REINHOLD ENVIRONMENTAL Ltd.

2010 APC Round Table & Expo Presentation

July 18-20, 2010, in Concord, NC / Hosted by Duke Energy



MARSULEX
ENVIRONMENTAL TECHNOLOGIES

Wet Scrubber Fundamentals

Mike Walsh, VP Engineering
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Global Technology Base – Wet FGD

MET's wet technology licensing strategy has resulted in **global leadership** in the application of Wet FGD technology – over 30 years of experience

Total FGD Awards:	**85,651 MW**
• United States	18,381 MW
• International Total	67,270 MW
– Europe	21,940 MW
– Asia	44,880 MW
– South America & Canada	450 MW

MET

Leaders in Worldwide Experience

Germany
8,240 MW

Canada
315 MW

United States
18,381 MW

France
1,800 MW

Japan
5,925 MW

Netherlands
2,585 MW

United Kingdom
2,000 MW

Finland
1,000 MW

Poland
1,740 MW

Austria
1,180 MW

Slovenia
275 MW

Korea
4,250 MW

China
32,500+MW

Taiwan
1,000 MW

Viet Nam
1200 MW

Brazil
135 MW

Slovakia
220 MW

Saudi Arabia
160 MW

Czech Republic
1,570 MW

Croatia
210 MW

Italy
960 MW
(in consortium)

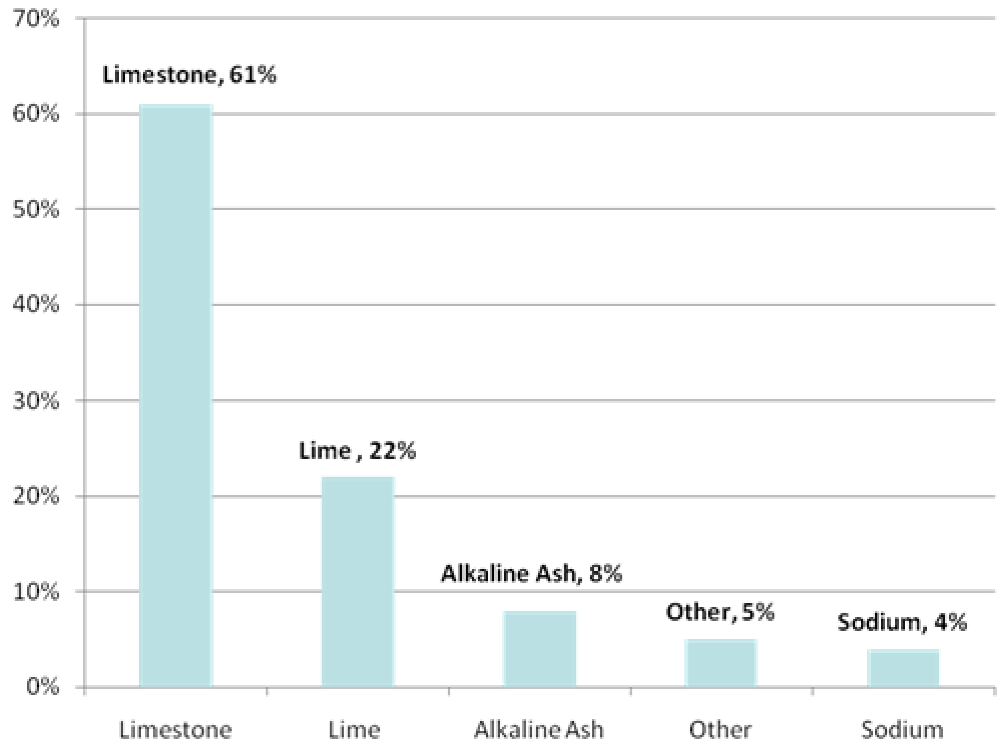
AGENDA

- **Overview of the WFGD Process**
- Basic Chemistry
- Typical FGD Processes
- Equipment Components
- Materials of Construction
- Dry FGD vs. Wet FGD
- Summary

Reagents

All wet flue gas desulfurization (FGD) require use of an alkaline chemical "reagent"

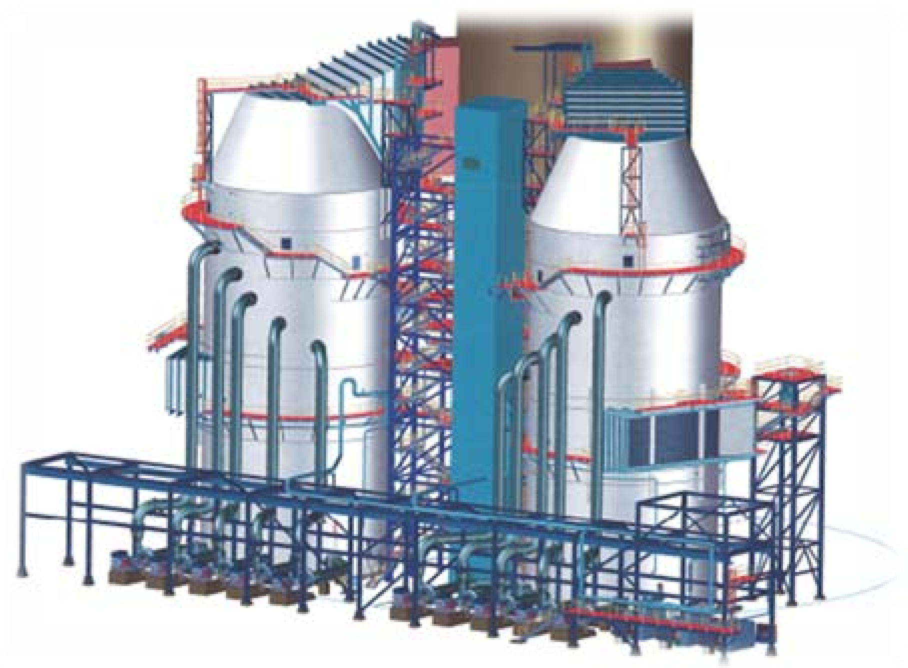
- Limestone
- Lime
- Ammonia
- Sodium



Byproducts

All convert gaseous SO_2 to either liquid or solid waste by-product

- Throwaway process
- Gypsum process
- Regenerative process
- Fertilizer product process



Wet Scrubber Fundamentals

- Overview of the WFGD Process
- **Basic Chemistry**
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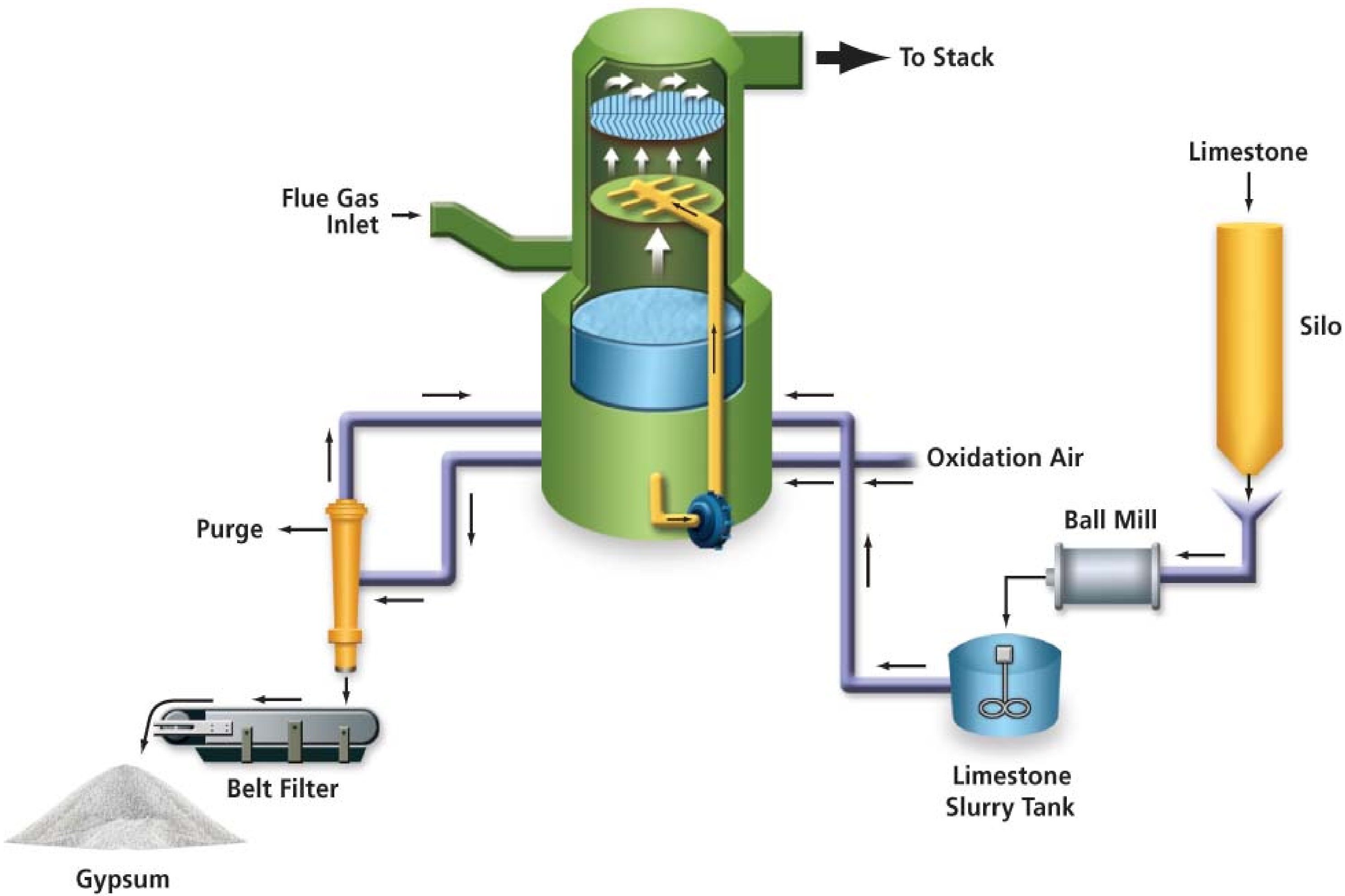
Typical Limestone WFGD



Limestone Systems

Overall Reactions

Reactions taking place in absorber & recycle tank:

1. $SO_2 + H_2O$	$\longleftrightarrow$	H_2SO_3	Absorption
2. $CaCO_3 + H_2SO_3$	$\longrightarrow$	$CaSO_3 + CO_2 + H_2O$	Neutralization
3. $CaSO_3 + ½\ O_2$	$\longrightarrow$	$CaSO_4$	Oxidation
4. $CaSO_3 + ½\ H_2O$	$\longrightarrow$	$CaSO_3 + ½\ H_2O$	Crystallization
5. $CaSO_4 + 2H_2O$	$\longrightarrow$	$CaSO_4 \cdot 2H_2O$	Crystallization

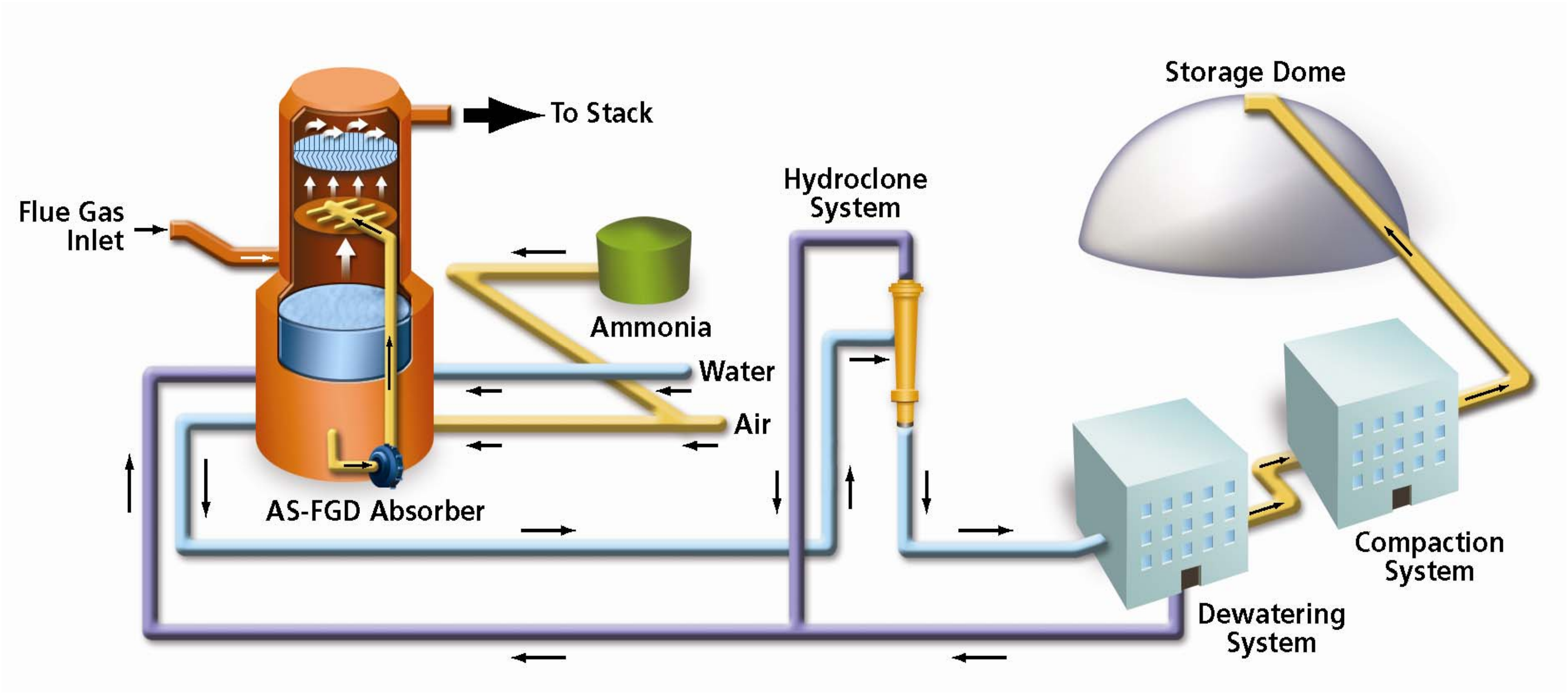
Lime Systems

Overall Reactions

Reactions taking place in absorber & recycle tank are very similar to those in the limestone system. The main chemical differences are:

1.	$SO_2 + H_2O$	$\longleftrightarrow$	H_2SO_3	Absorption
2.	$CaO + H_2O$	$\longrightarrow$	$Ca(OH)_2$	Slaking
3.	$H_2SO_3 + Ca(OH)_2$	$\longrightarrow$	$CaSO_3 + 2H_2O$	Neutralization

Ammonia-Based WFGD System



Ammonia WFGD Process

Overall Reactions

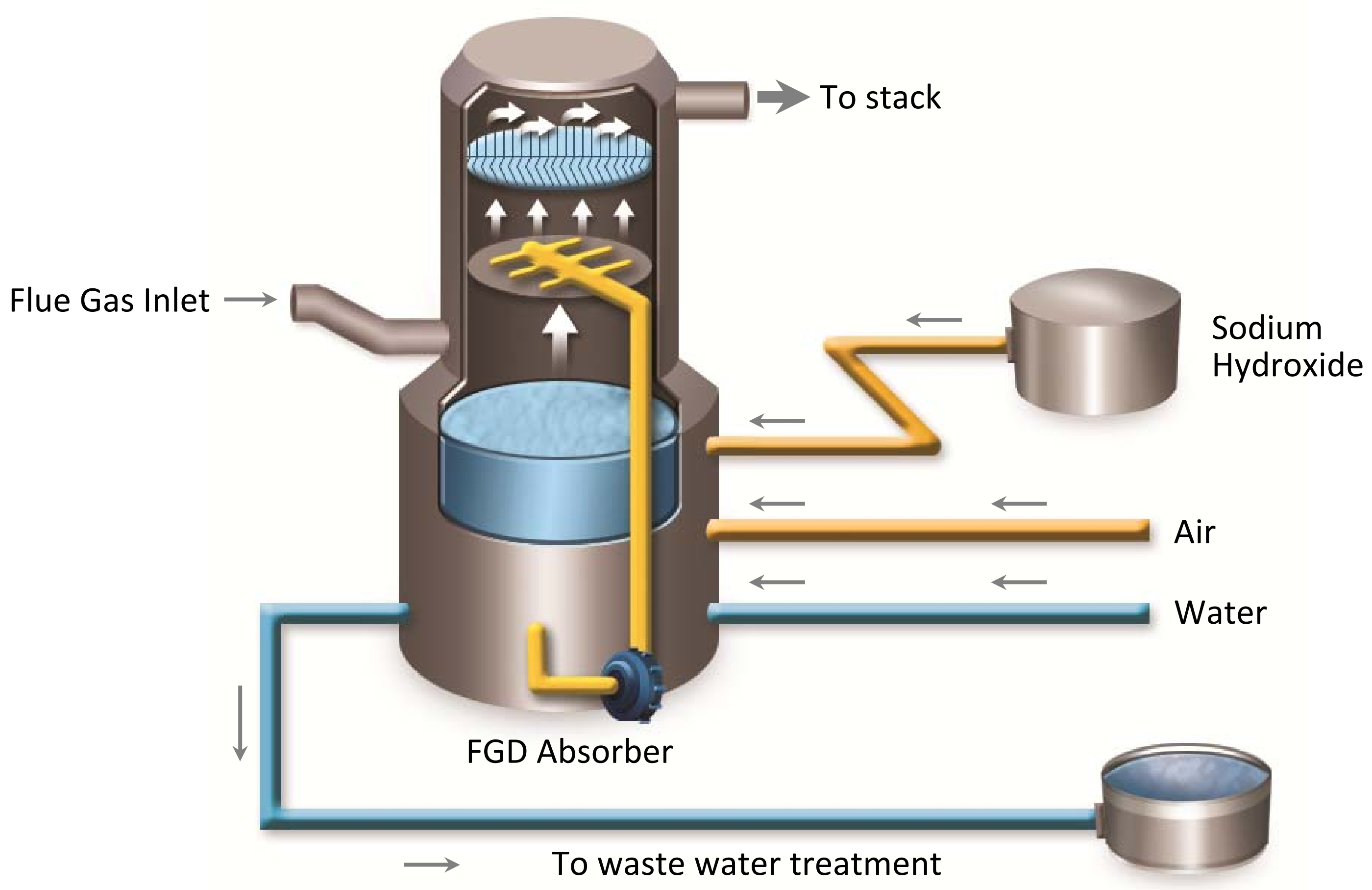
$$SO_2 + 2NH_3 + H_2O \longrightarrow (NH_4)_2SO_3 \qquad (1)$$

$$(NH_4)_2SO_3 + 1/2\ O_2 \longrightarrow (NH_4)_2SO_4 \qquad (2)$$

- For every pound of SO_2 removed:
  - Need one-half pound Ammonia
  - Produces two pounds of Ammonium Sulfate
- One pound of Ammonia generates four pounds Ammonium Sulfate

4:1 product / feed ratio generates favorable economic leverage

Sodium-Based WFGD



Sodium-Based WFGD

Overall Reactions

- SO_2, HCl and HF are absorbed into alkaline solution more readily than Ca-based systems as gas-phase mass transfer limited
- Overall reactions are:

$$2SO_2 + Na_2CO_3 + H_2O \rightarrow 2NaHSO_3 + CO_2$$

$$SO_2 + Na_2CO_3 \rightarrow Na_2SO_3 + CO_2$$

$$2\ NaHSO_3 + O_2 + Na_2CO_3 \rightarrow 2Na_2SO_4 + H_2O + CO_2$$

$$Na_2SO_3 + \tfrac{1}{2}\ O_2 \rightarrow Na_2SO_4$$

Wet Scrubber Fundamentals

- Overview of the WFGD Process
- Basic Chemistry
- **Typical WFGD Processes**
- Equipment Components
- Materials of Construction
- Dry FGD vs. Wet FGD
- Summary

Typical WFGD Processes

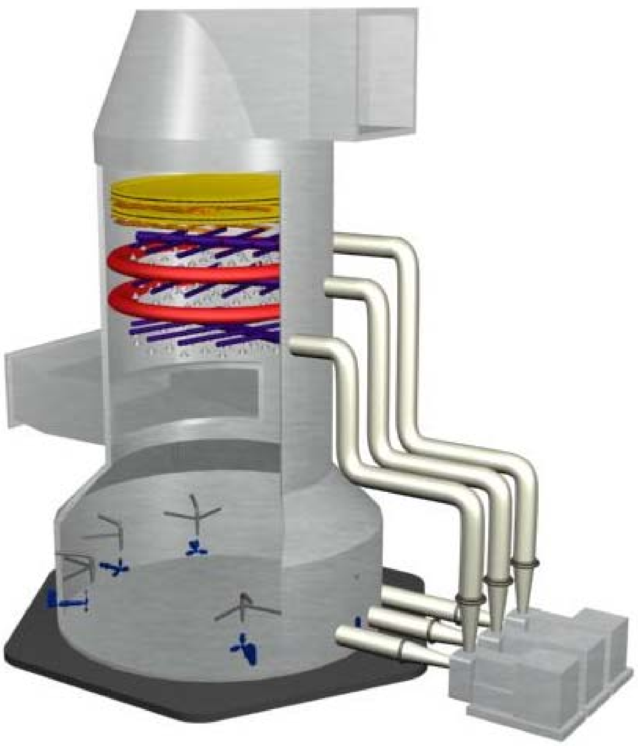
Operations and Design

Operations

- Gas distribution & wet/dry interface at Inlet
- Gas-Liquid contact in spray zone
- Liquid-Gas separation with mist eliminators
- Oxidation & dissolution in reaction tank

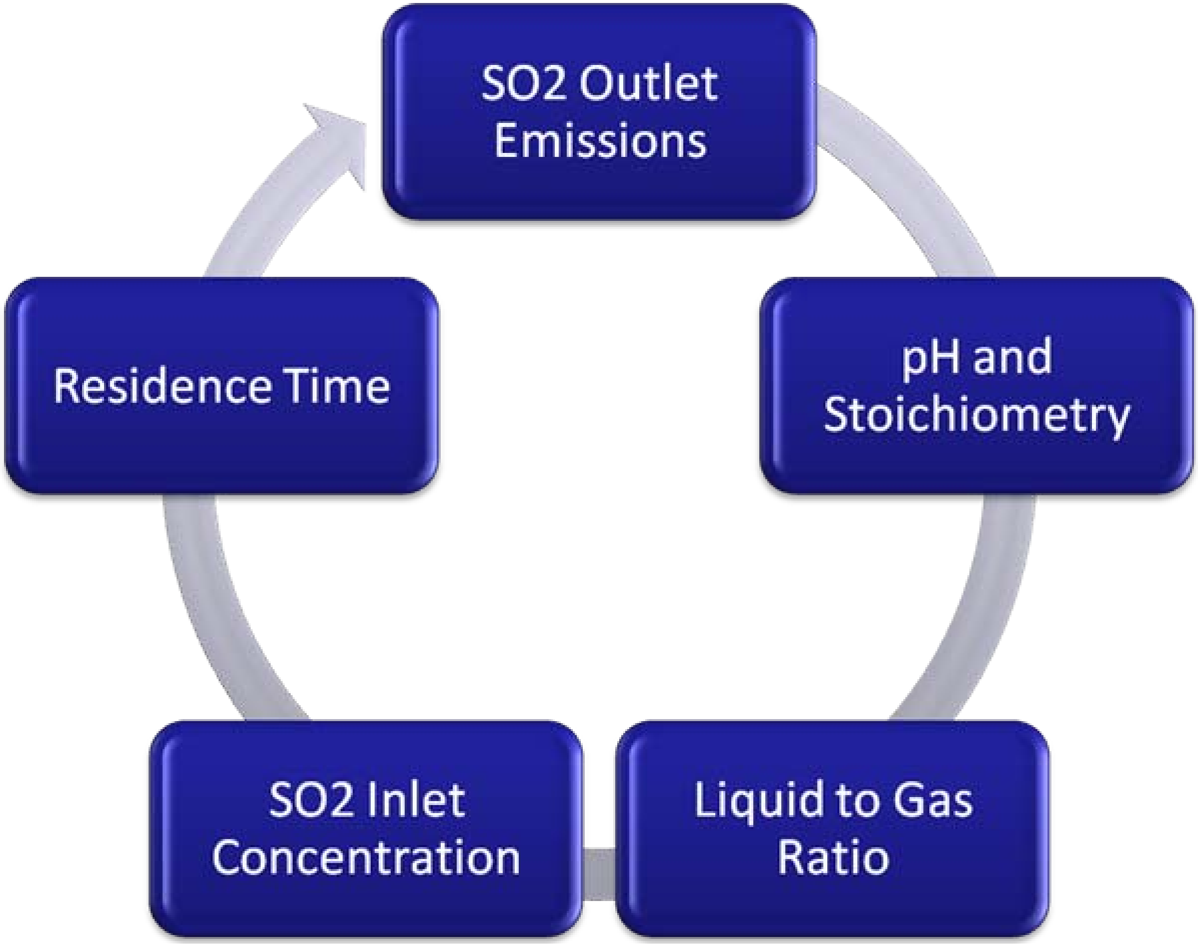
System Design

- Low lifecycle cost
- High availability



Typical WFGD Processes

Terminology & Process Impacts



Terminology & Process Impacts

SO_2 Outlet Emissions

- Allowable SO_2 outlet emissions are based on either maximum outlet level or on overall system SO_2 removal efficiency
- Requirements dictated by environmental regulations
- Depending on requirements, absorbers may be designed to treat all or only a portion of flue gas

Stoichiometry & pH

- Slurry pH is likely the most important control variable for absorber operation
- pH determines amount of reagent used
- pH is related to reagent stoichiometry – the number of mols of reagent added per mol of SO_2 removed

Typical WFGD Processes

Terminology & Process Impacts

Liquid-to-Gas Ratio

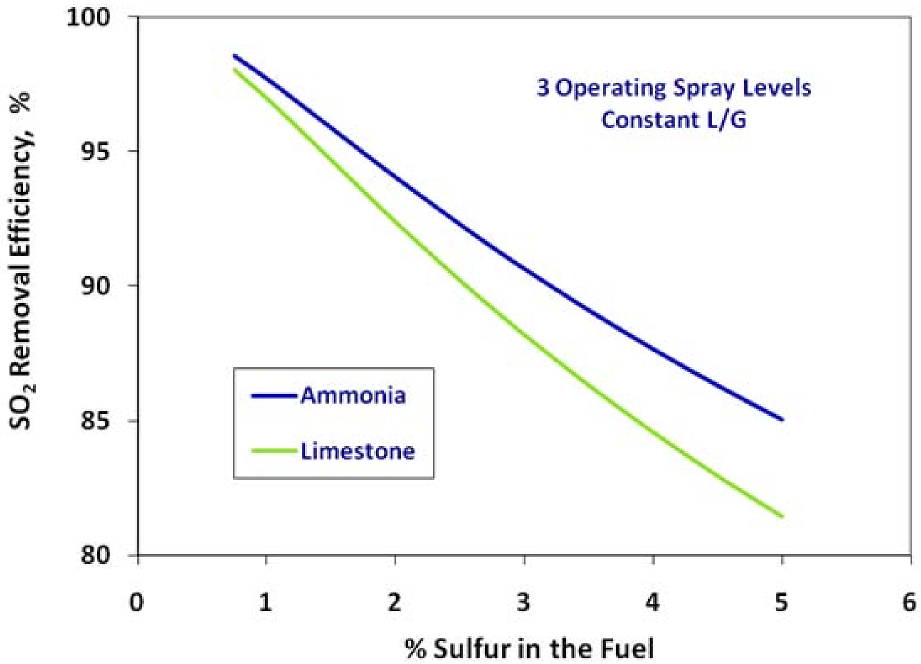
- L/G is the ratio of recycle slurry (in l/hr) to absorber outlet gas flow (m^3/hr, actual)
- The amount of surface system available for reaction with SO_2 is determined by L/G
- L/G ratio can be changed by altering either recycle flow rate or flue gas flow rate
- Liquid flow is typically varied by changing the number of operating recycle pumps
- s

Residence Time

- The time that slurry spends in the reaction tank before being recycled for further SO2 absorption
- Residence time allows the liquid to de-supersaturate and avoid scaling in lime/limestone systems
- Typically, for limestone systems, a residence time of 3-5 minutes is provided

Typical WFGD Processes

SO_2 Inlet Concentration



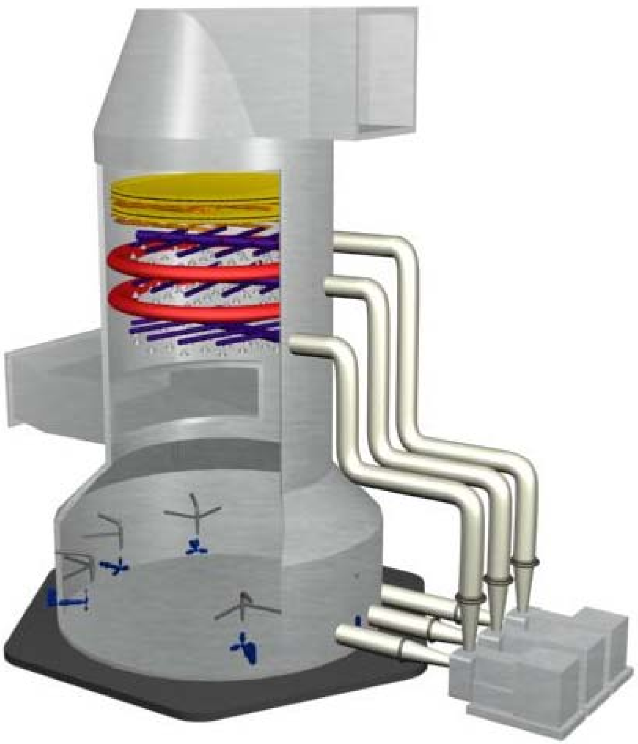
- **At constant operating conditions, increasing the inlet concentration of SO_2 will decrease SO_2 removal. Increased SO_2 concentration causes an increased depletion of liquid phase alkalinity**

Absorber | Configurations

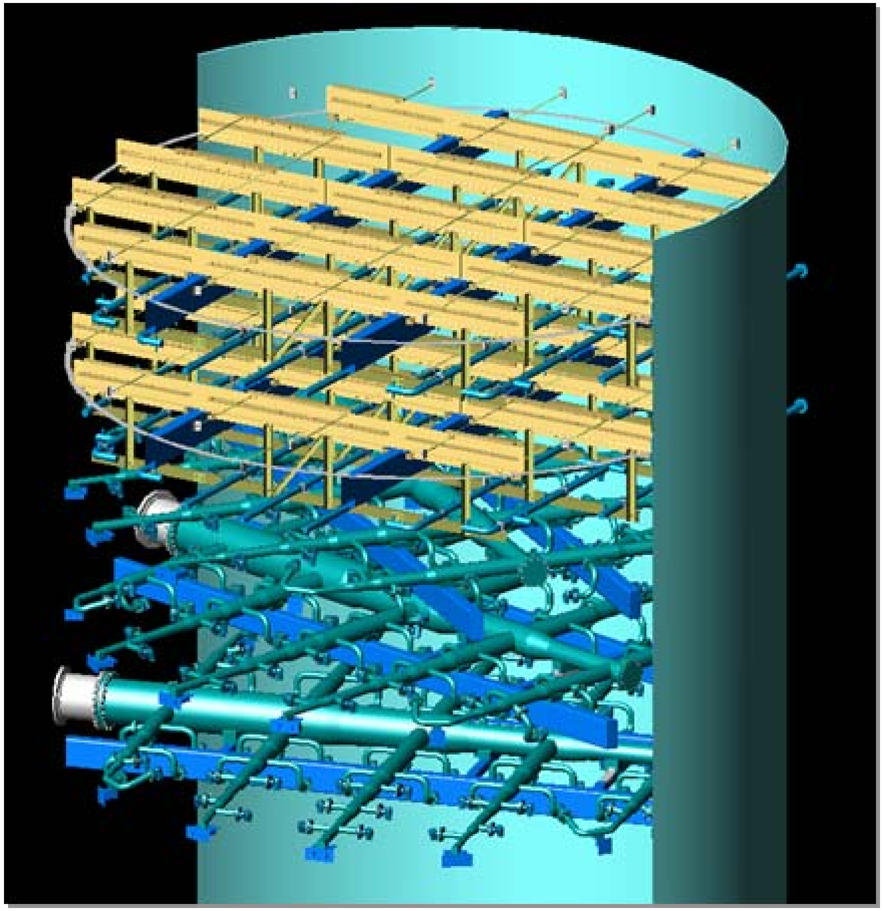
- Spray Absorber – Open Tower
- Tray Towers
- Packed Towers
- Jet Bubbling Reactors
- Spray Dryers
- Circulating Fluid Bed FGD

Spray Absorbers

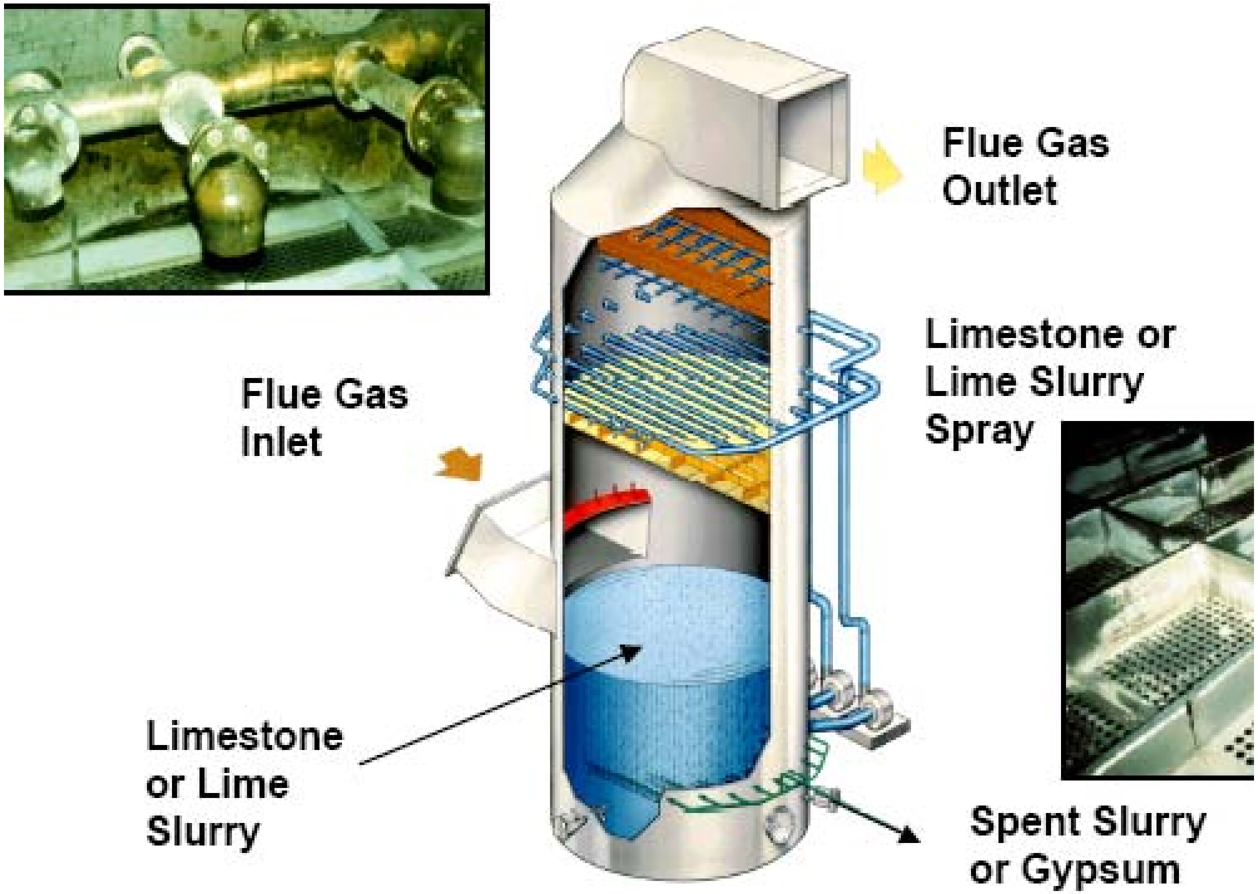
- **SO_2** – Sulfur Dioxide - readily absorbed
  - 95-99% removal efficiency
  - Converted to Calcium Sulfate = Gypsum
- **HCl** – Hydrogen Chloride - easily absorbed
  - > 99% removal efficiency
  - Converted to Calcium Chloride
  - Is highly soluble
  - Has effect on process chemistry
- **HF** – Hydrogen Fluoride - easily absorbed
  - > 99% removal efficiency
  - Converted to Calcium Fluoride
  - Is highly soluble
- **SO_3** – Sulfur Trioxide - poorly absorbed
  - ~ 30% removal efficiency
  - Converted to Calcium Sulfate
- **Fly Ash** - absorbed
  - ~ 50-70% removal efficiency
  - Can affect process chemistry



Isometric of "Open" Spray Absorber

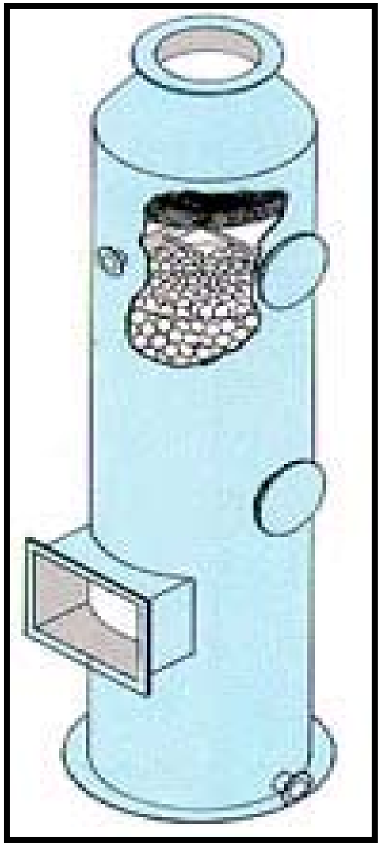


Tray Towers



Courtesy of Babcock & Wilcox

Packed Towers



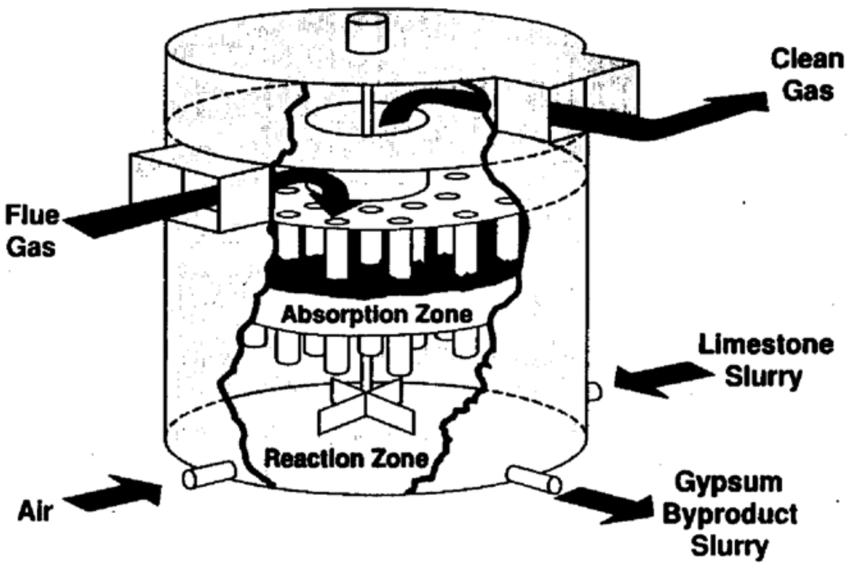
- Gas enters the base of the tower and passes up through the packing countercurrent to the scrubbing liquor which is introduced at the top of the tower
- The liquid is dispersed by means of inert, stationary or molded packings of various shapes and configurations designed to add surface area and thus promote maximum vapor-liquid contact

Jet Bubbling Reactor

In one vessel combines concurrent chemical reactions of:

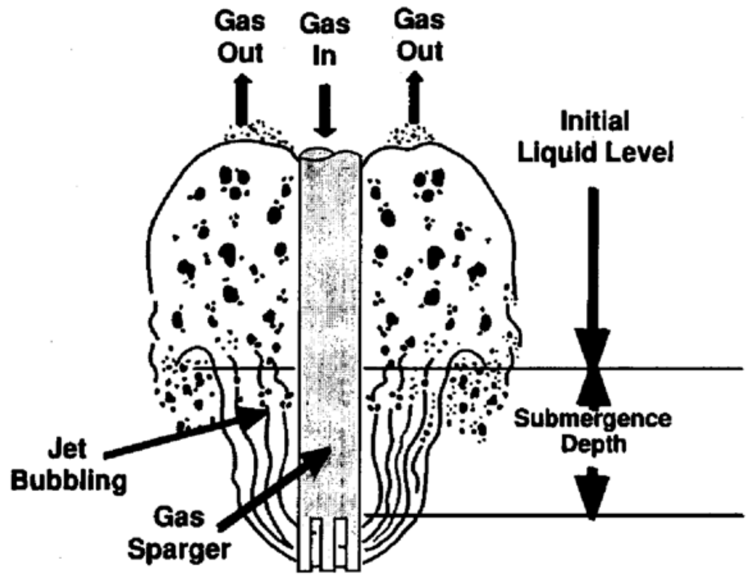
- Limestone dissolution
- SO_2 absorption
- Neutralization
- Sulfite oxidation
- Gypsum precipitation
- Gypsum crystal growth

Jet Bubbling Reactor



Cut-Away of JBR

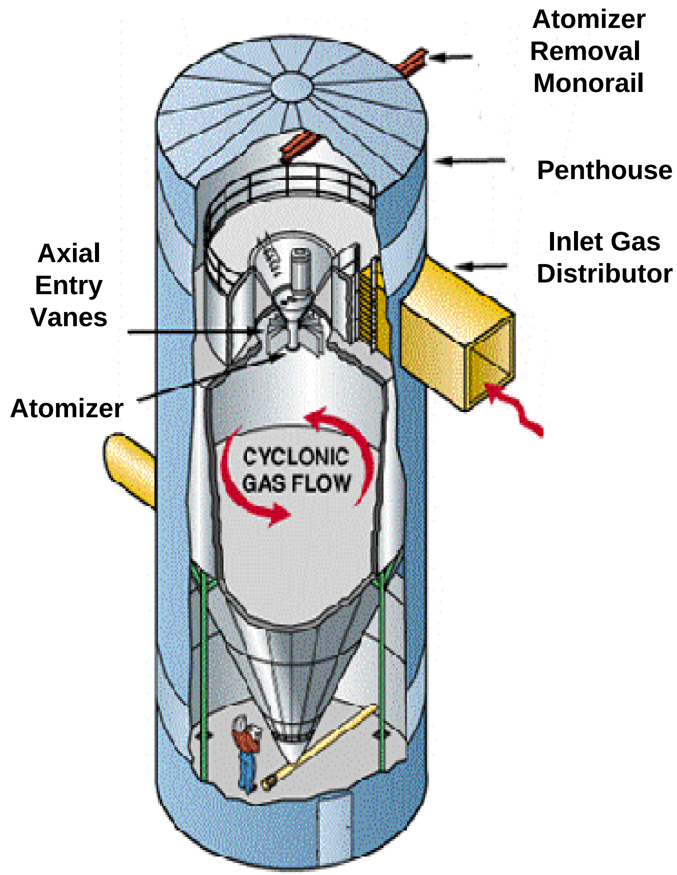
Gas Sparger Action



Spray Dryer Absorber

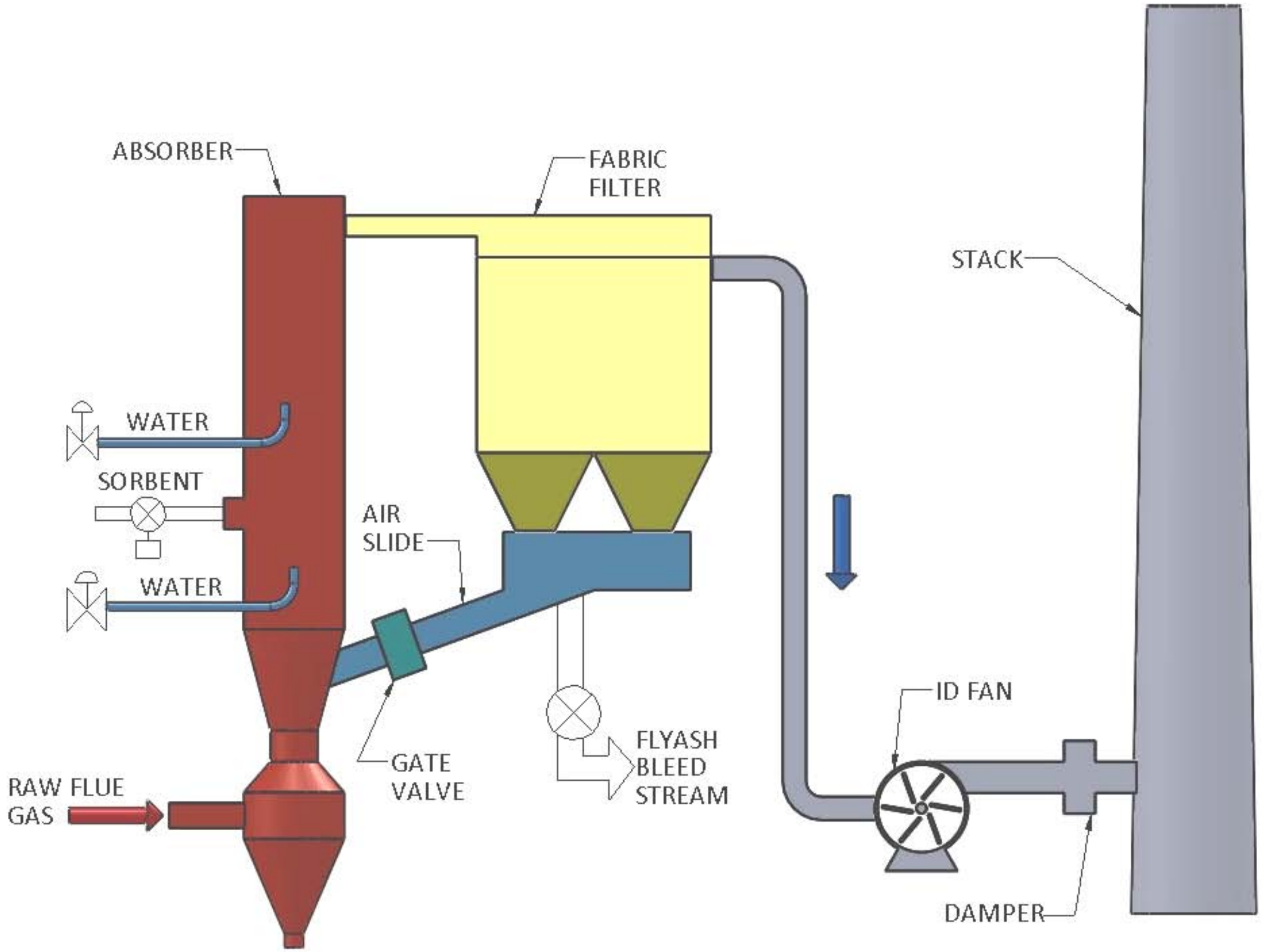
Lime Reagent

- Rotary atomizer (shown) or dual fluid atomization
- Lime slurry or lime + recycle reagent
- ~95% SO_2 efficiency on low to medium sulfur applications; practical limit due to stoichiometry



CFB-FGD

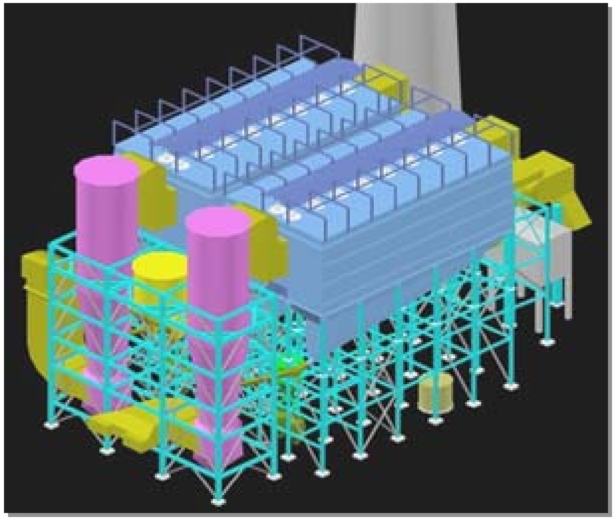
Simplified Process Flow Diagram



CFB-FGD

Process Description

- Sulfur Dioxide absorption in a fluidized bed absorber vessel
- Dry injection of the lime reagent
- Recycle of collected fly ash, by-product and un-reacted sorbent(s) back to the absorber
- Multi-stage humidification
  - Spray injection of water to provide wetted surface on particulate for reaction with sorbent
  - Two stages of humidification increases the residence time for reaction
- Additional sorbent optional for enhanced mercury control

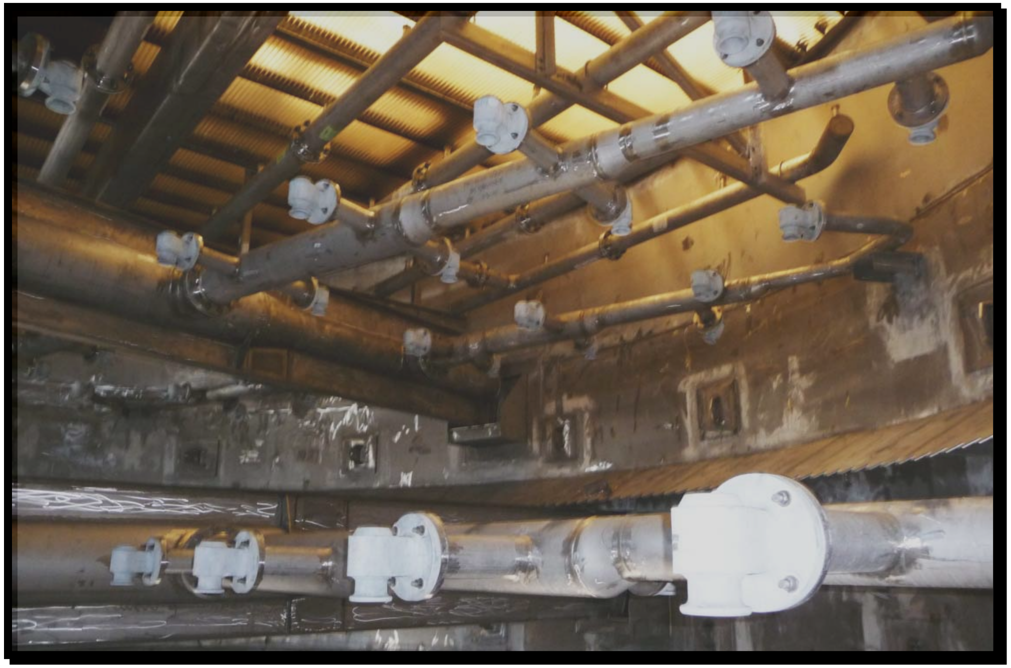


Wet Scrubber Fundamentals

Equipment Components

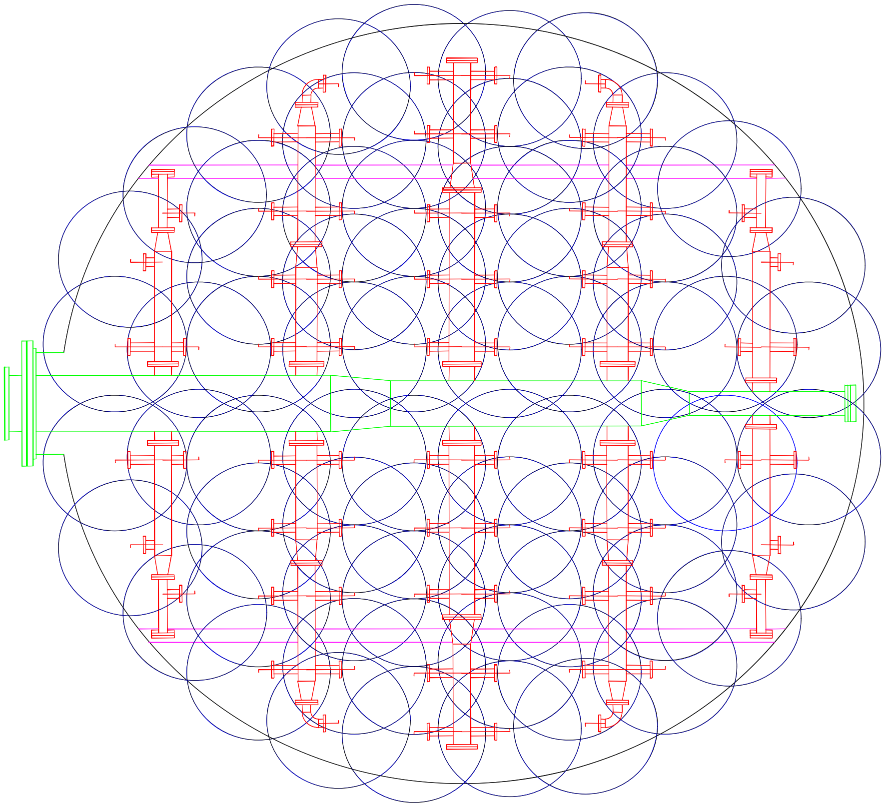
Spray Headers

- Headers may be stainless steel, FRP, alloy or rubber lined carbon steel
- May be self or internally supported



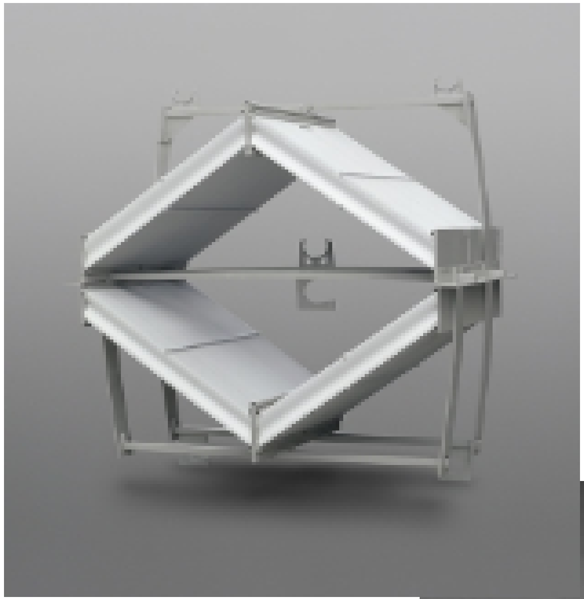
Absorber Spray Levels
Milton R. Young | Center, North Dakota

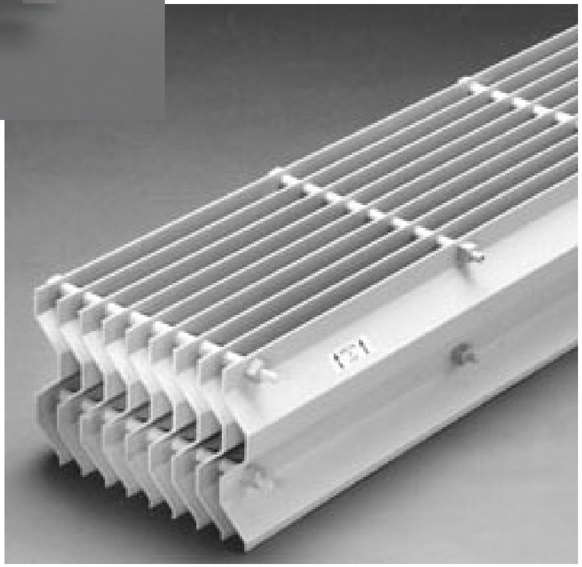
Typical Spray Pattern



Proper spray pattern design achieves high level of coverage

Mist Eliminators



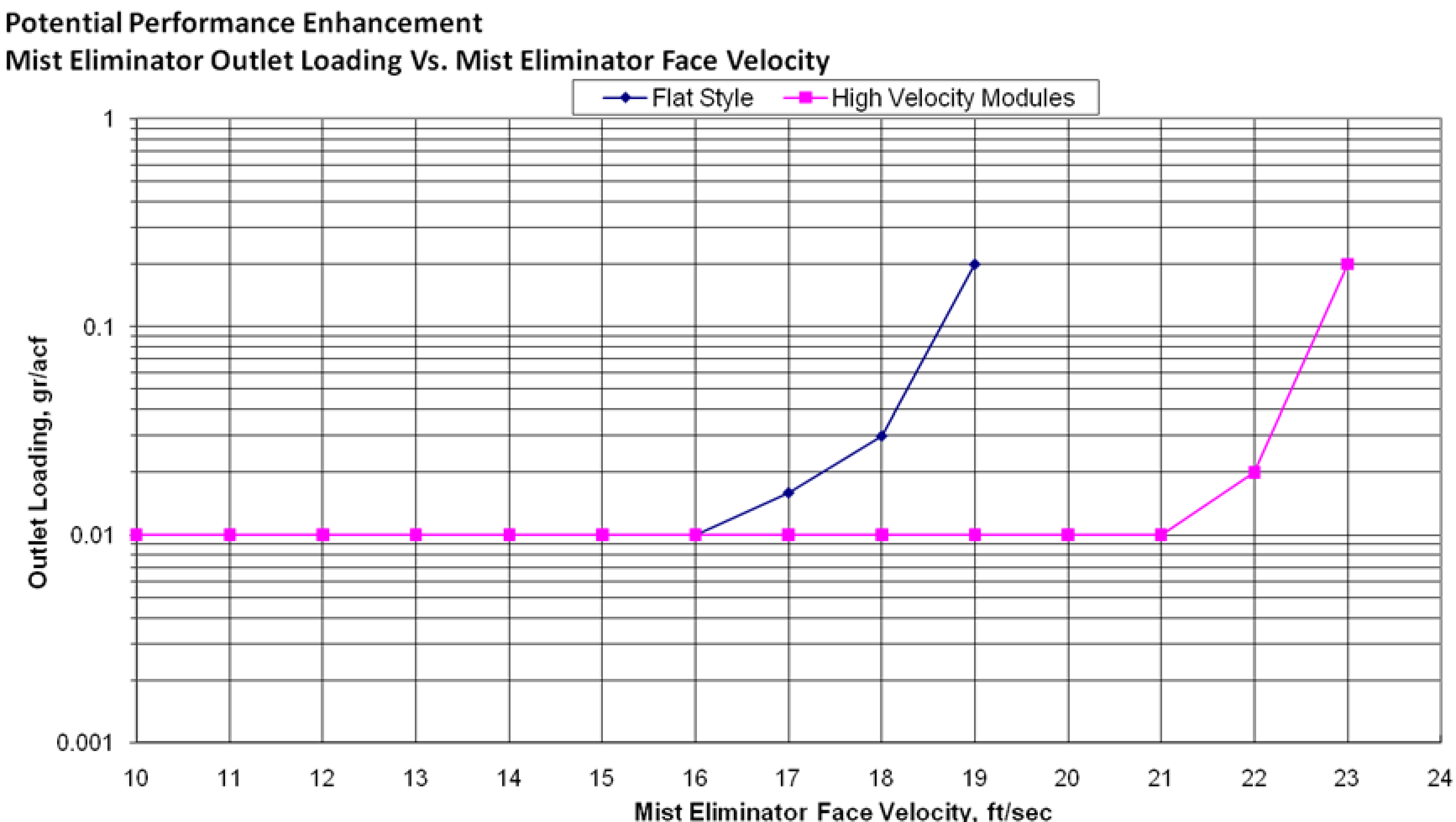


Mist Eliminator
Improvements

Mist Eliminator Wash System

Mist Eliminator Performance

Impact of velocity on emissions



Courtesy of Koch

Mist Elimination

Major parameters to be considered for proper mist eliminator washing include:

- Wash water rate
- Water quality
- Timing sequence
- Washing area coverage
- Nozzle pressure
- Nozzle spray angle

Equipment Components

Absorber Recycle Pumps

- Centrifugal Horizontal End Suction Pump
- Rubber Lined Casing, Metal Impeller
- Up to 85,000 gpm
- Mechanical Seal

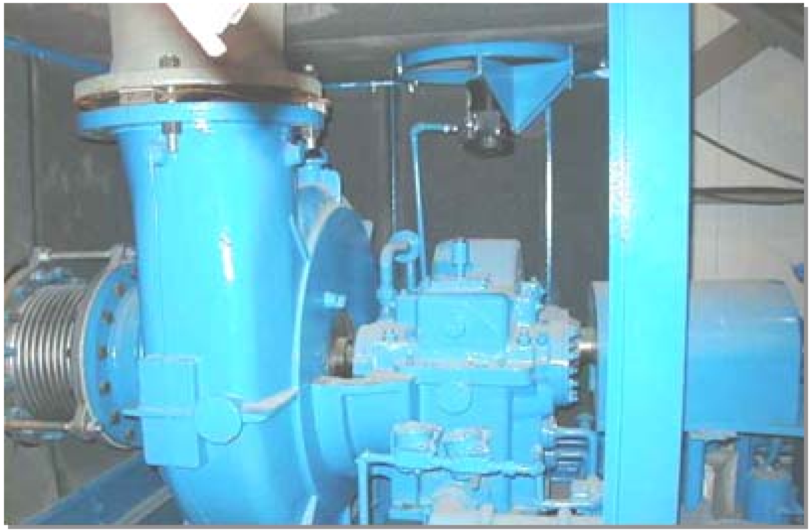
Equipment Components

Agitator and Oxidation Air Lance

Agitator with Air Lance in Operation

Photo courtesy of Ekato

Oxidation Air Compressors



Equipment Components

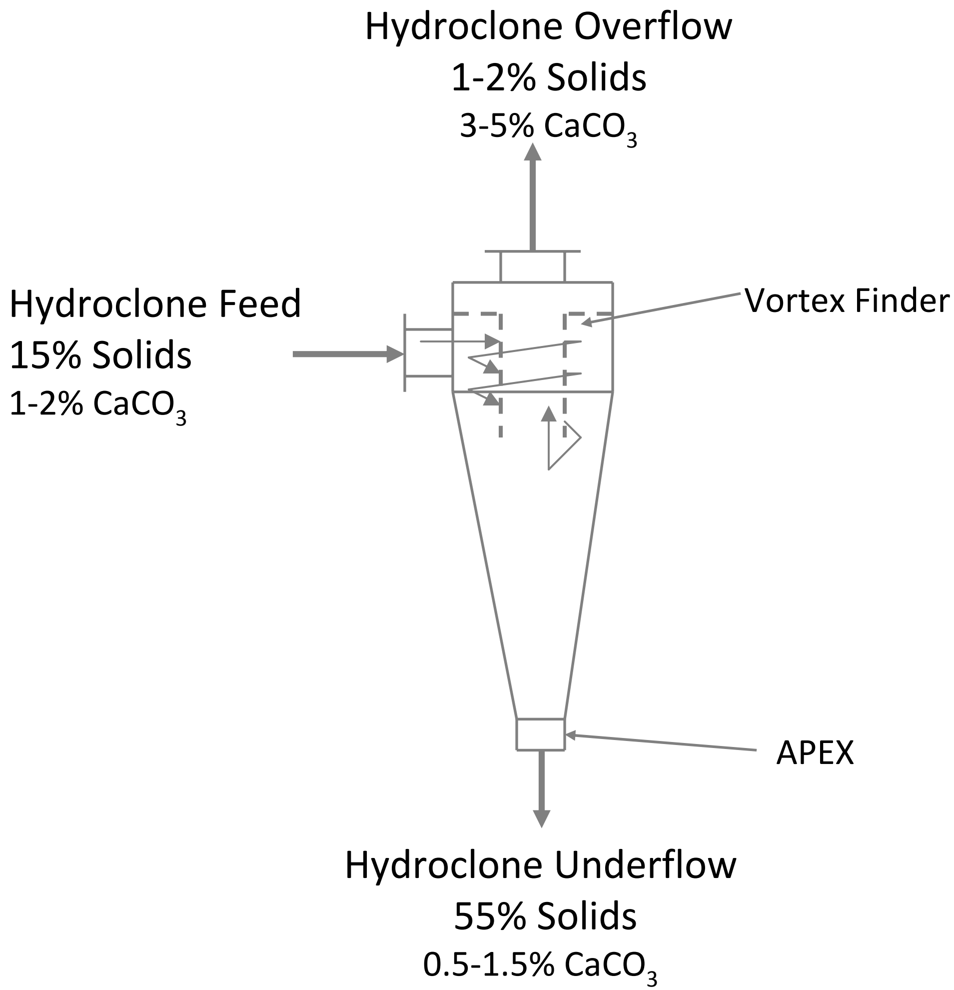
Absorber Solids Concentration and Primary Dewatering Systems

Slurry Solids Concentration

- Solids concentration is maintained by placing the hydroclones into service and removing them from service based on predetermined density set points.
- Absorber solids concentration also needs to be evaluated with the performance of the FGD system; higher solids concentrations produce:
  - improved gypsum relative saturation and minimize scaling
  - maximized limestone utilization
  - enhanced $CaCO_3$ effects

Equipment Components

Absorber Solids Concentration and Primary Dewatering Systems



Equipment Components

Secondary or Final Dewatering

Secondary Dewatering – Belt Filter

- Solids concentration is maintained by setting the speed and thickness of cake on the belt filter
- The moisture from a belt filter design is 10% by weight
- The vacuum on the belt is held constant
- The gypsum particle size and the amount of flyash in the system will affect the filter performance
- Feed solids concentration needs to be consistent via the hydroclone performance to ensure repeatable results from the filter

Equipment Components

Secondary or Final Dewatering

Drum Filter

- Drum filters are utilized when lower mositure concentrations are desired
- Moisture concentrations are typically 15+% moisture in the final product
- Often used when the gyspum is to be disposed of and not sold

Rotary Drum Vacuum Filter

Equipment Components

Secondary or Final Dewatering

Secondary Dewatering - Vacuum Pump

- Vacuum pump skid is fixed speed with no variability in performance
- Seal water must be maintained at the design requirements

Secondary Dewatering – Vacuum Receiver

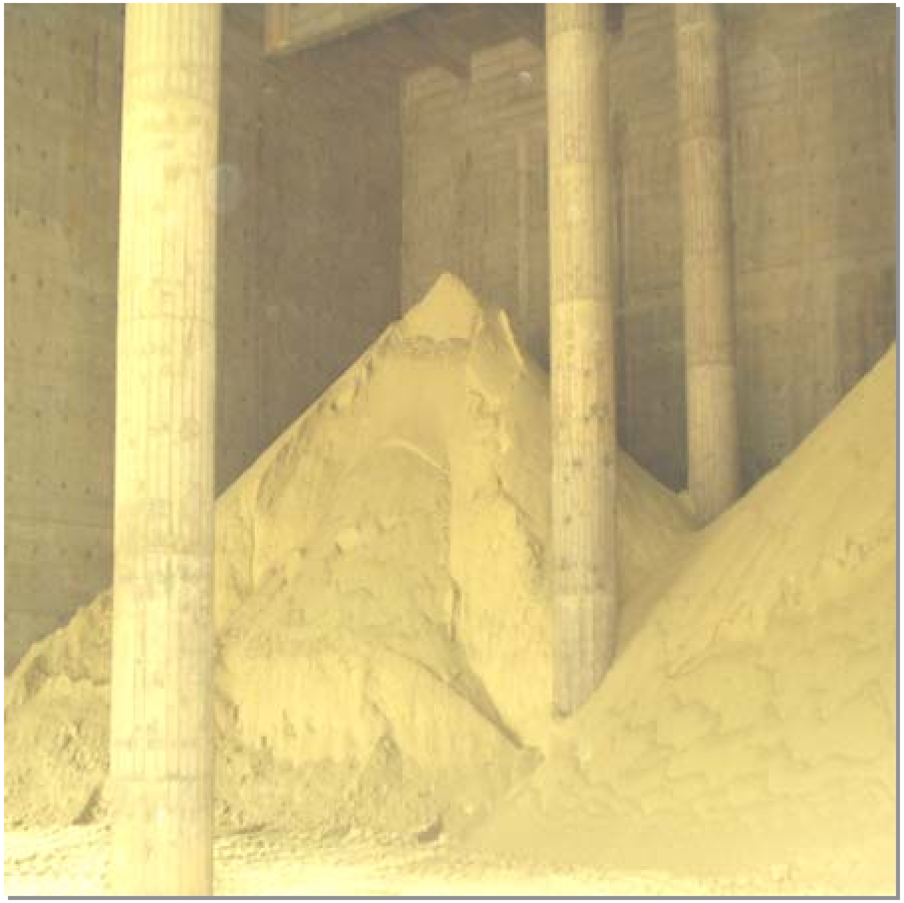
- Vacuum receiver is the tank where the filtrate once drawn from the gypsum product is accumulated
- The filtrate can gravity drain from the tank or be pumped

Equipment Components

Secondary or Final Dewatering

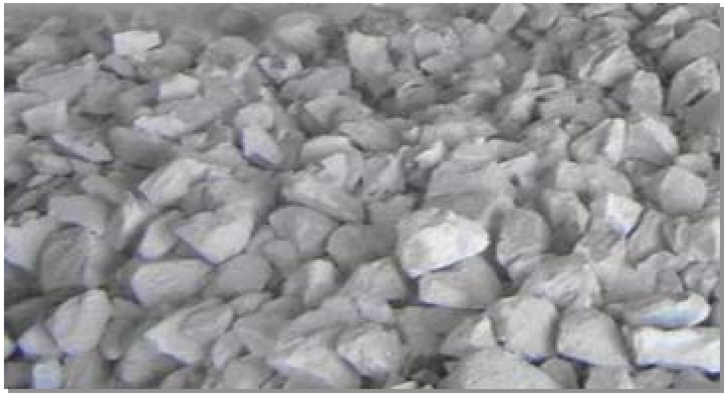
Final Product Handling

- Final Gypsum product is typically conveyed to or dumped into pile/s in the dewatering building or adjacent stack out areas
- The Gypsum product is loaded with large front-end loading equipment and then into trucks for final distribution



Equipment Components

Lime/Limestone Preparation



Lime/Limestone Preparation Systems

- Limestone is typically delivered by Truck or Rail
- The limestone can be stored on grade or in silos
- Lime must be stored in silos
- Unloading of limestone is done mechanically via loaders and conveyors
- Unloading of Lime is done pneumatically

Equipment Components

Lime/Limestone Preparation

Lime/Limestone Preparation Systems

- Both products are weighed before being processed in the milling circuit.

Equipment Components

Lime/Limestone Preparation

Horizontal Ball Mill

- Most prevalent method of grinding limestone in the FGD industry
- The mill is filled with steel balls that vary in size up to 2” in diameter
- Limestone is added to the mill with water and the mill rotates at a fixed speed

- The product from the grinding overflows out the mill and is then processed in hydroclones
- Lime can also be processed in a horizontal mill but uncommon

Equipment Components

Lime/Limestone Preparation

Vertical Ball Mill

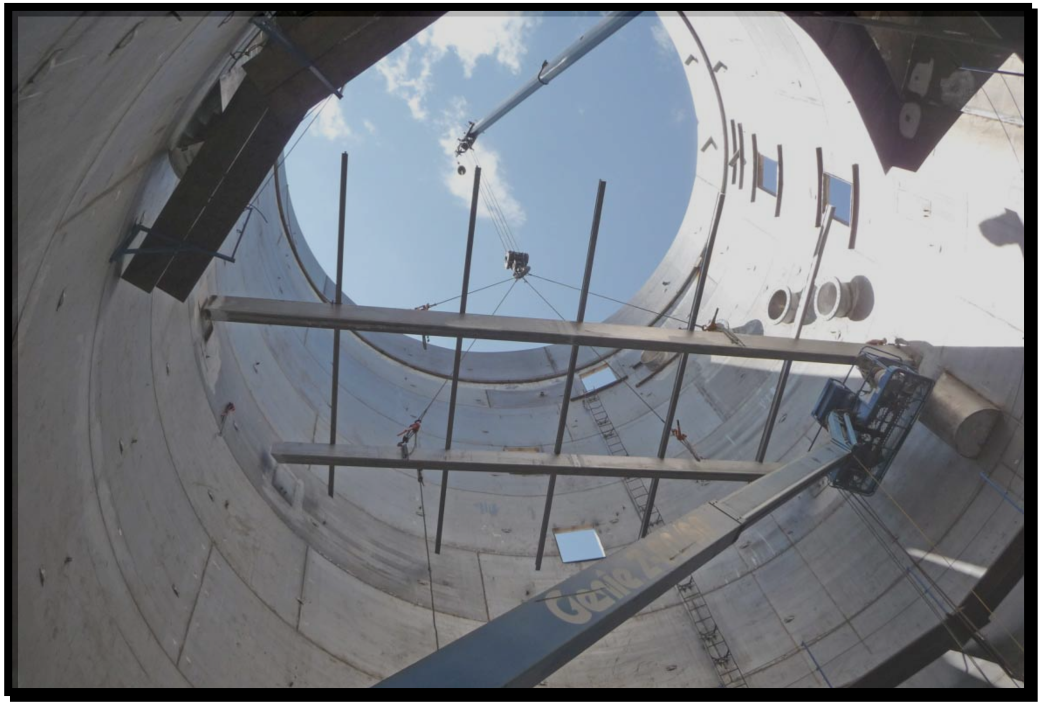
- A recent development in grinding limestone
- The mill is filled with steel balls that vary in size up to 1 1/2” in diameter
- Similar to the horizontal mill limestone is added to the mill with water and there is a center screw that rotates and the stone is ground
- Lime is processed in the same manner as limestone

Lime/Limestone Preparation

Hydroclone Classifiers

- Hydroclones are used to classify the final product, ensure it is the proper size
- The desired grind for limestone is 95% passing 325 mesh for most applications
- Most lime applications do not require hydroclones

Equipment Components



Maintenance Platform Installation
Milton R. Young | Center, North Dakota

Wet Scrubber Fundamentals

Overview of the WFGD Process

Basic Chemistry

Typical WFGD Processes

Equipment Components

Materials of Construction

Dry FGD vs. Wet FGD

Summary

Materials of Construction

Major Variables that WFGD Design Engineers Must Balance

- Installed Capital Cost, e.g. material selections – raw cost, fabrication, erection, coatings, and quality assurance
- System Reliability
- Procurement / Construction Cycle
- Ongoing Maintenance and Life Cycle Costs

Materials of Construction

The WFGD Environment

- Equipment in the Gas Path
  - Dampers
  - Inlet Duct, Absorber and Internals
  - Outlet Duct, Reheat System, and Stack
- Slurry Handling Components
  - Tanks, Agitators, Pumps
  - Pipes, Valves, Dewatering Equipment

Materials of Construction

MET Experience

Absorber Vessel

- Stainless steels and high nickel alloys
- Lined carbon steel (flakeglass, rubber, Stebbins)
- Carbon steel with C-276 cladding / wallpaper
- Concrete with Stebbins tile lining
- Fiberglass reinforced plastic (FRP)

Inlet Nozzle

- C-276 / C22 alloy steels
- Carbon steel with C-276 alloy wallpaper
- Carbon steel with PennGuard block linings
- Stainless steels
- Fiberglass reinforced plastic (FRP)

Spray Piping

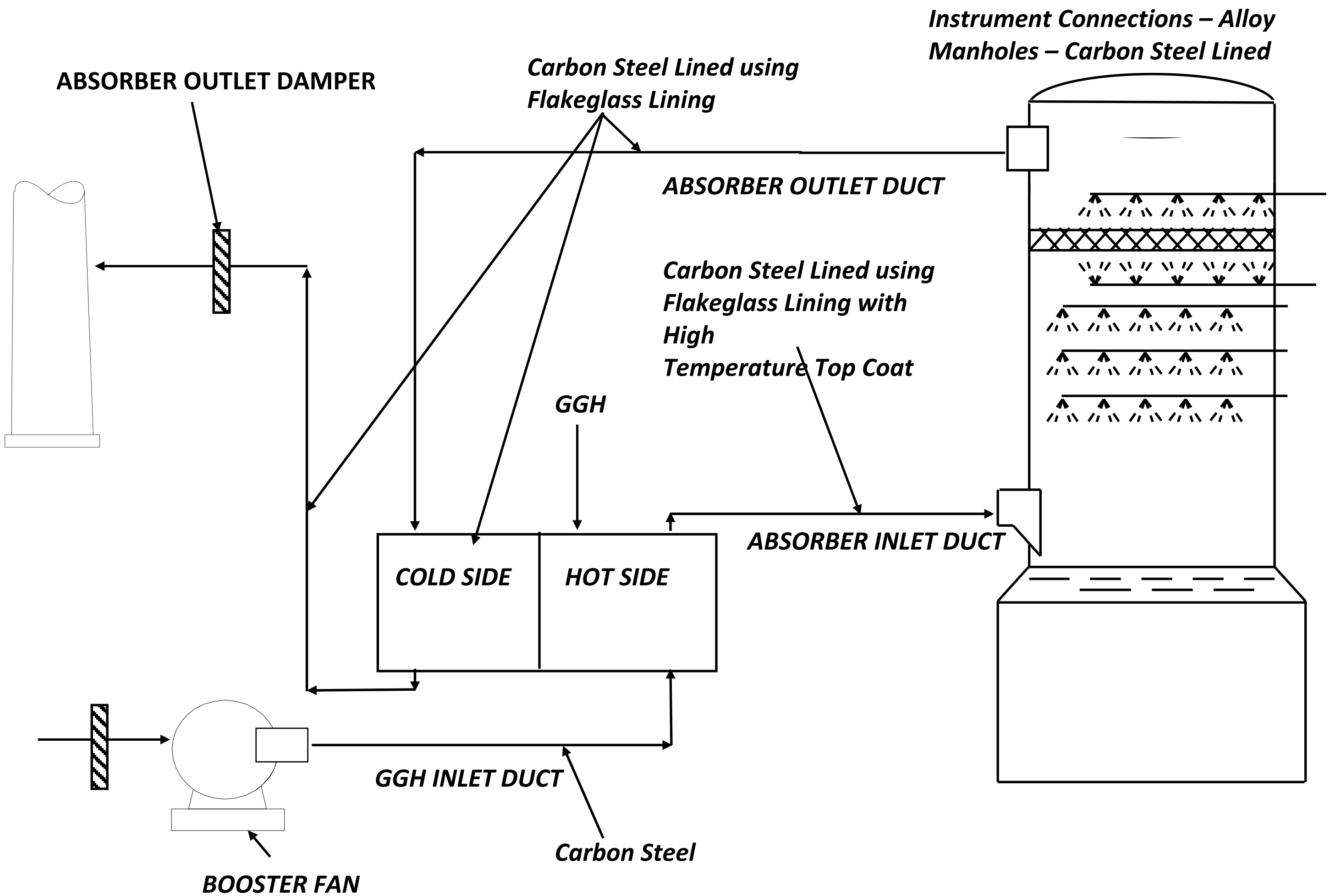
- Fiberglass reinforced plastic (FRP)
- Carbon steel with rubber lining
- Stainless steels and high nickel alloys

Outlet Duct

- Carbon steel with C-276 alloy wallpaper
- Lined carbon steel (flakeglass and PennGuard
- Fiberglass reinforced plastic (FRP)
- Solid alloy

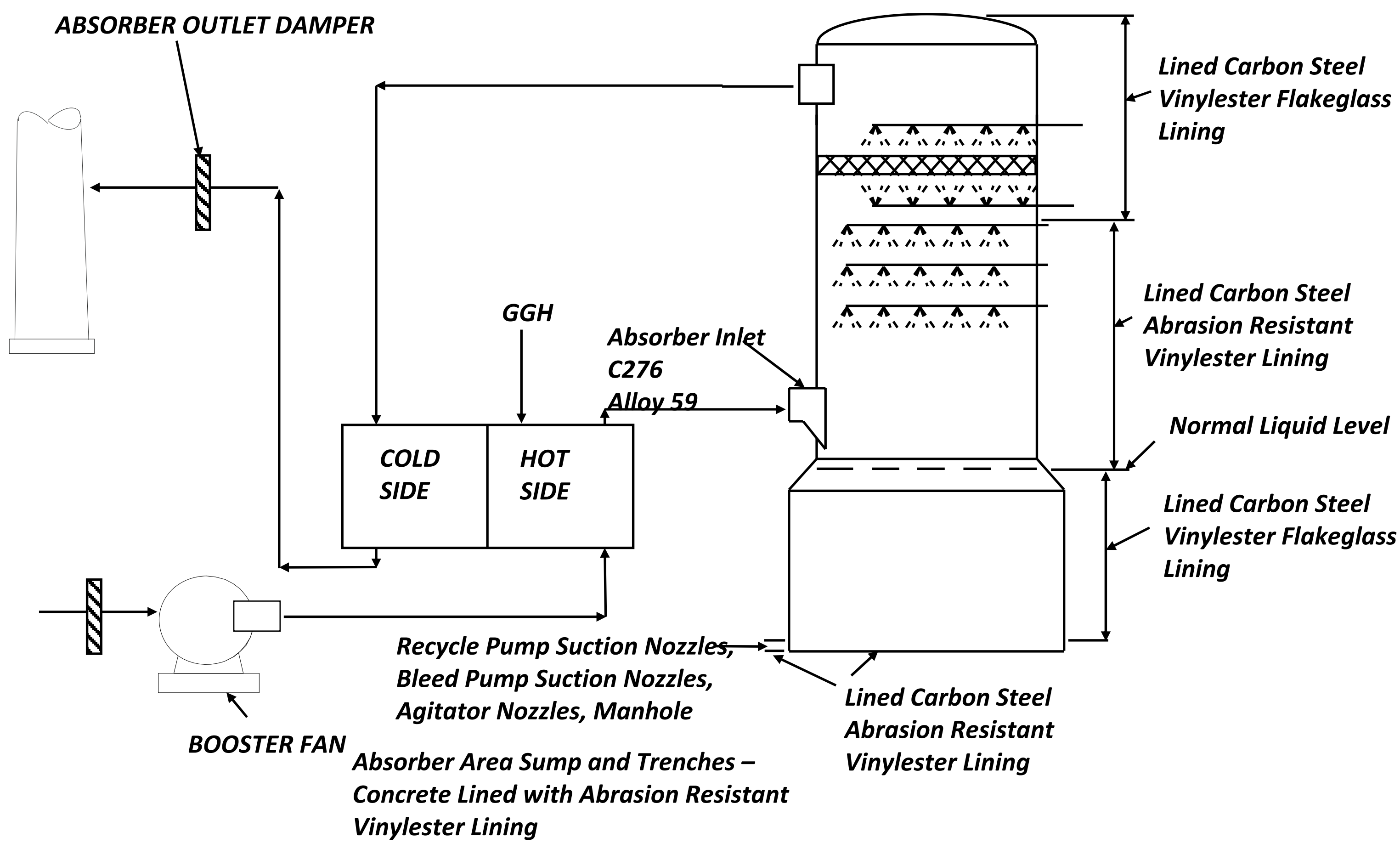
Materials of Construction

Duct / GGH



Materials of Construction

Absorber Shell



Materials of Construction

FRP TURRET TOP
Mount Storm Unit 2 | Mount Storm, West Virginia

Materials of Construction

Absorber Inlet Area

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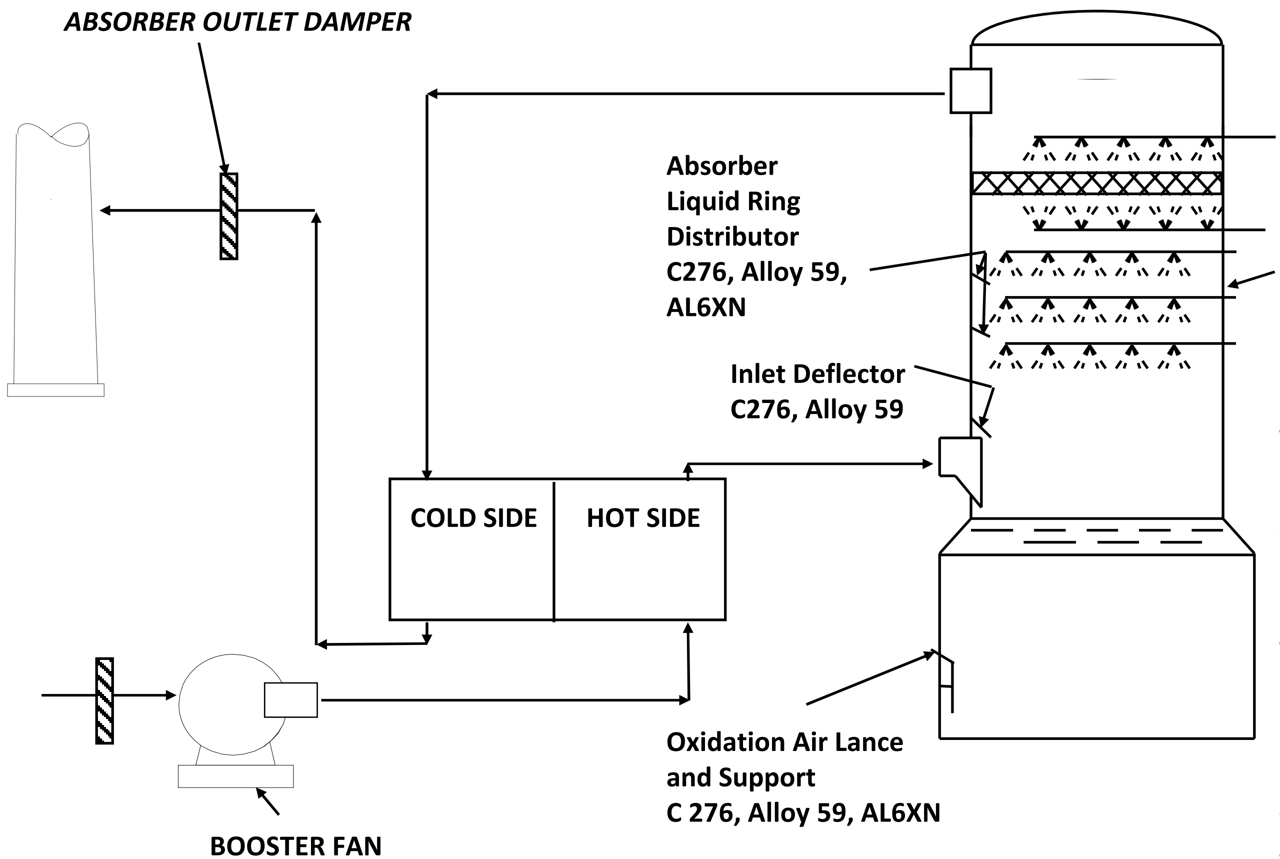
Materials of Construction

Absorber Internals



Recycle Pipe – FRP

Recycle Pipe Supports
Rubber Lined Carbon Steel Tubes

Recycle Pipe Support Brackets
C276, Alloy 59, AL6XN

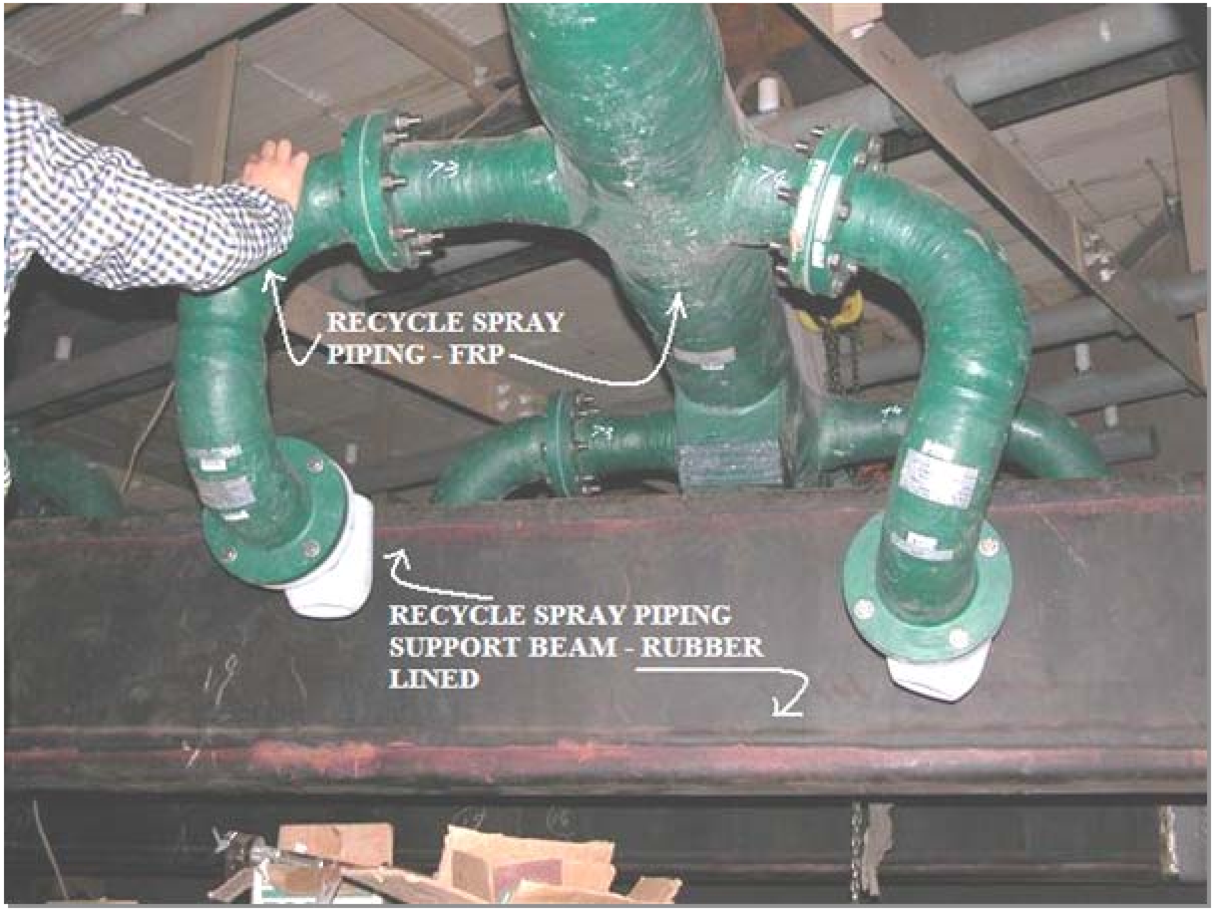
Recycle Nozzles
Silicon Carbide

Nuts, Bolts, Washers
C276, Alloy 59, AL6XN

Gaskets
Solid Silicone Rubber, Shore A Durometer 45 - 55

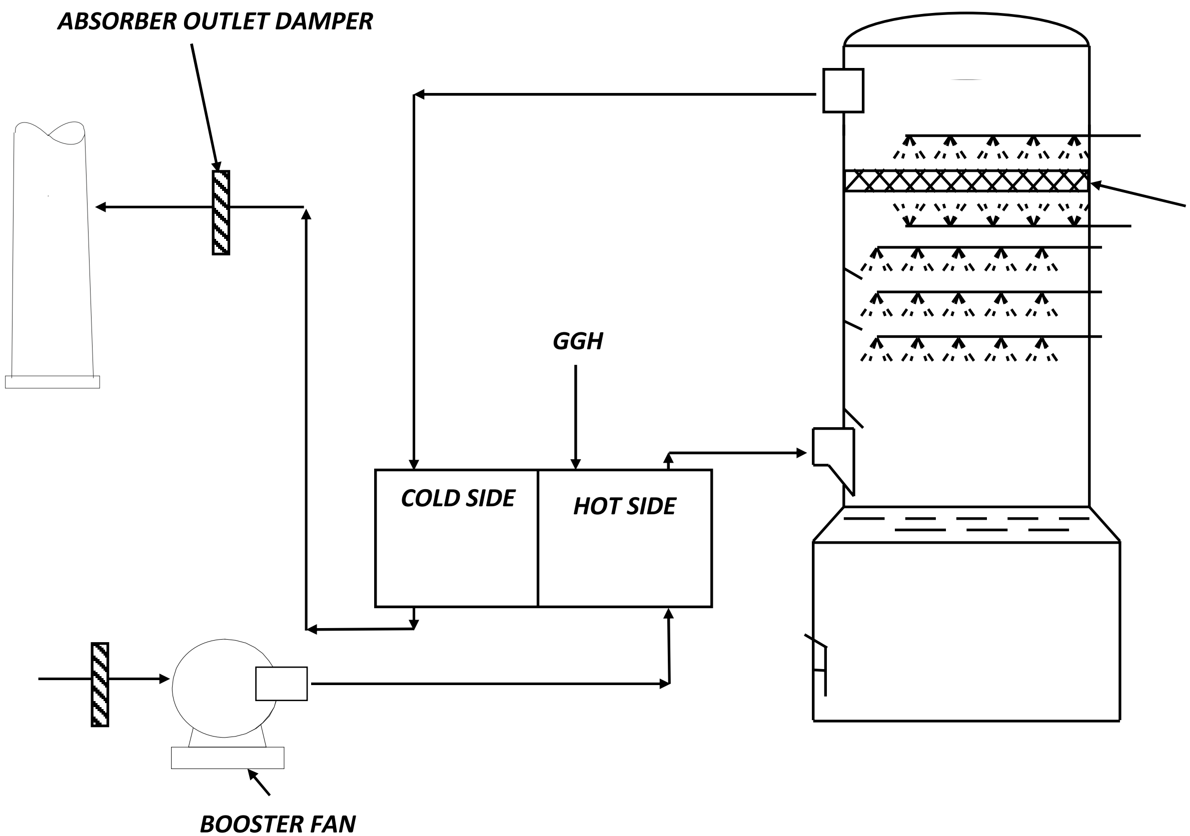
Materials of Construction

Absorber Spray Zone



Materials of Construction

Absorber Internals



Mist Eliminator Wash Pipe – FRP

Mist Eliminator Main Supports
Rubber Lined Carbon
Steel Tubes

Mist Eliminator Secondary and
Wash Pipe Supports – FRP

Mist Eliminator Wash Nozzles
Polypropylene

Mist Eliminators
Polypropylene with 20% Glass or
FRP

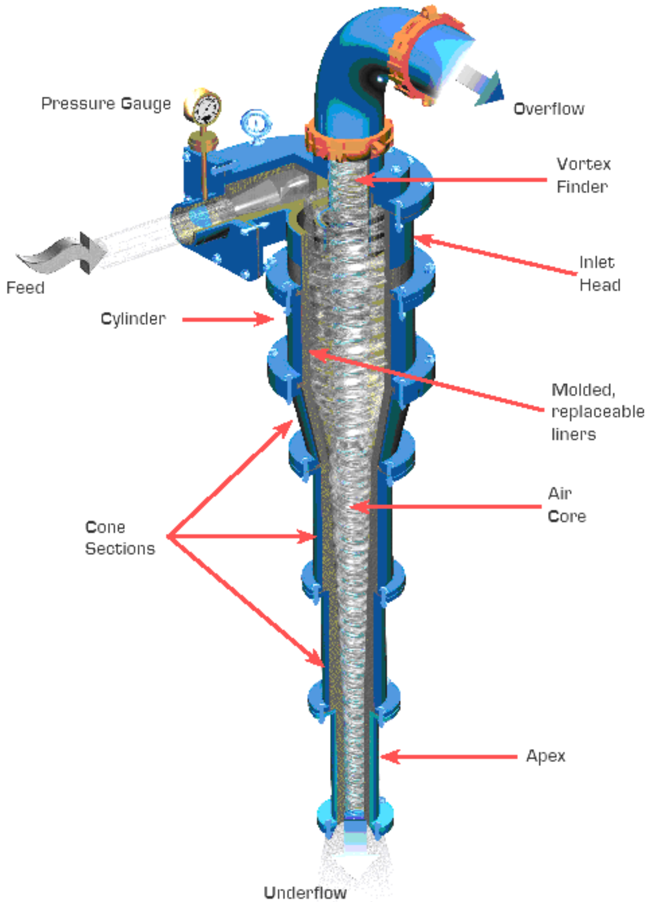
Nuts, Bolts, Washers
FRP

Materials of Construction

Mist Eliminator

Materials of Construction

Hydroclone

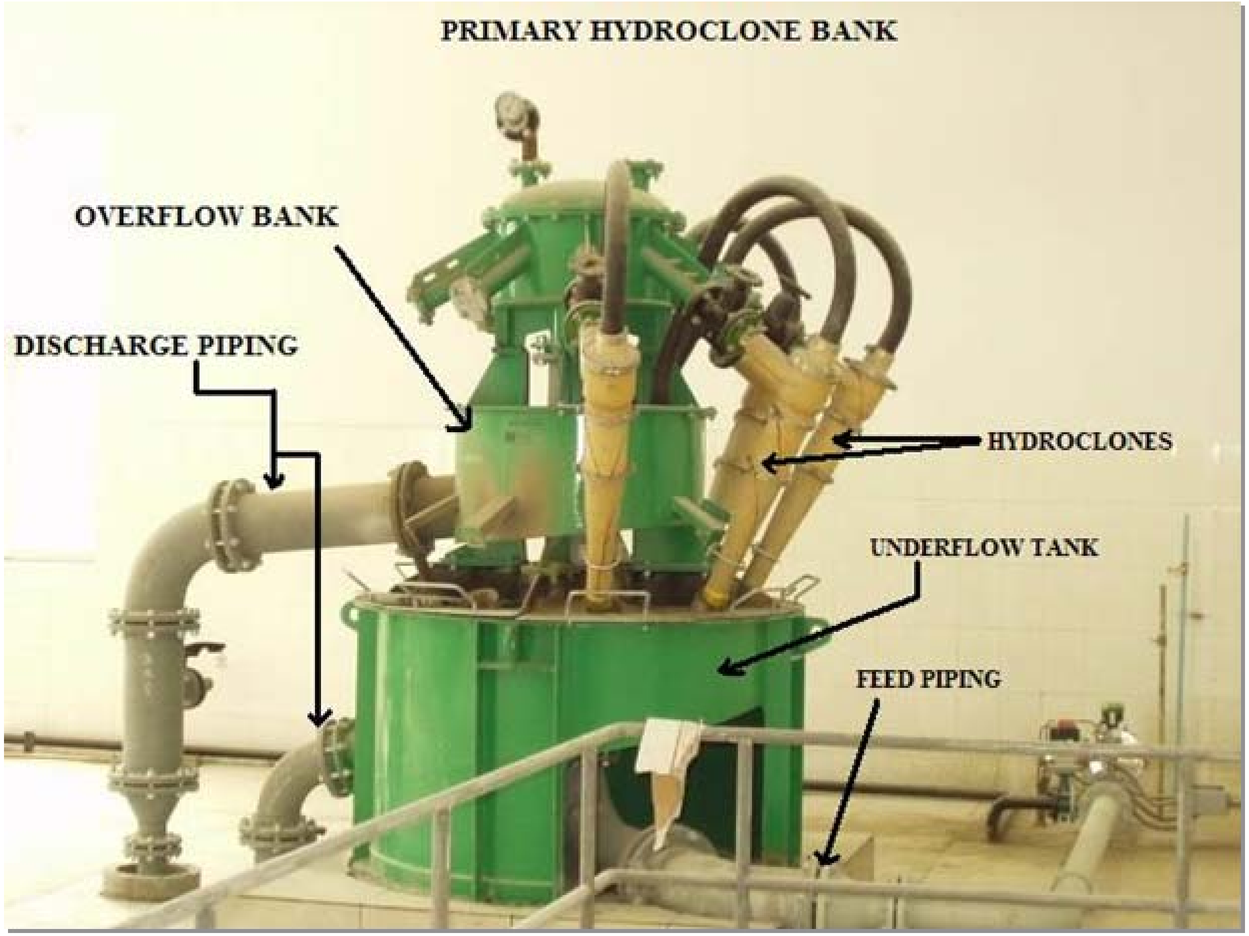


Courtesy of Krebs

- Cylinder – Carbon Steel or FRP
- Vortex Finder – Carbon Steel or FRP
- Cone Sections - Carbon Steel or FRP
- Inlet Head - Carbon Steel or FRP
- Liner – Elastomer, Replaceable
- Apex – Rubber or Ceramic
- Overflow Pipe – HDPE or FRP
- Underflow Tank: Painted Carbon Steel w/ Rubber Lining

Materials of Construction

Dewatering Area



Materials of Construction

Absorber Recycle Pump Impeller

Wrong Material Choice !!!

Wet Scrubber Fundamentals

- Overview of the WFGD Process
- Basic Chemistry
- Typical WFGD Processes
- Equipment Components
- Materials of Construction
- **Dry FGD vs. Wet FGD**
- Summary

CFB-FGD

Historical Comparative | Wet FGD vs. Spray Dryer FGD

	WET FGD	SPRAY Dryer FGD
SO_2 Removal Capability	Typically Higher (98+%)	Limited to 94 +/- %
Capital Cost	Higher	Lower
Acid Gas Removal	Limited	Good
Water Consumption	Higher	Lower
High Sulfur Fuels	Capable	Problematic
Unit Load Changes	Resilient	Less Resilient

CFB-FGD

Comparatives | WFGD, Spray Dryer FGD, CFB-FGD

	WET FGD	SPRAY Dryer FGD	CFB-FGD
High SO_2 Removal Capability	+		+
Lower Capital Cost		+	+
High Acid Gas Removal		+	+
Lower Water Consumption		+	+
High Sulfur Fuels Capability	+		+
Unit Load Change Resilience	+		+

CFB-FGD exhibits certain advantages of both technologies

CFB-FGD

Advantages

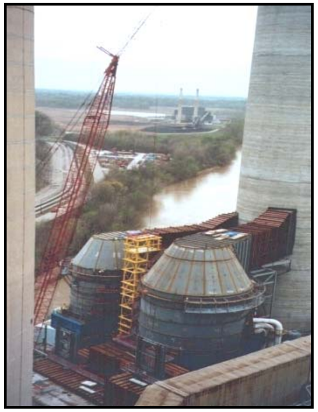
- High SO_2 and acid gas removal capability, 98+%
- Mercury removal capability 90+%
- Carbon steel vessel construction
- Compact size / footprint
- Operational stability
  - Ability to accept transient gas flows and temperature variations
  - Not dependent on maintaining a critical flue gas approach point temperature (unlike spray dryer)
  - Simple feedback control loops
- Utilizes proven mechanical design and components

Dry FGD vs. Wet FGD

Decision

- % Sulfur in coal is the primary driver
- Wet FGD can accommodate lower (than design) sulfur coal
- Dry FGD faces performance limitations with higher (than design) sulfur coal
- Decisions maybe influenced by site-specific:
  - Permit requirements
  - Delivered cost of reagents
  - Disposition of by-product
- SO_3 emission requirements may drive economics to dry FGD in some cases

Representative WFGD Projects



Minnkota Power Cooperative

250 MW | Lime Based WFGD

Milton R. Young
North Dakota

Fuel:	**Lignite**
% Sulfur:	**1.3%**
Inlet Gas Volume: (acfm)	**1,362,800**
Reagent:	**Lime**
Absorber Type:	**Spray Tower**
Oxidation Mode:	**Inhibited**
SO_2 Removal Efficiency:	**97%**
Oxidized Hg Removal Efficiency:	**80%**
Startup Date:	**2011**

Lower Colorado River Authority

2x600 MW | Limestone WFGD

The LCRA project is MET's first application of Stebbins tile with carbon steel absorber vessels.

Fayette Power Project, Units 1, 2 and 3
Texas

Fuel:	**PRB Coal**
% Sulfur:	**0.8%**
Inlet Gas Volume: (acfm)	**2,548,000**
Reagent:	**Limestone**
Absorber Type:	**Spray Tower**
SO_2 Removal Efficiency:	**97%**
Startup Date:	**Unit 1: Dec 2010** **Unit 2: Feb 2011**

PacifiCorp Energy

Project Facts

FGD System Upgrades
Hunter Units 1 & 2 and Huntington Canyon Unit 1

- Won by MET in sealed bid competition; Owner's Engineer is Sargent & Lundy; 12/09 award
- Design, supply and erection of absorber system modifications, conversion to forced oxidation, civil works, balance of plant upgrades and new reagent preparation system (Hunter Plant)
- Each unit is 430+ MW rated with 4 FGD absorbers (12 total)
- Substantial completion dates:
  - Huntington Unit 1: July 2011
  - Hunter Unit 2: September 2011
  - Hunter 1&2 Reagent Prep System: May 2012
  - Hunter Unit 1: May 2013

Huntington Station and Hunter Station | Utah

PacifiCorp Energy

Lime Based WFGD

Plant:	Hunter	Huntington
MW:	Units 1&2: 430	Unit 1: 445
Fuel:	Coal	Coal
% Sulfur:	1.3%	1.3%
Inlet Gas Volume: (acfm)	2,065,000	1,906,000
Reagent:	Lime	Lime
Absorber Type:	Spray Tower	Spray Tower
Oxidation Mode:	Inhibited- Lances	Inhibited- Lances

US Emissions from Energy Consumption at Conventional Power Plants & Combined Heat and Power Plants, 1994 through 2005

	Carbon Dioxide (CO_2)	Sulfur Dioxide (SO_2)	Nitrogen Oxides (NO_x)	FGD Installations	Capacity (MW)
2005	2,513,609	10,340	3,961	248	101,648
2004	2,456,934	10,309	4,143	248	101,492
2003	2,415,680	10,646	4,532	246	99,567
2002	2,395,048	10,881	5,194	243	98,673
2001	2,389,745	11,174	5,290	236	97,988
2000	2,429,394	11,297	5,380	192	89,675
1999	2,326,559	12,444	5,732	192	89,666
1998	2,313,008	12,509	6,237	186	87,783
1997	2,223,348	13,520	6,324	183	86,605
1996	2,155,452	12,906	6,282	182	85,842
1995	2,079,761	11,896	7,885	178	84,677
1994	2,063,788	14,472	7,801	168	80,617

Source: Energy Information Administration, Form EIA-767, "Steam-Electric Plant Operation and Design Report"

Note: These data are for plants with a fossil-fueled steam-electric capacity of 100MW or more. Beginning in 2001, data for plants with combustible renewable steam-electric capacity of 10 MW or more were also included. Data for Independent Power Producers and Combined Heat and Power Plants are included beginning with 2001 data. Totals may not equal sum of components because of independent rounding.