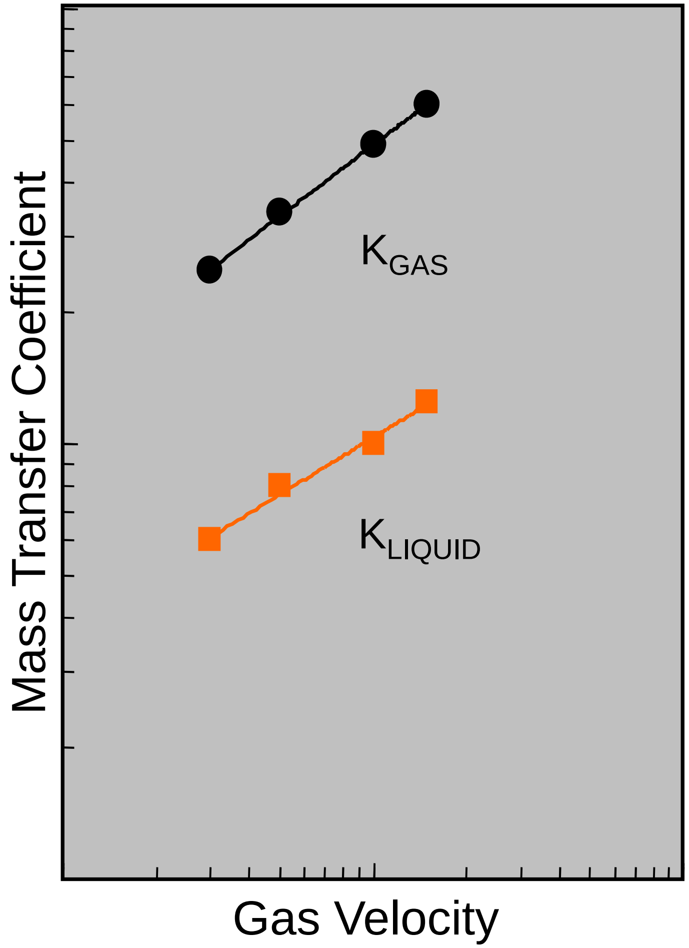
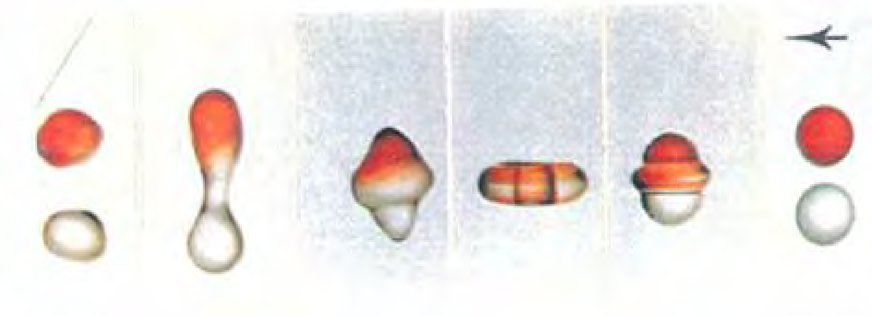


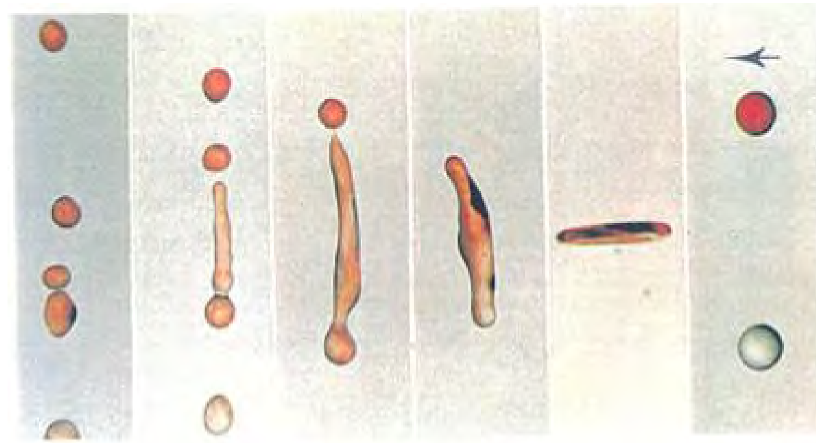
Enhanced Surface Mixing
Increases Pollutant Removal



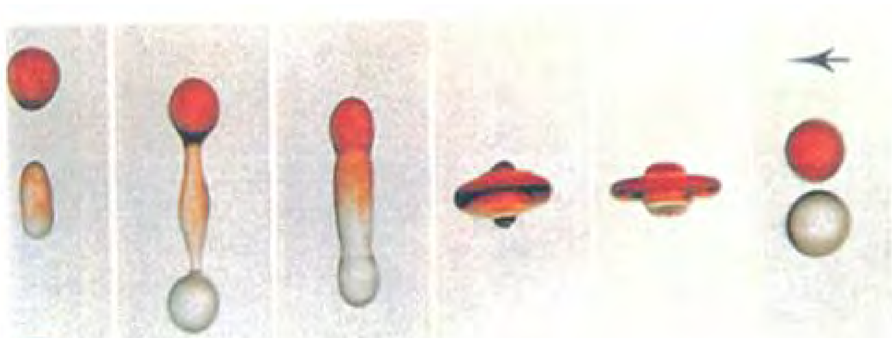
Efficient removal of pollutants and compact scrubber size



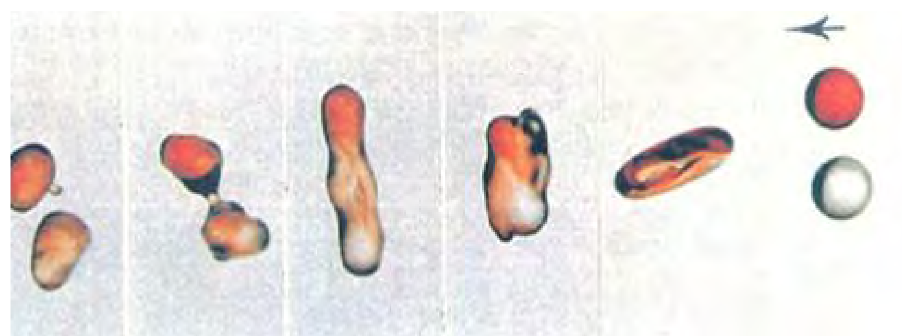
Reflexive Separation
We=23, x=0.05



Five-Drop Reflexive Separation
We=96, x~0



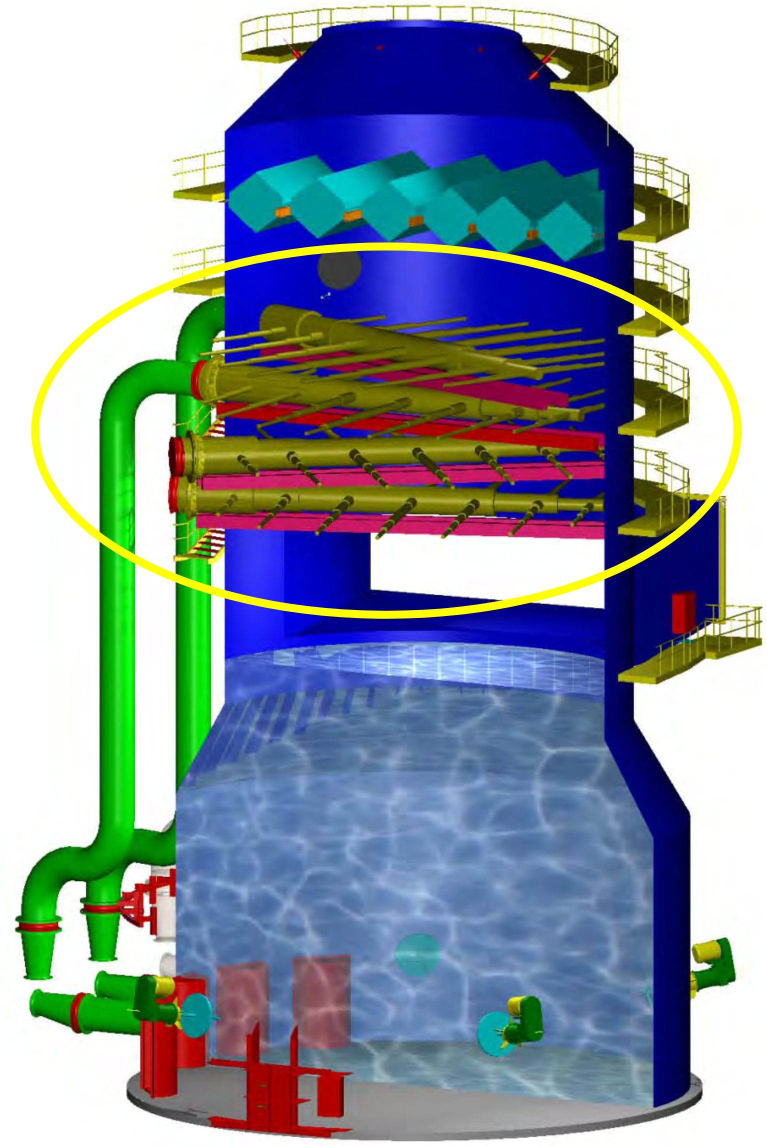
Three-Drop Reflexive Separation
We=40, x=0



Off-Center Reflexive Separation
We=40, x=0.1

Spray Zone

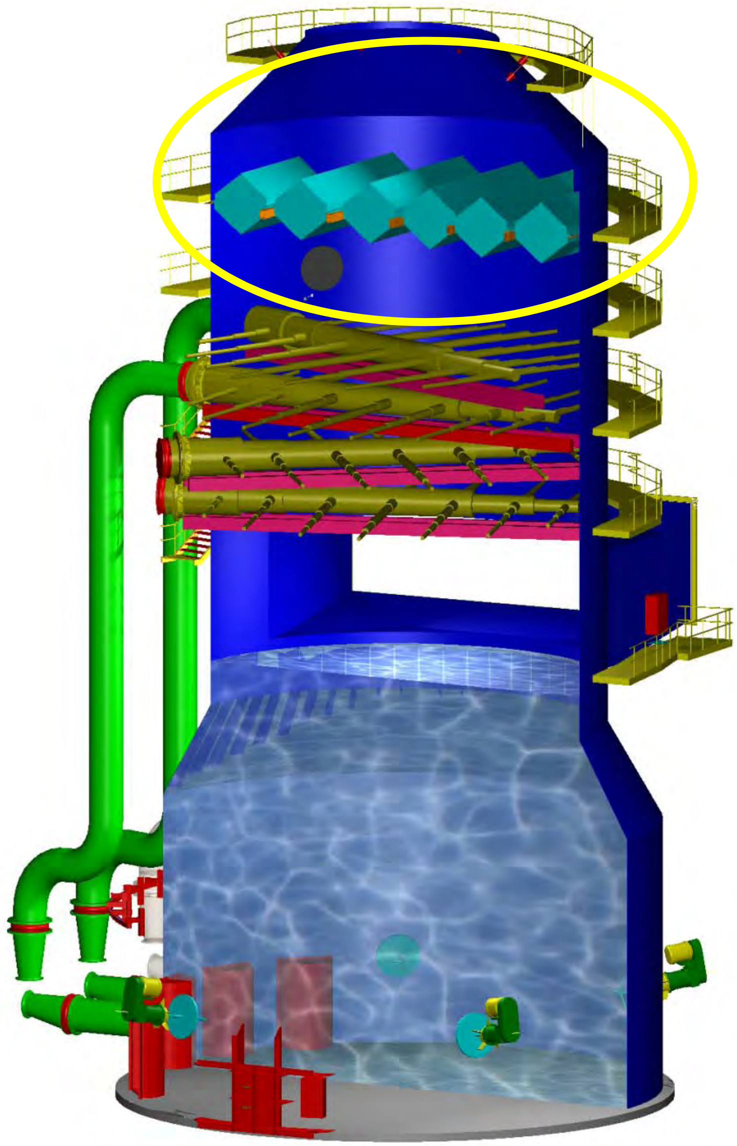
- Optimum Flue Gas Velocity For Mass Transfer & Pressure Drop (13 – 14 ft/s)
- Single-Penetration Spray Headers For Ease of Fabrication & Erection
- High Spray Flux Minimizes Velocity Variation & Maximizes Gas-Liquid Contact
- Radial Baffles (Wall Rings) Eliminate Sneakage
- Dedicated recirculation pump at each spray header

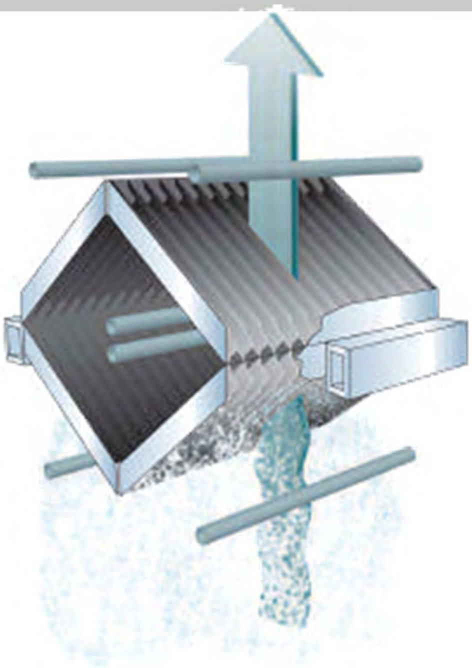


High Flux, Variable Density Spray Arrangement

- High Spray Flux Minimizes Velocity Variation
- High Spray Flux Maximizes Gas-Liquid Contact
- Higher Nozzle Density Near Absorber Wall Increases Spray Coverage and Eliminates Sneakage

- Progressive Flux Density Moves Gas Away From the Absorber Wall Toward the Center

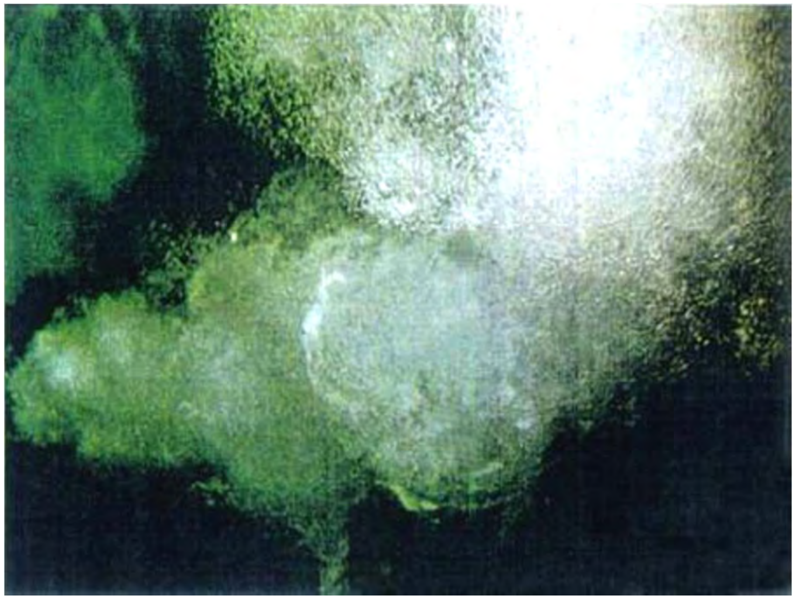




- Munters DV210+
- High Breakthrough Velocity
- FRP Frames & Polysulfone Blades
- Washed Bottom & Top of 1st Stage & Bottom of 2nd Stage

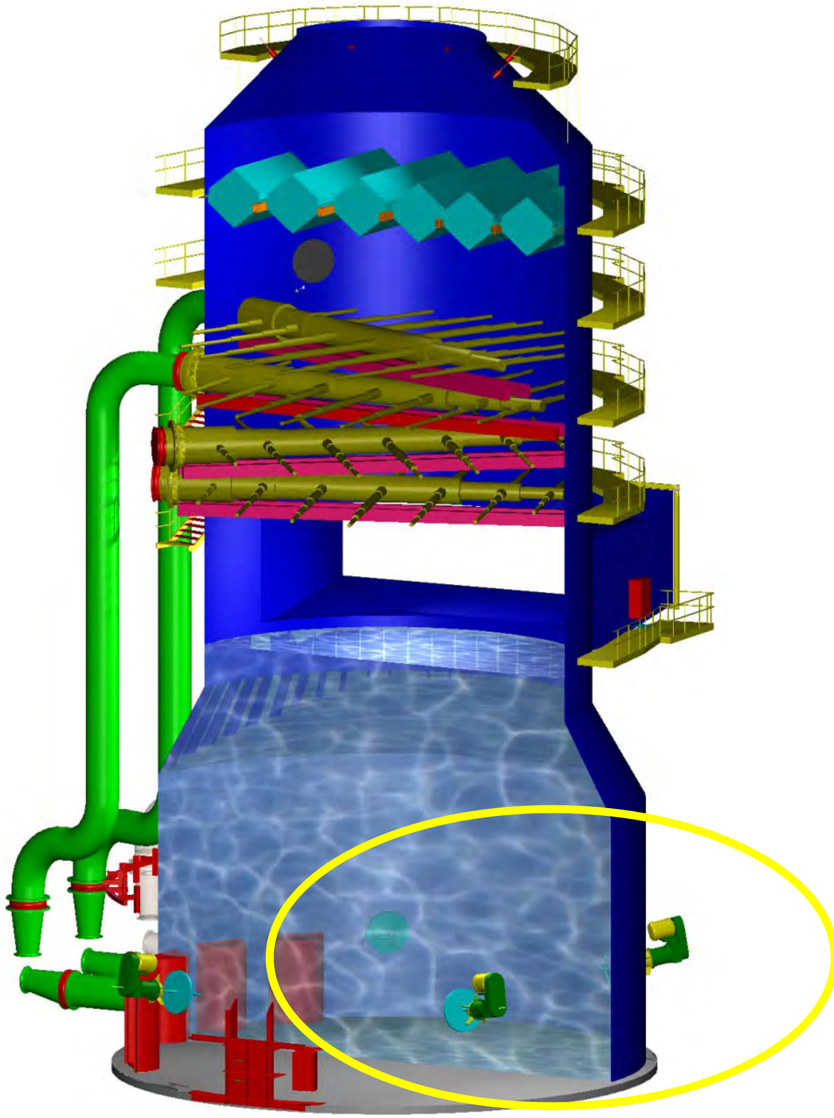
Reaction Tank Design

- In-Situ Forced Oxidation Employs Side-Entering Agitators and Air Lances.
- Reaction Tank Solids Residence Time Ensures Good Crystal Growth.



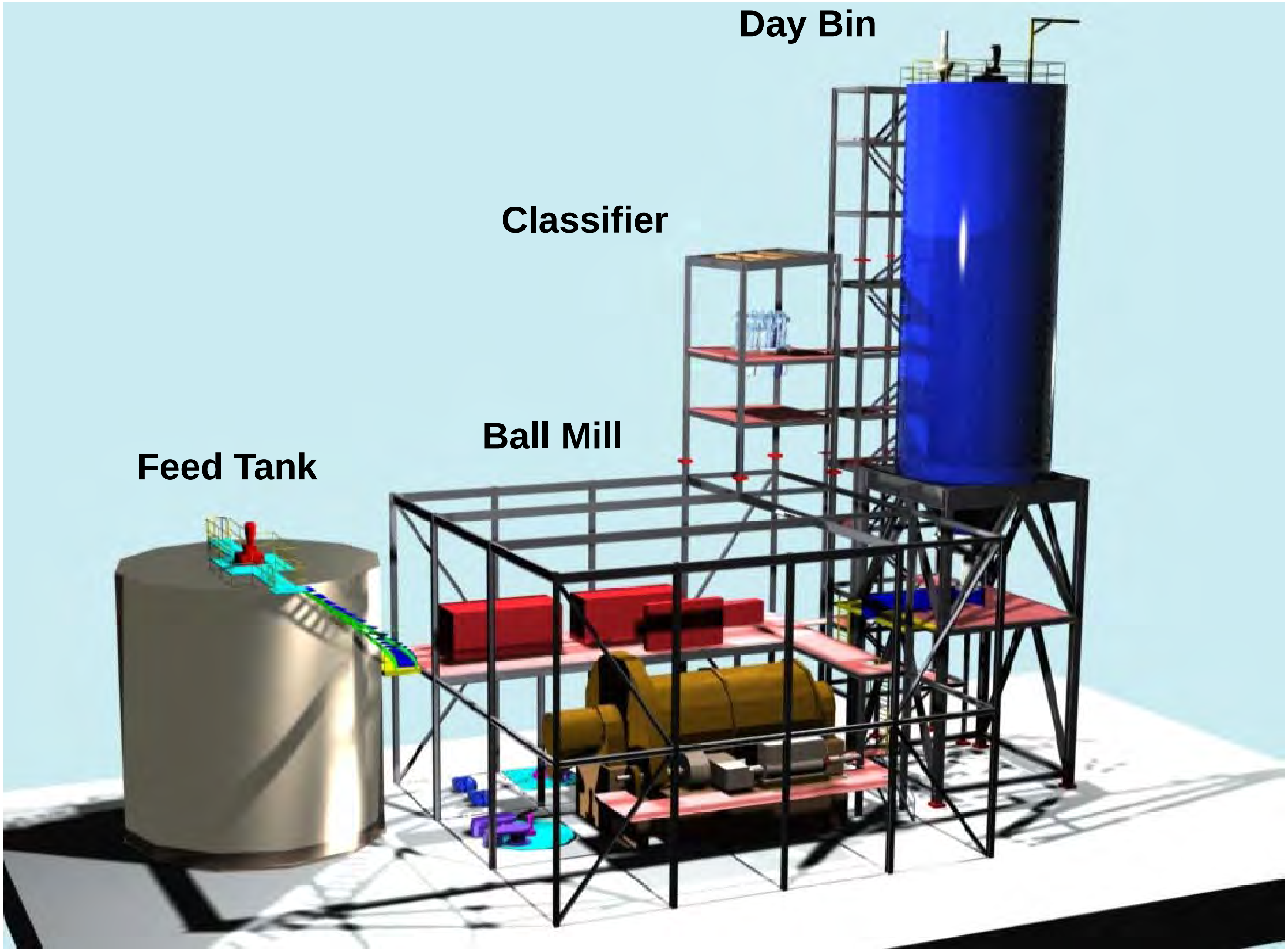
- High Solids For Enhanced SO_2 Removal and Better Dewatering

Reaction Tank



- High Suspended Solids For Enhanced SO_2 Removal & Better Gypsum Dewatering
- In-Situ Forced Oxidation Using Side-Entering Agitators & Air Lances

Reagent Preparation



Reagent Preparation

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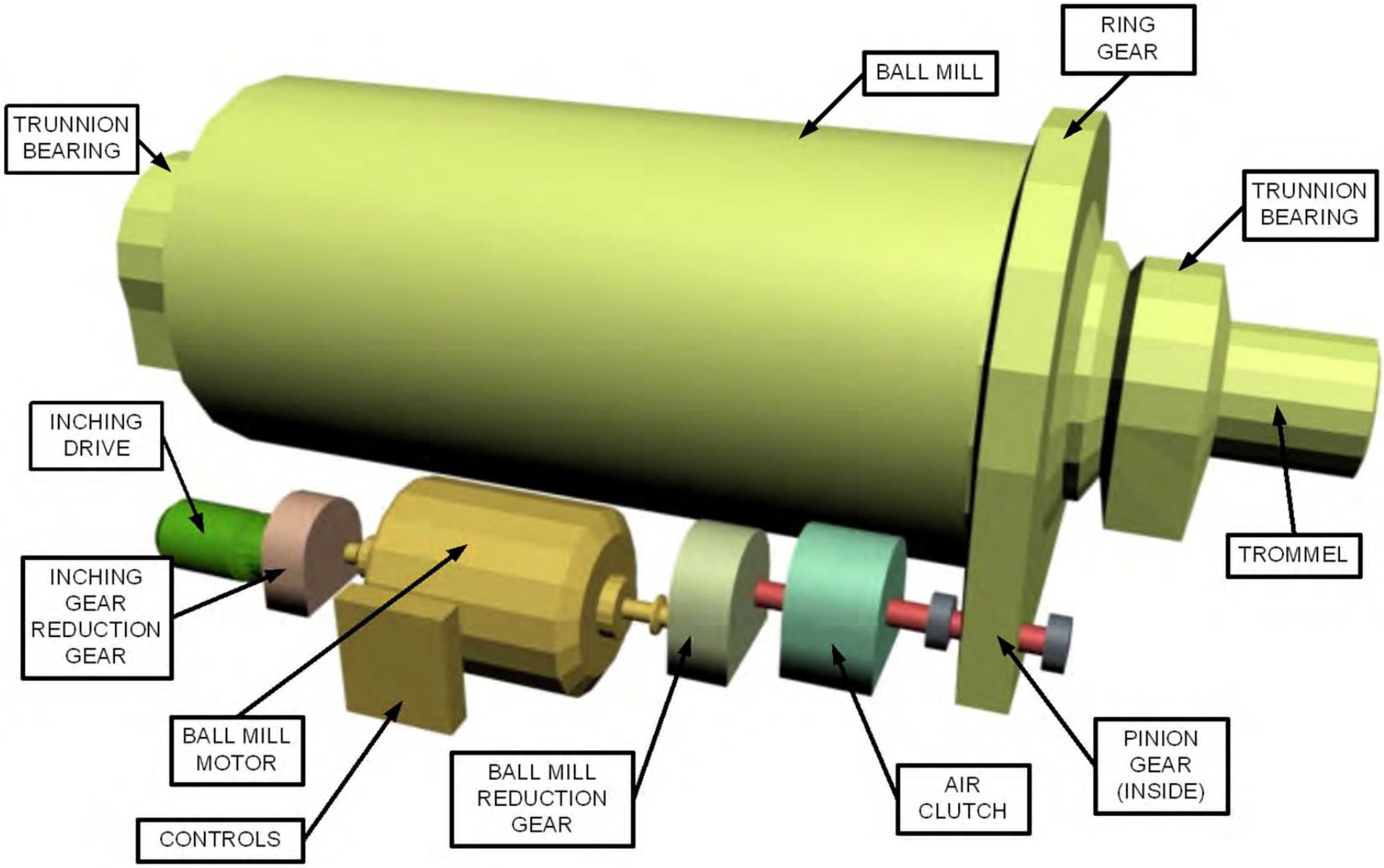
- Limestone Grinding:
  - Horizontal Ball Mill
  - On site preparation
  - 95% ~ 325mesh
  - Rubber lined with hardened steel balls

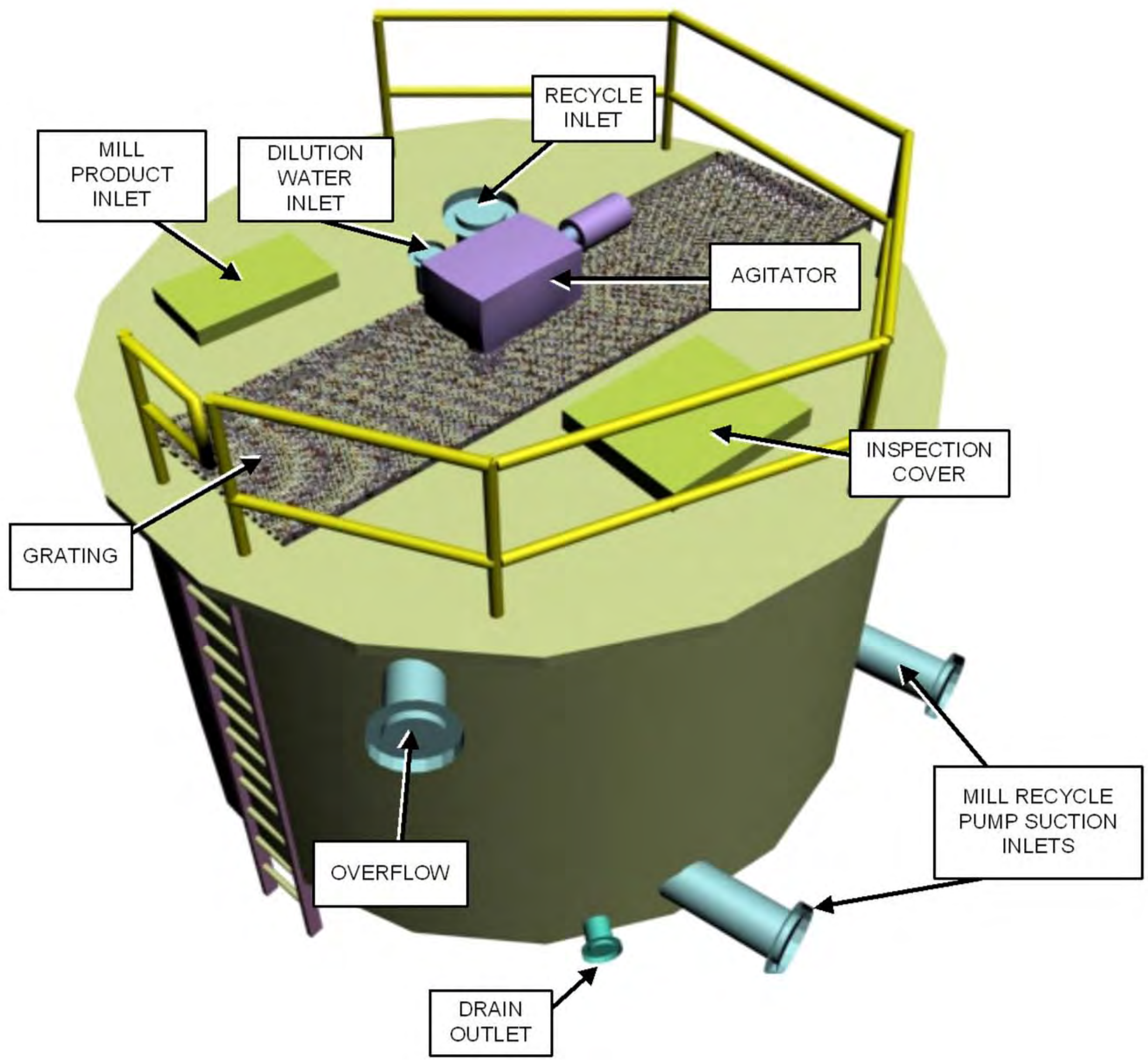
Courtesy: Metso

Ball Mill



TRUNNION BEARING
BALL MILL
RING GEAR
TRUNNION BEARING
INCHING DRIVE
TROMMEL
INCHING GEAR REDUCTION GEAR
BALL MILL MOTOR
CONTROLS
BALL MILL REDUCTION GEAR
AIR CLUTCH
PINION GEAR (INSIDE)

Mill Slurry Product Tank



Pre- Ground Limestone Injection

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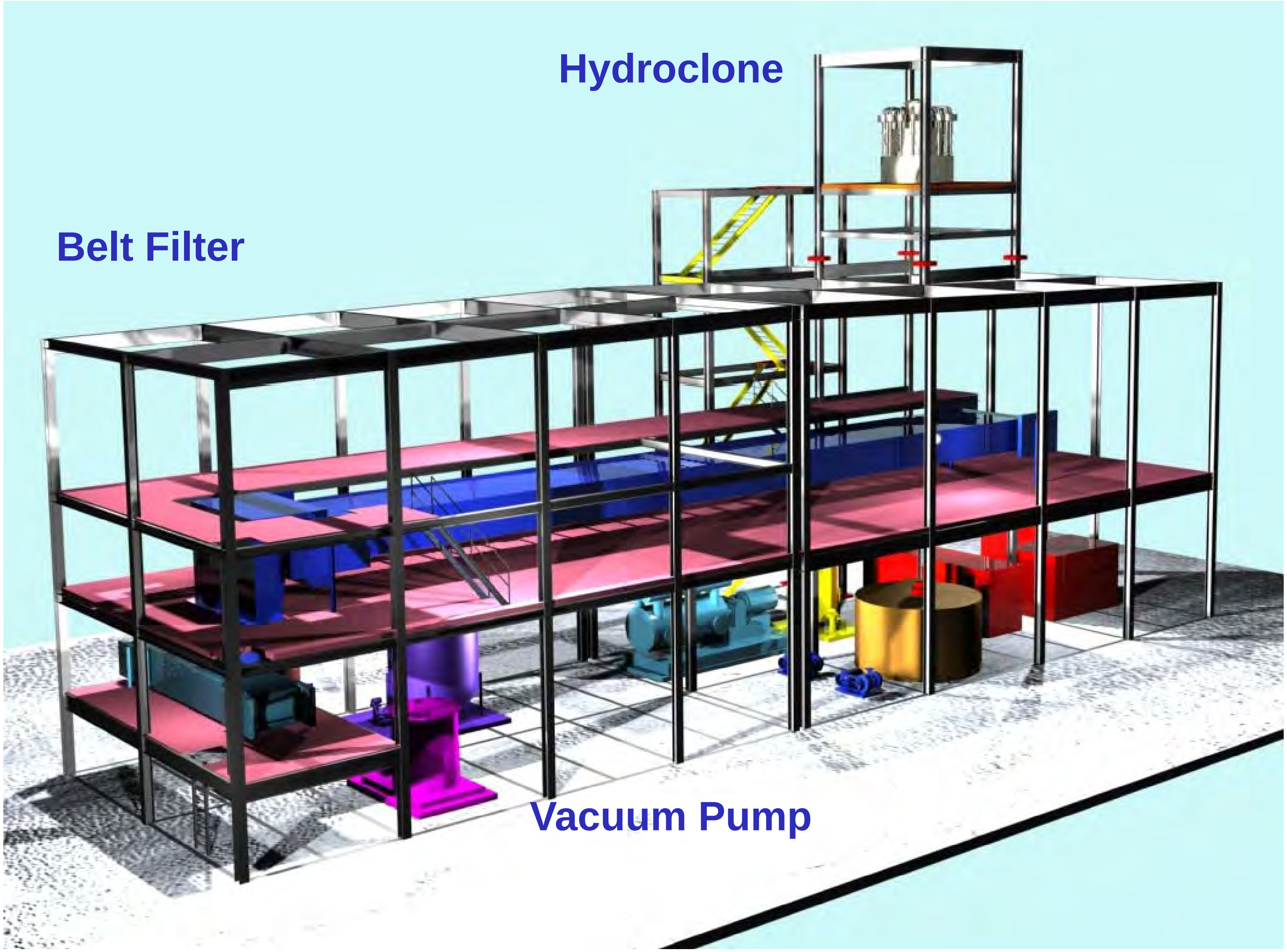
- Dry, pre-ground limestone feed options
- Pneumatic injection into reaction tank below slurry level
- Pre-slurry in small tank
- Advantages
  - Low capital cost (i.e. no ball mills, auxiliary equipment, buildings, etc.)
  - Less equipment to maintain
- Disadvantages
  - Higher delivered cost
  - Lifecycle cost evaluation on case-by-case basis

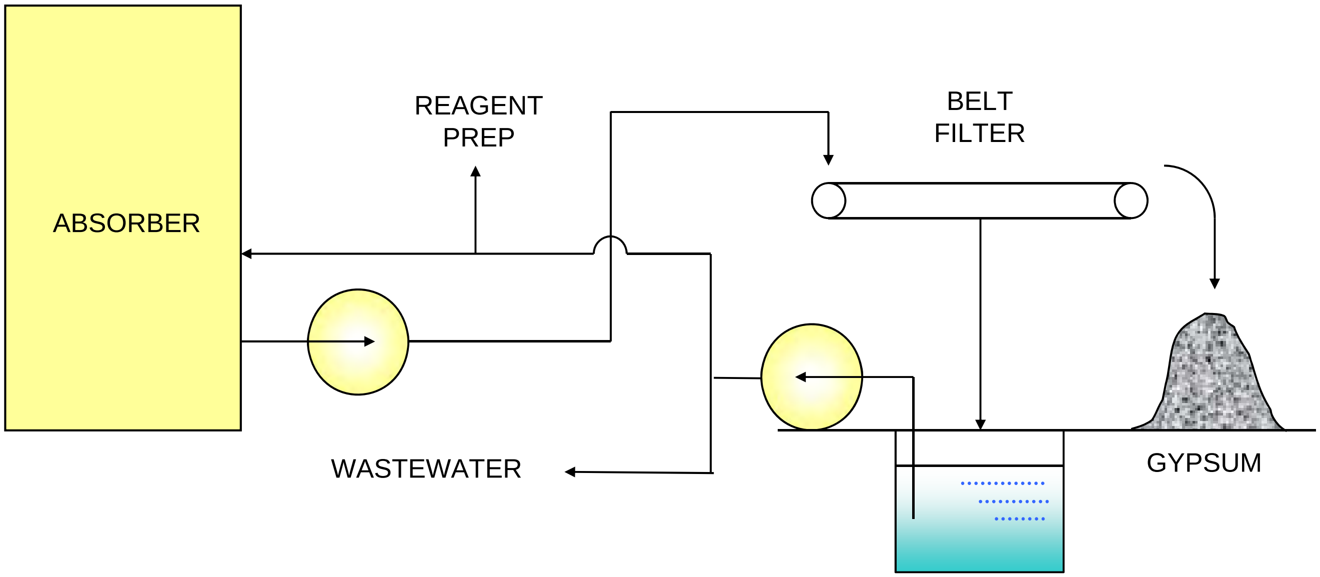
Absorber Recycle Pump

- Typical size: 50,000–85,000gpm at 55–85 TDH (Total Dynamic Head)
- Pump Efficiency: 87–90+%
- 800–1,500 hp (~1 MW)
- Horizontal, centrifugal
- Rubber-lined casing
- Metal Impeller
- Mechanical Seal

Dewatering



Single Stage Dewatering (Commercial Gypsum)

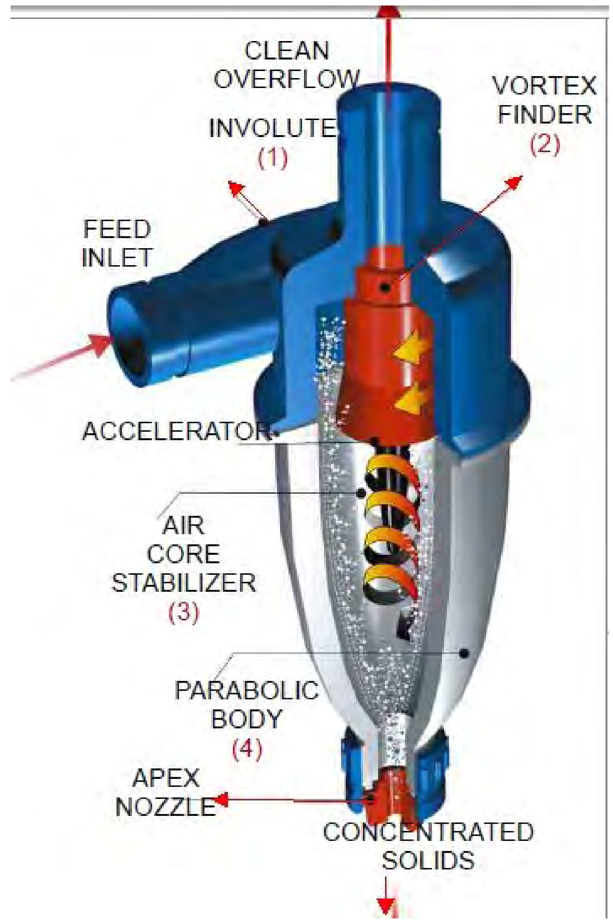


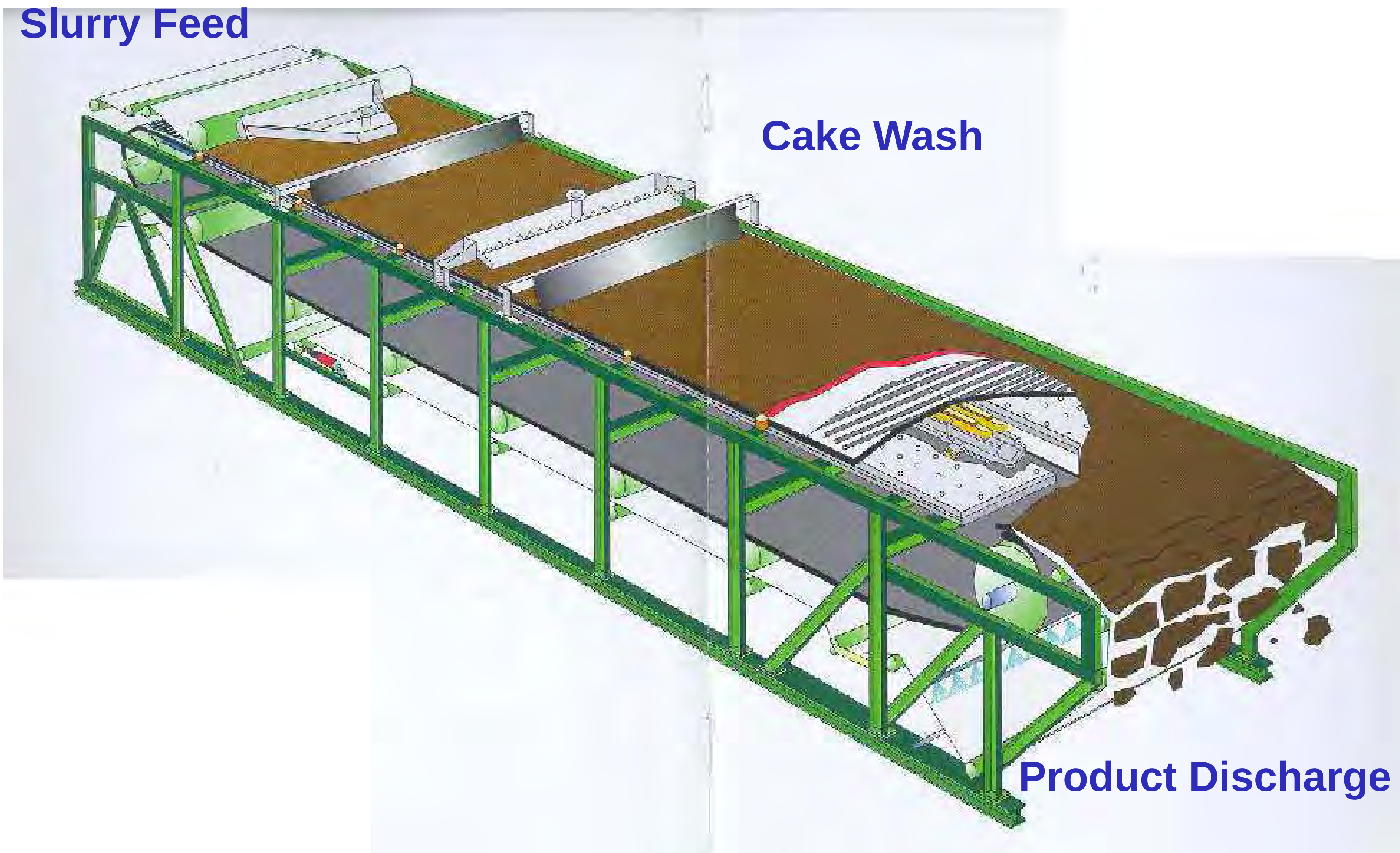
INSTALLATION	MW	BYPRODUCT MOISTURE (%)	GYPSUM PRODUCED (tons/hr)	STARTUP DATE
Ohita Refinery	149	6 to 8	10.4	3/99
Tamashima Unit 2	350	8	11.3	7/00
Tachibanawan Unit 2	1,050	8	19.9	12/00
Tamashima Unit 3	500	8	16.6	4/01
Sakaide Unit 3	450	9 to 10	11.0	12/03
Aichi Refinery	250	7 to 9	21.4	4/04

Primary Dewatering

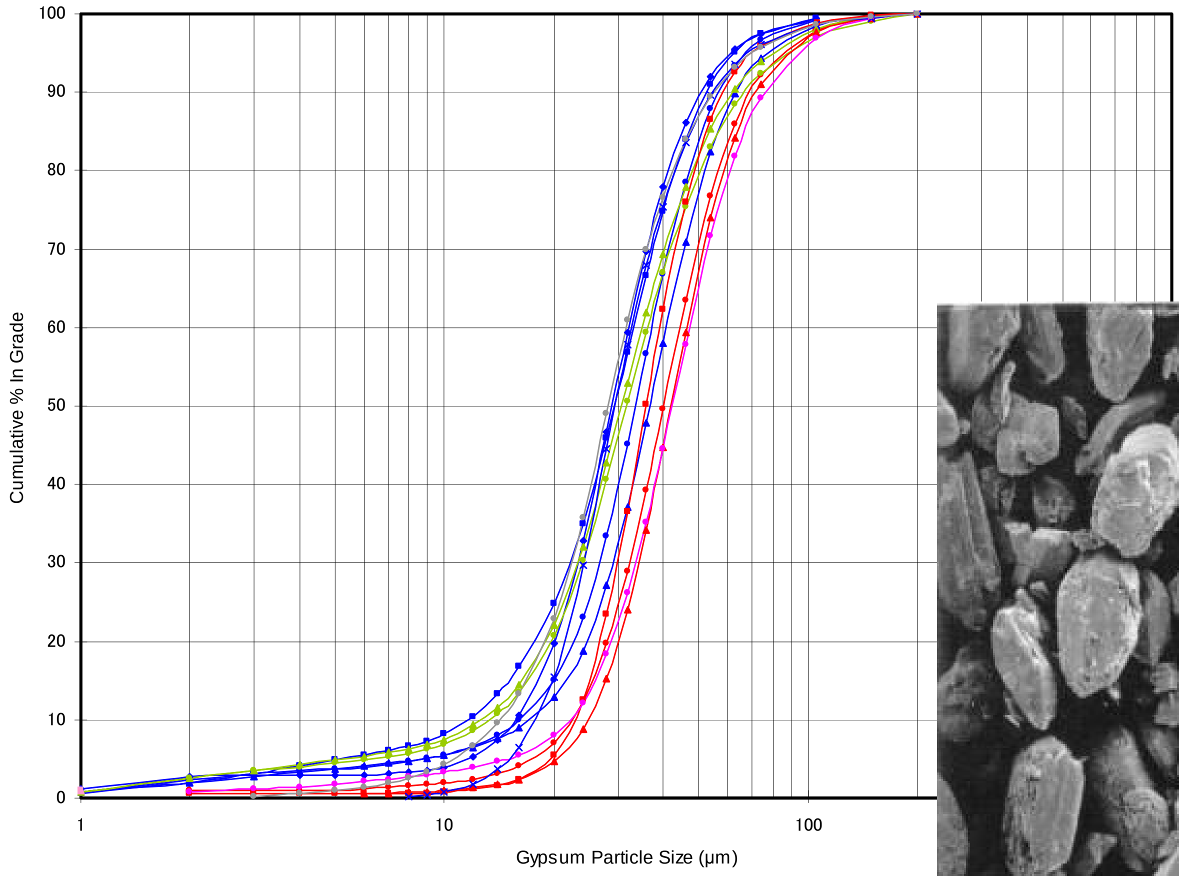
Gypsum Hydroclone:

- ✓ Heavy, coarse particles to underflow to secondary dewatering
- ✓ Lighter, fine particles to overflow including flyash, limestone
- ✓ No moving parts




Slurry Feed
Cake Wash
Product Discharge

High Quality Gypsum Byproduct



Agenda

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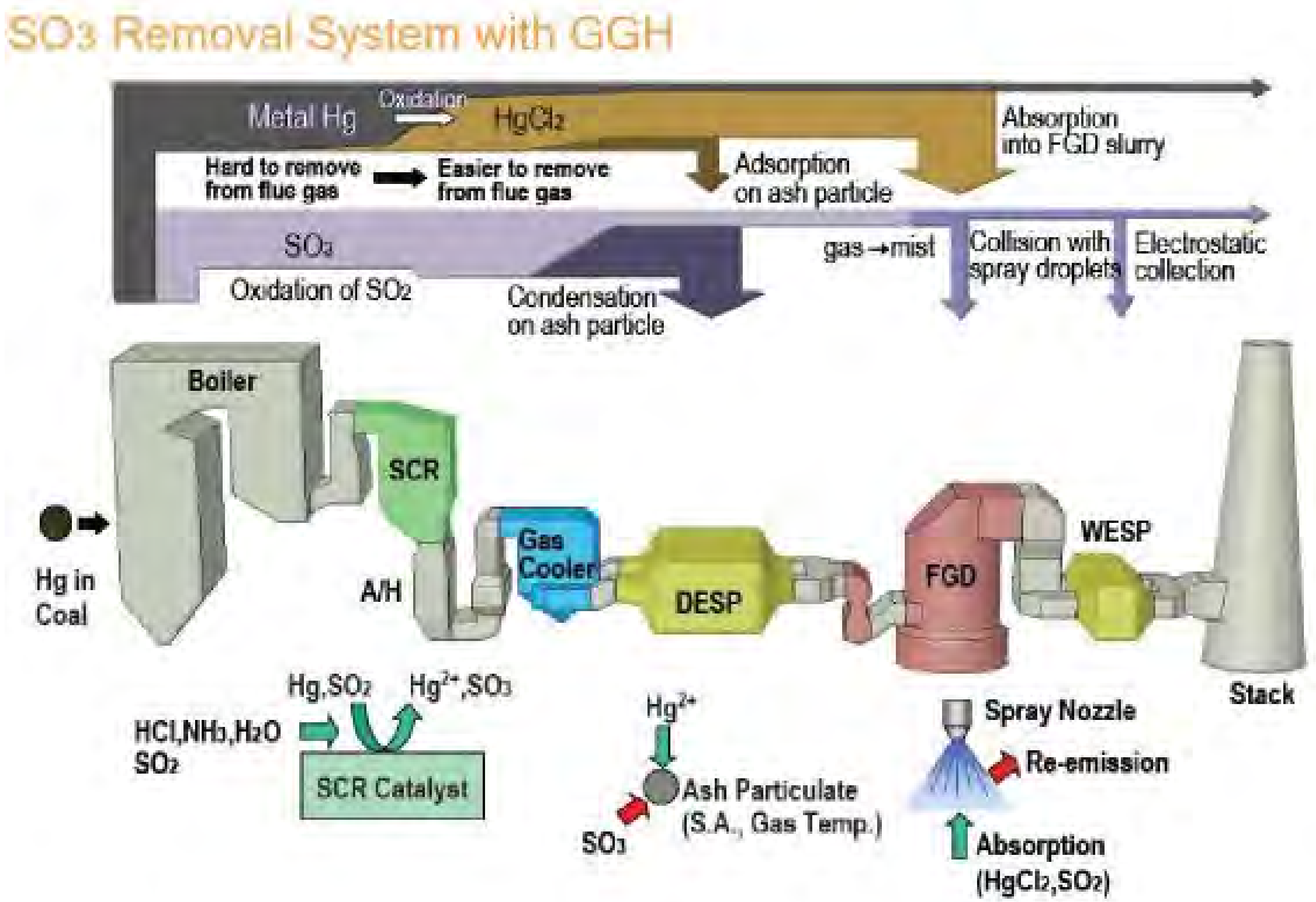
- Major Process Equipment
  - Absorber Inlet
  - Spray Zone
  - Mist Eliminator
  - Reagent Preparation
  - Dewatering
- **Secondary Emissions**
- Summary

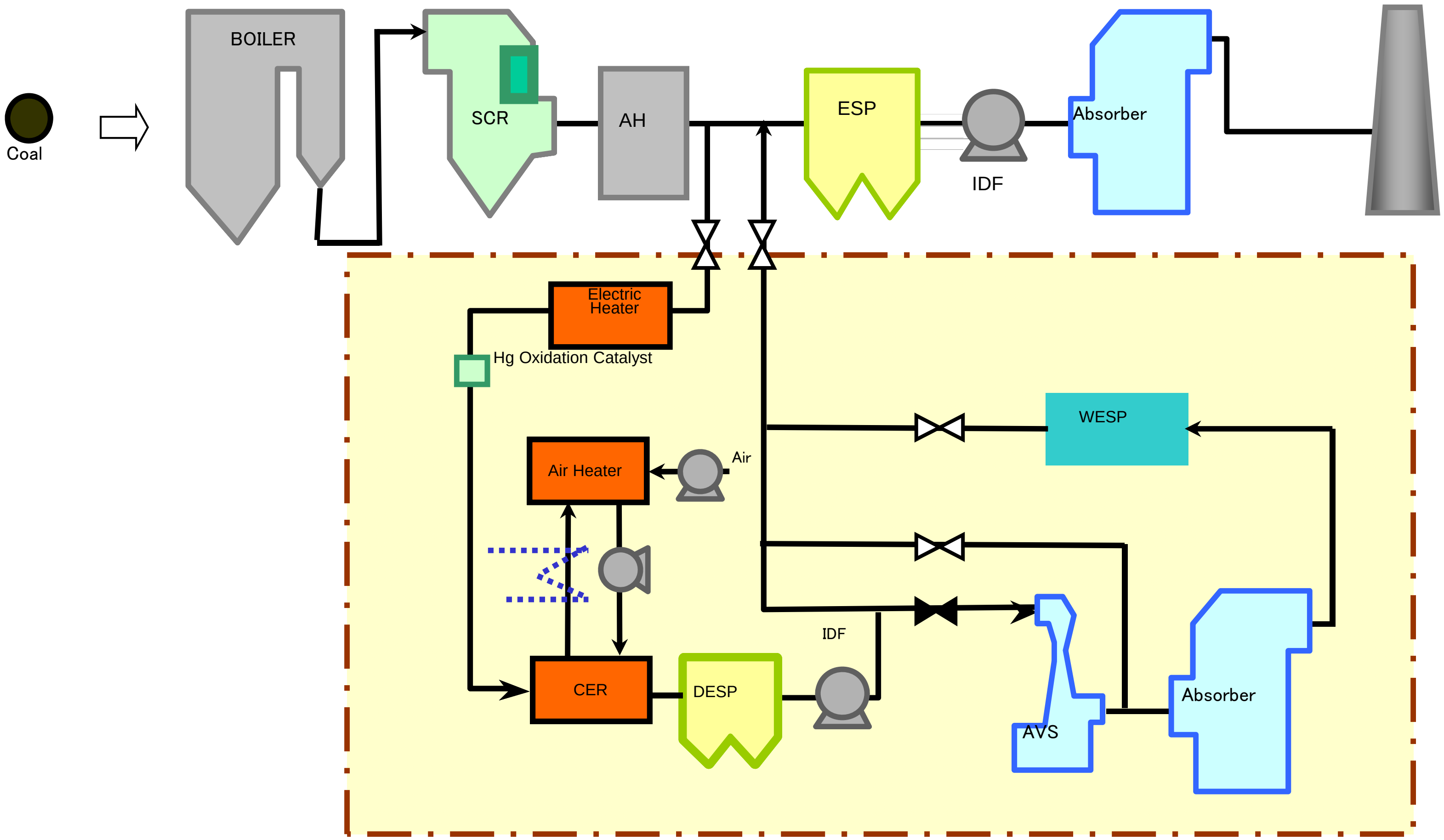
Sulfuric Acid Mist

- SO_3 Inlet concentration
  - <1 ppm for PRB (western sub-bituminous)
  - >50ppm for BIT (eastern bituminous)
  - H_2SO_4 mist – caused by rapid quenching of flue gas in absorber
- SO_3Control Techniques
  - Current technologies
    - Alkali's – lime, trona, sodium bicarbonate
    - DowntreamWet ESP
  - New technologies
    - (CGR)Clean Gas Recuperator – finned tube gas cooler located upstream of DESP
    - Successfully demonstrated at Duck Creek Pilot Plant and in service in 5 Power Plants in Japan

SO3 Removal System with GGH (CER)



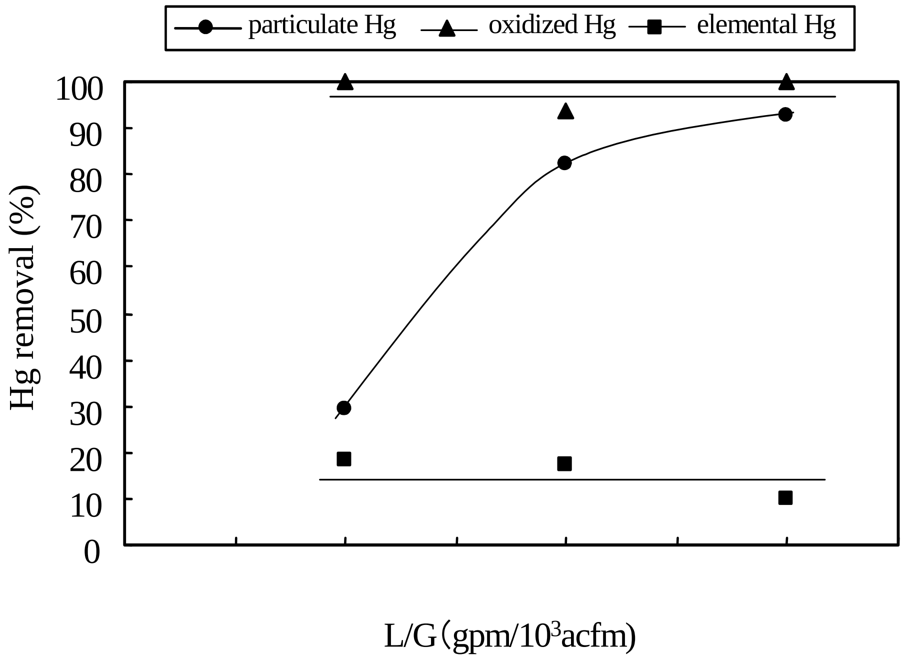
Ameren Duck Creek Pilot Plant – Advanced WFGD

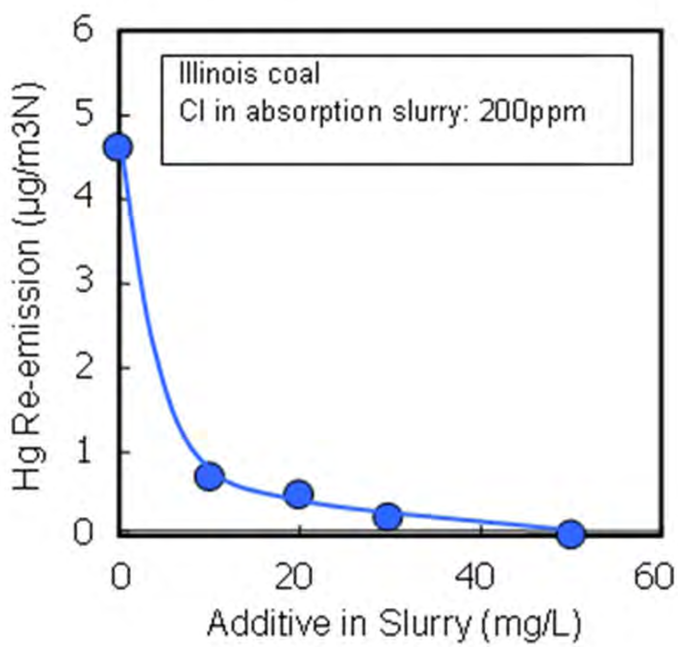


Mercury

- Mercury enters the WFGD via the fuel
  - Small amounts of Mercury can also enter WFGD with limestone and/or make-up water
- WFGD systems remove 70-90% of incoming Mercury Chloride ($HgCl_2$)
  - but very little elemental mercury (Hg^0)
- $HgCl_2$ is water soluble and is absorbed efficiently in the WFGD
  - Oxidized Hg is a function of
    - Fuel (higher chlorine content in fuel can aid in oxidizing mercury)
    - Boiler operating conditions – UBC has similar benefit as ACI
    - Upstream equipment – SCR, ESP, FF
- Effluent flue gas contains mostly elemental, vapor-phase Hg
  - % of Oxidized mercury captured by WFGD can be reduced to elemental mercury and re-emitted

Mercury Removal Across Wet FGD

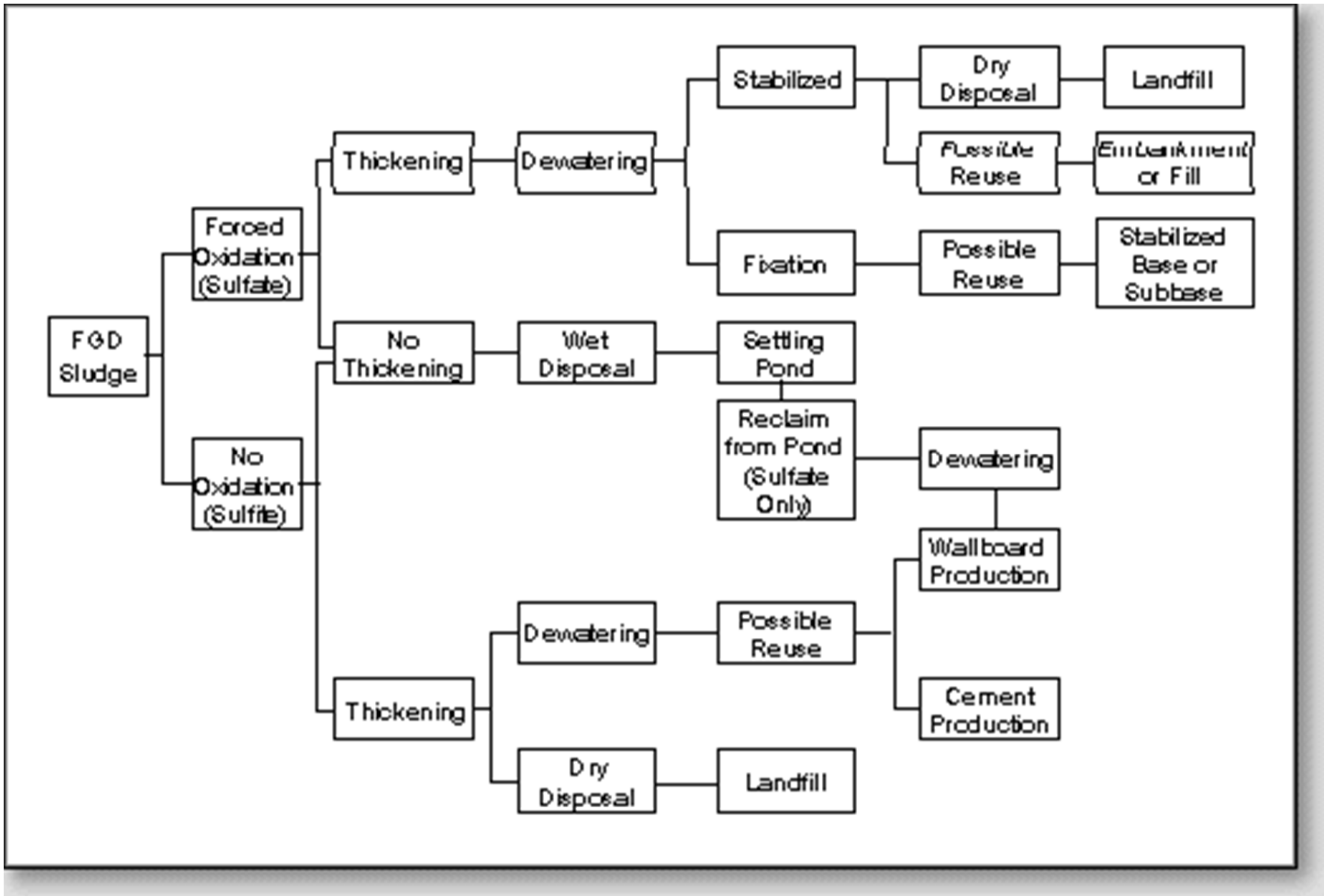




- **Oxidized and particulate mercury is effectively removed in WFGD**
- **Effective additives are being developed for controlling re-emissions**

- Almost all FGD scrubber material generated is disposed of in holding ponds or in landfills
- Stabilization or fixation and placement in landfills is the most common method of disposal

WFGD Sludge Disposal



Summary WFGD Technical Considerations

- Environmental targets
- Design considerations
  - Footprint
  - Materials of construction
- Limestone Usage
  - On site grinding
  - Off site grinding
- Gypsum Production
  - High Quality
  - Disposal
- Water Consumption
- Power Consumption

- Rules of Thumb
  - 1.7T of limestone for every 1 ton of SO2 removed
  - 3 T of gypsum (95% purity, 10% moisture) for every 1 ton of SO2 removed
  - Power Consumption
    - 1.2 to 2% generation – depending on fuel

WFGD For Tomorrow

2025

- Integral Chimneys for Tight Site Retrofits
- New Materials (PP Headers & Linings!)

2020

- Mercury Sequestration (WFGD Absorber Additives)
- WFGD Wastewater Treatment
- Byproduct Stabilization

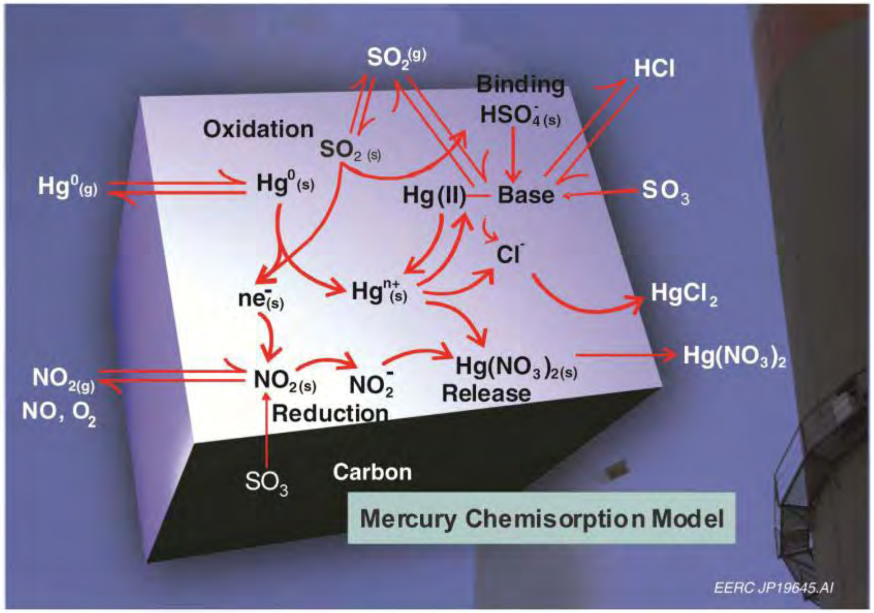
2015

Integral Chimneys for Tight Sites

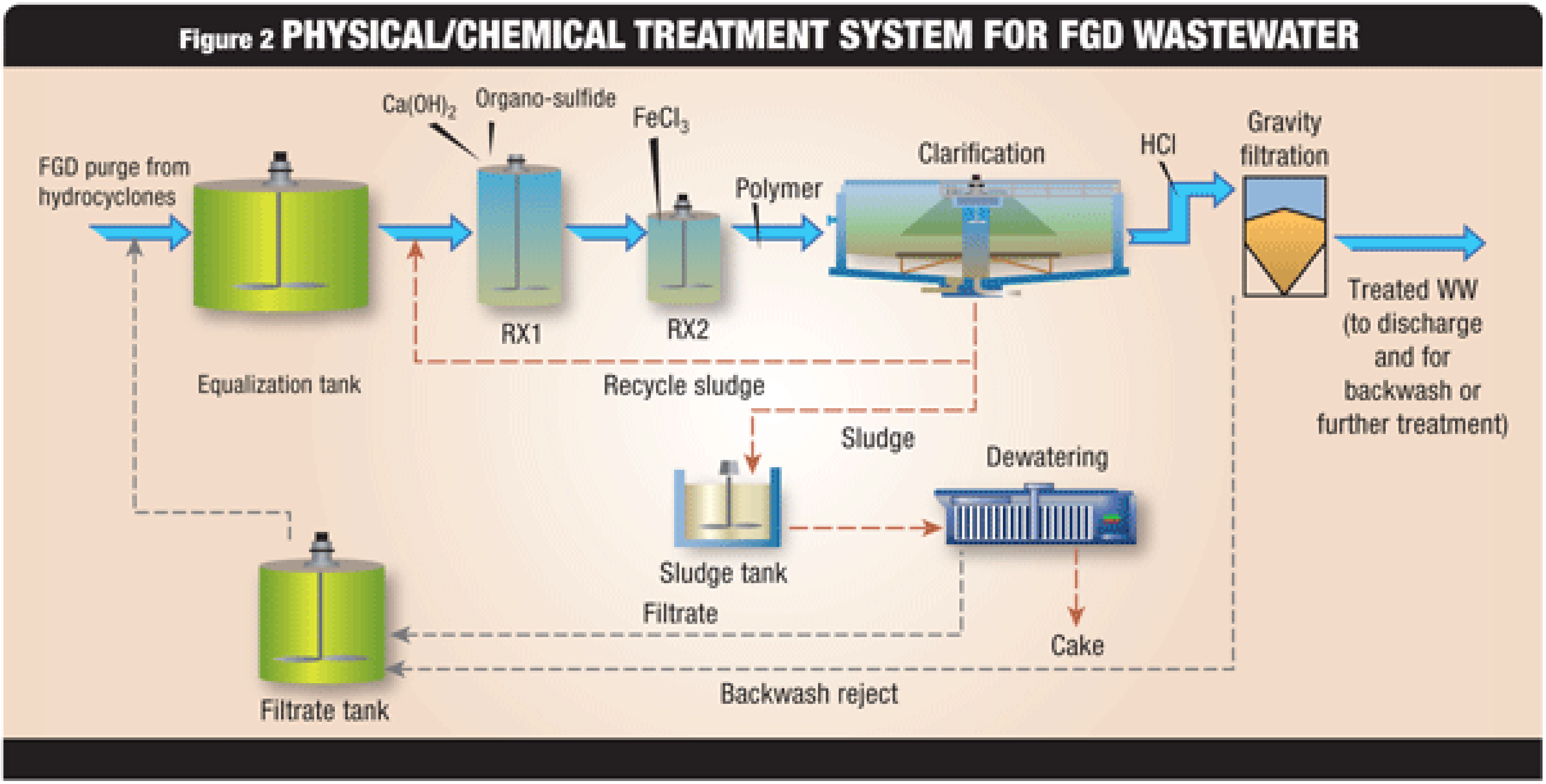
Mercury Sequestration

- Several new absorbent types are being developed in the market place.
  - For example, TMT 15® can be used in an WFGD to minimize the mercury (Hg) emissions. In this case, the chemical reduction of ionic mercury to elementary mercury by SO_2 is suppressed by fixing the ionic mercury with TMT 15®. Thus, Hg is separated from the flue gas and the emission in the cleaned gas can be minimized

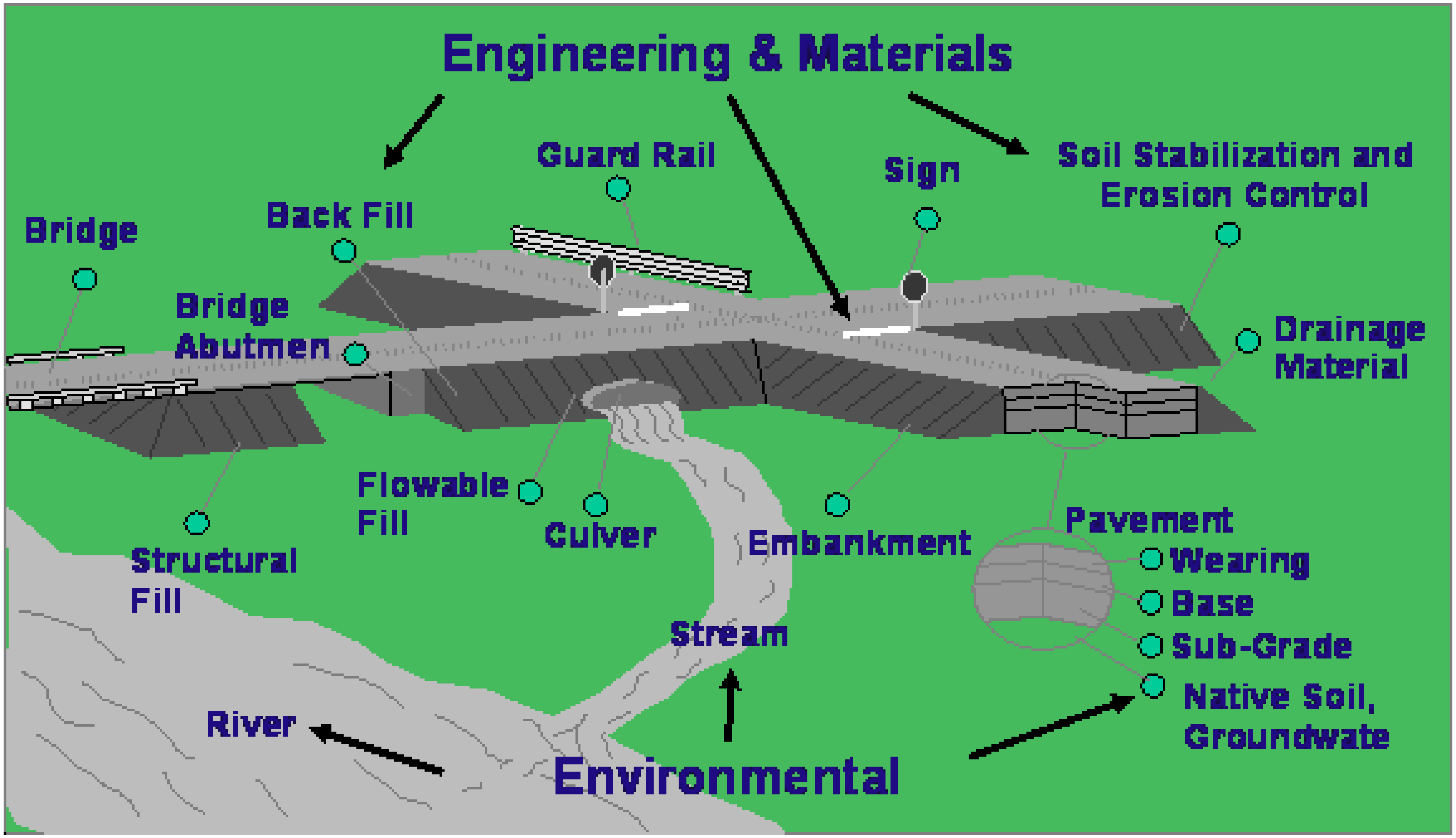
- Chemisorption - adsorption which involves a chemical reaction between the surface and the adsorbate. New chemical bonds are generated at the adsorbant surface.



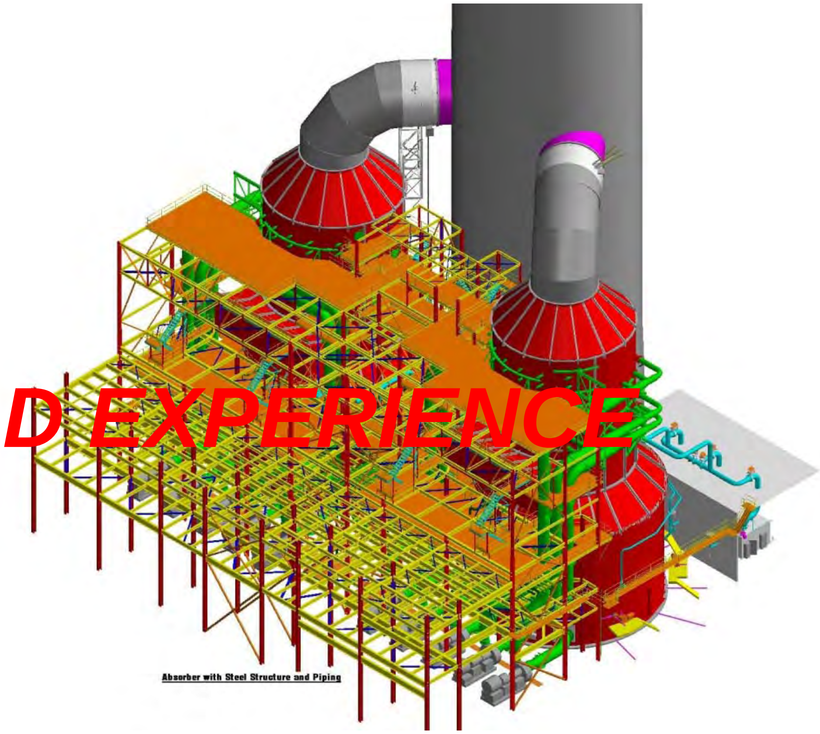
WFGD Waste Water Treatment



WFGD Byproduct Stabilization



AMEREN WET FGD EXPERIENCE



AMEREN Duck Creek, Coffeen & Sioux

Coal Being Utilized Today Much Different Than Design Basis of all Bituminous Coal

• Duck Creek	70% PRB/30% Bituminous
• Coffeen	95% PRB/5% Bituminous
• Sioux	80% PRB/20%Bituminous

OPERATING PERFORMANCE

RESULTS OF PERFORMANCE TESTS AT DUCK CREEK

Parameter	Guarantee	Test Result
• Particulate Emissions	≤ 0.015 lb/MMBtu	0.0045 lb/MMBtu
• SO_2 Removal	≥ 99% Removal	99.83% Removal
• SO_2 Emissions	≤ 0.064 lb/MMBtu	0.0038 lb/MMBtu
• SO_3 Removal	≥ 60% Removal	72.1% Removal
• Mercury Removal	≥ 90 % Removal of Oxidized Mercury	99.0% Removal

RESULTS OF PERFORMANCE TESTS AT COFFEEN

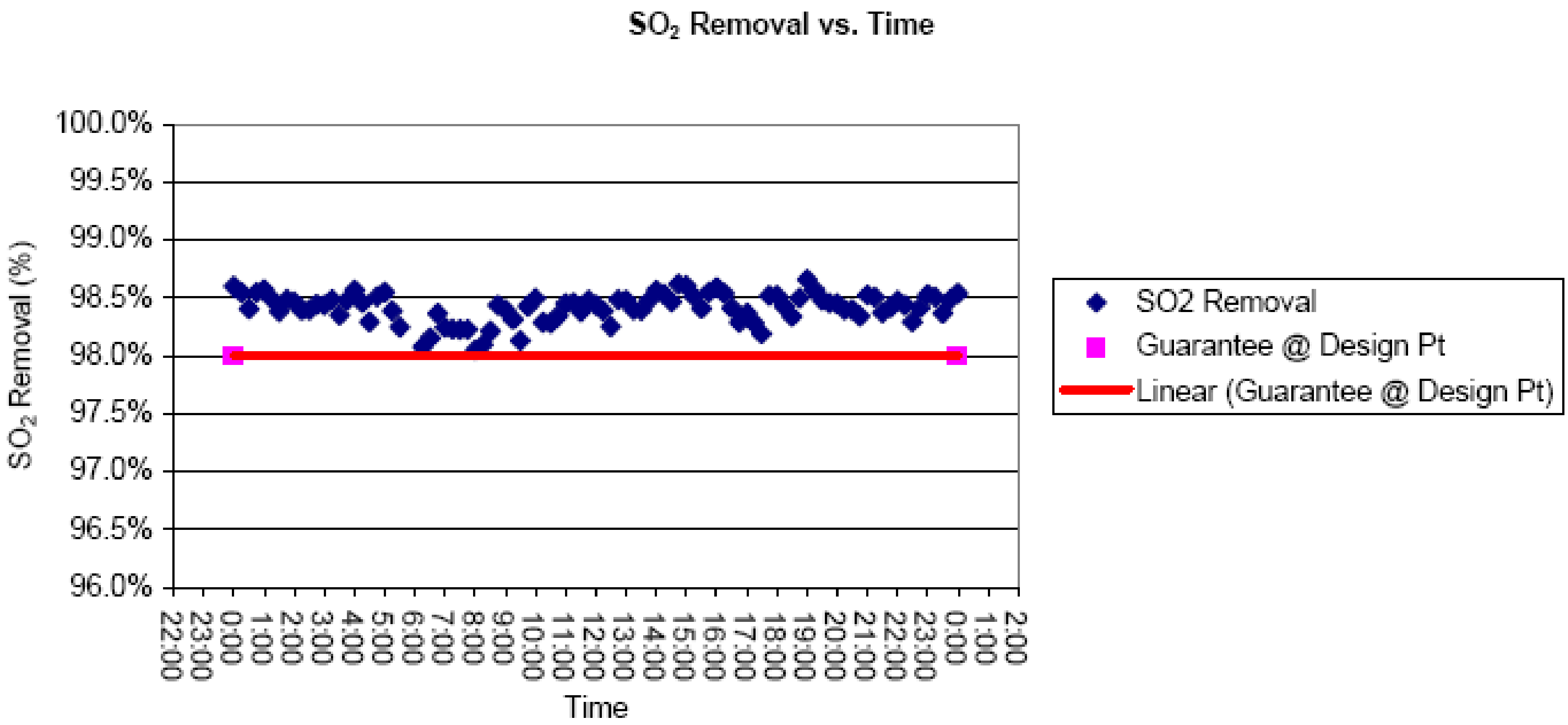
Parameter	Guarantee	Test Result
• Particulate Emissions	≤ 0.015 lb/MMBtu	0.0047 lb/MMBtu
• SO_2 Removal	≥ 99% Removal	99.95% Removal
• SO_3 Removal	≥ 60% Removal	67.45% Removal
• Mercury Removal	≥ 90% Removal of Oxidized Mercury	84.35% Removal (Note)

RESULTS OF PERFORMANCE TESTS AT SIOUX

Parameter	Guarantee	Test Result
• Particulate Emissions	≤ 0.015 lb/MMBtu	0.0062 lb/MMBtu
• SO_2 Removal	≥ 99% Removal	99.65% Removal
• SO_2 Emissions	≤ 0.04 lb/MMBtu	0.005 lb/MMBtu
• SO_3 Removal	≥ 60% Removal	72.25% Removal
• Mercury Removal	≥ 90% Removal of Oxidized Mercury	98.7% Removal

Boswell – Cohasset, MN

Boswell FGD Performance



Wet FGD Experience in North America

Plant Name	Ameren Sioux Units 1 & 2	Ameren Duck Creek	Ameren Coffeen Unit 1	Ameren Coffeen Unit 2	Minnesota Power Boswell 3	KCP&L La Cygne Unit 1	KCP&L La Cygne Unit 2
Capacity (MW)	2 x 535	444	360	590	355	817	715
In-Service Date	Oct. 2008 Dec. 2008	Nov. 2008	Mar. 2009	Apr. 2009	Oct. 2009	Under Construction	Under Construction
Inlet Flue Gas Flow rate (acfm)	1,915,000	1,485,900	1,337,200	2,214,400	1,288,000	3,200,000	2,900,000
Inlet Flue Gas Temp. (^oF)	340	305	305	305	295	312	303
Inlet SO2 (ppmd)	1,749	2,903	2,734	2,734	743	1,277	1,216
Inlet SO3 (ppmd)	12	44	70	56	11.2	2	2
Inlet HCl (ppmd)	58	89	78	78	16	14	13
Inlet Dust (lb/10^6 Btu)	0.05	0.058	0.021	0.021	0.012	0.012	0.012
SO2 Removal Efficiency (%)	99	99	99	99	98	98	98
Absorber Dimensions - Reaction Tank Diameter (ft) - Spray Zone Diameter (ft) - Height (ft)	 68 50 130	 66 45 126	 61 42 125	 78 54 137.25	 41.5 41.5 112.25	 63.5 63.5 138.75	 61.0 61.0 136.5
Absorber Gas Velocity (ft/s)	13.2	13.3	13.2	13.2	14	14.0	14.0
Design L/G (gal/1000acf)	140	161	159	159	93	100	96
Solids Residence Time (hr)	45	32	33	33	40	30	30
Liquid Residence Time (min)	6	6	6	6	4	4	4

The End

- Any questions

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