

MARSULEX
ENVIRONMENTAL TECHNOLOGIES



Michael A. Walsh, P.E.
VP Engineering



WET FGD TYPES AND FUNDAMENTALS

Solutions. Performance. Relationships.



1. Overview of the WFGD Process

2. Basic Chemistry

3. Typical FGD Processes

4. Dry FGD vs Wet FGD

5. Summary

1. Overview of the WFGD Process

All require use of an alkaline chemical “reagent”

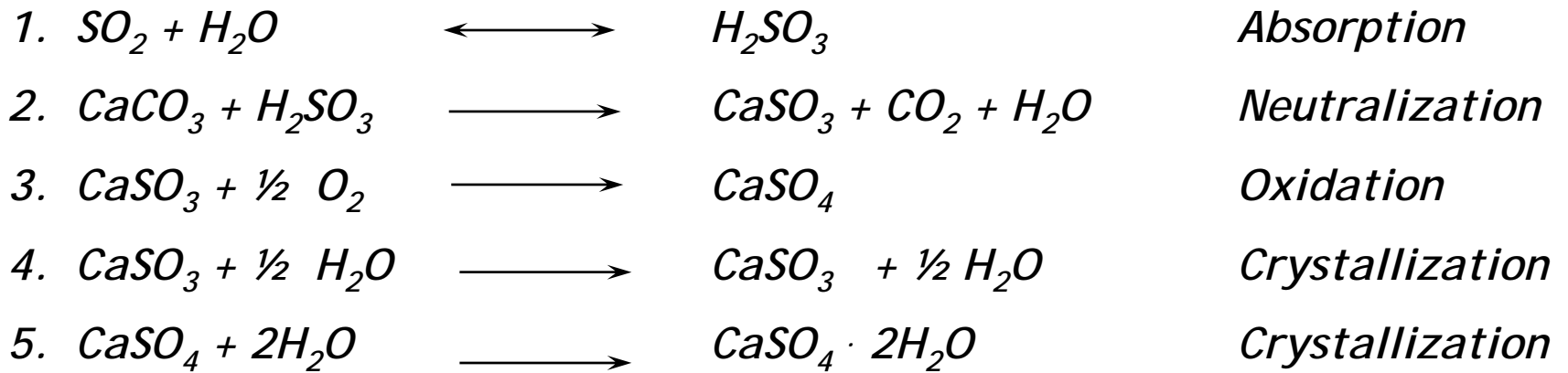
- Limestone
- Lime
- Ammonia
- Sodium

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

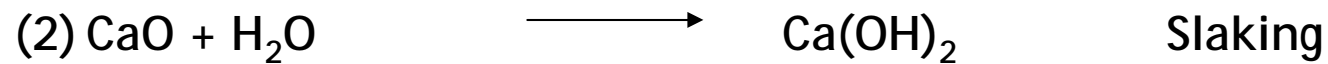
- Throwaway process
- Gypsum process
- Regenerative process
- Fertilizer product process

2. Basic Chemistry

Reactions taking place in absorber & recycle tank:

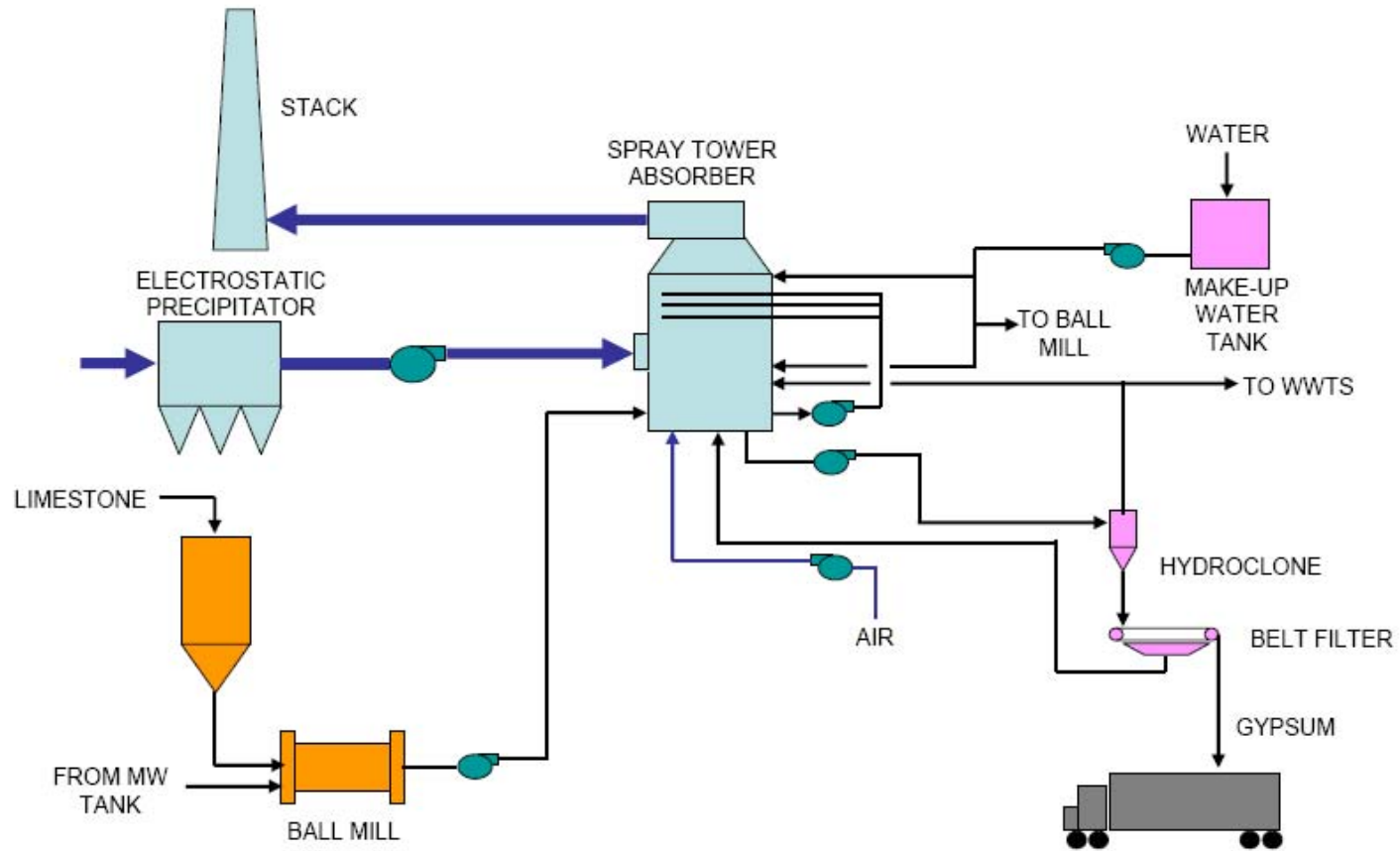


Reactions taking place in absorber & recycle tank are very similar to those in the limestone system. The main chemical differences are:



Typical Limestone FGD

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved

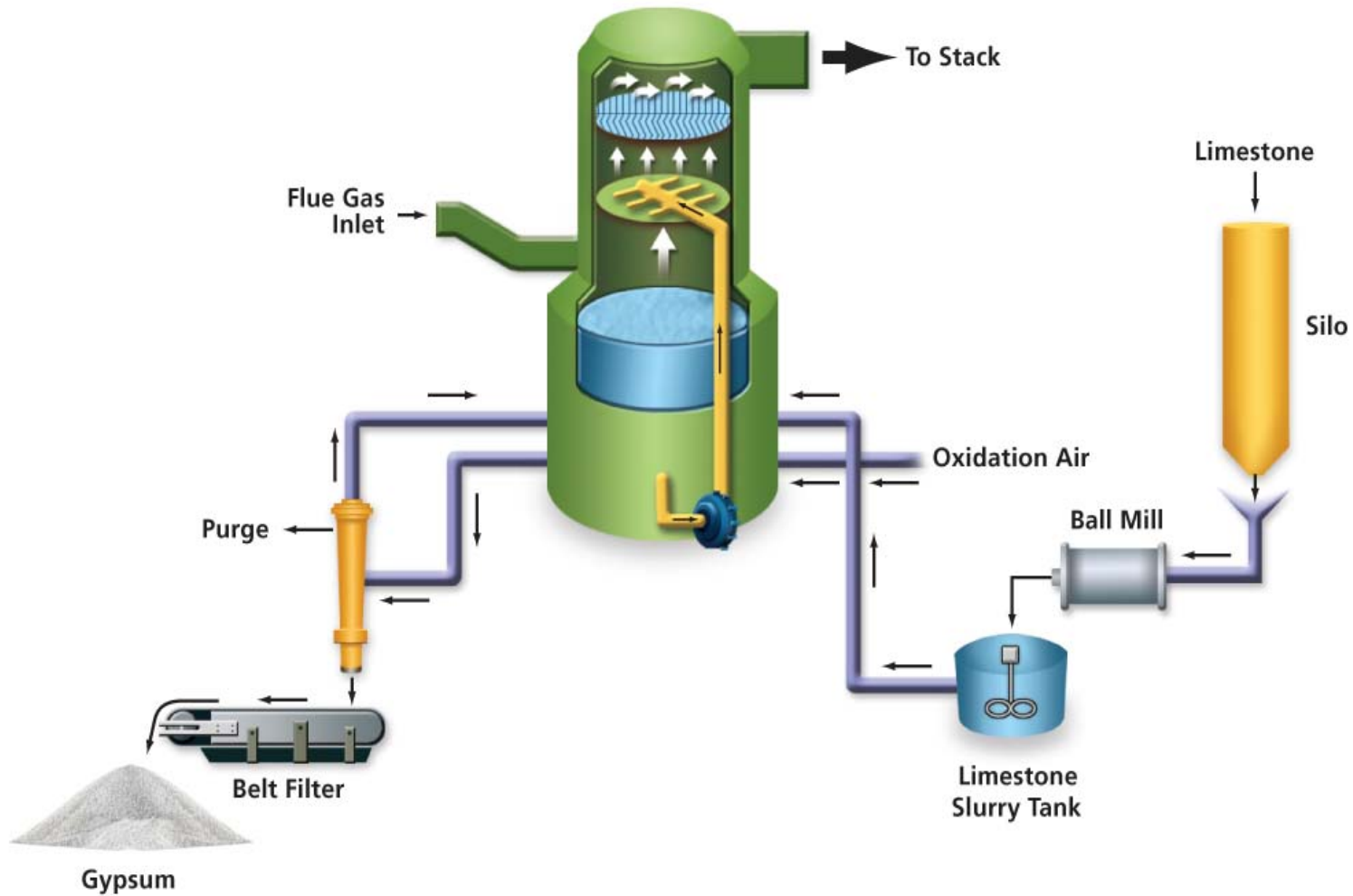


Solutions. Performance. Relationships.

MARSULEX

Typical Limestone FGD

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved

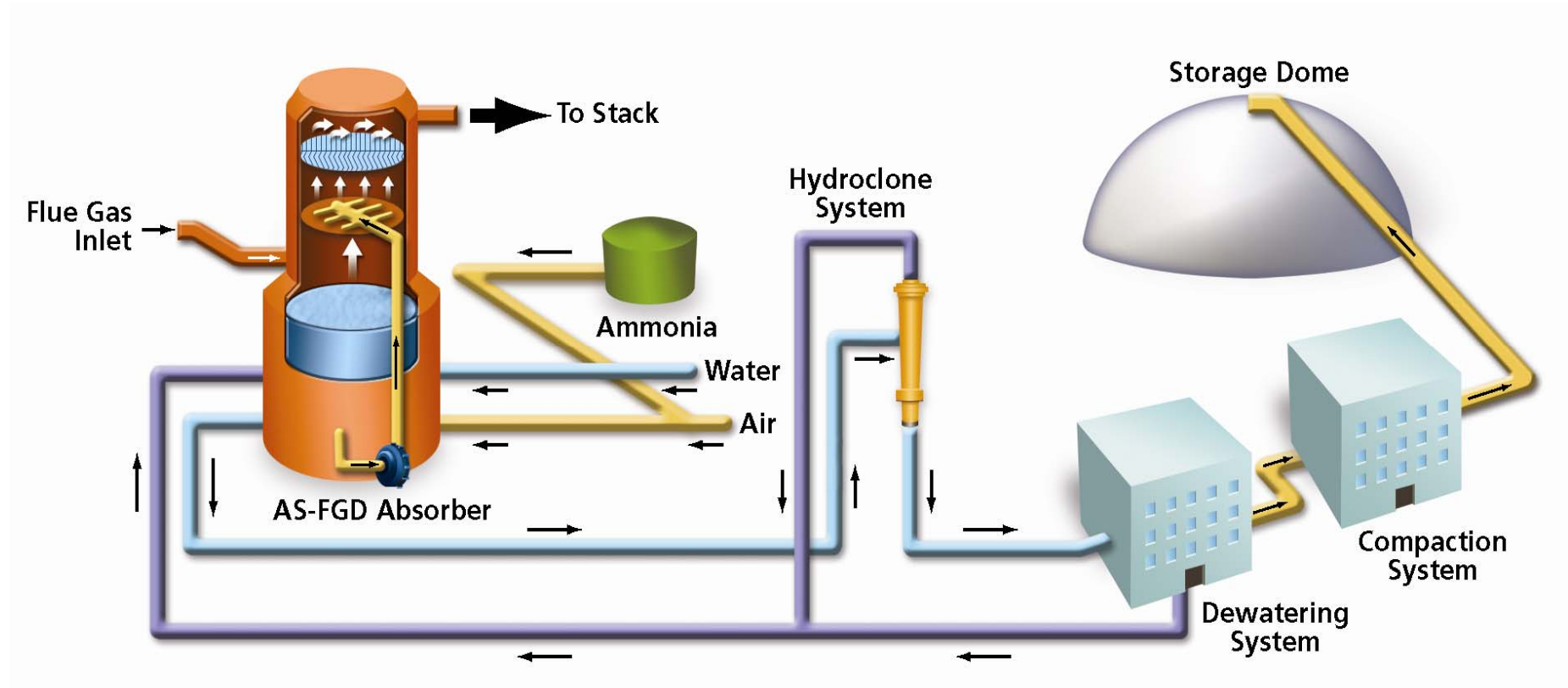


Solutions. Performance. Relationships.



Ammonia-Based WFGD System

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



Solutions. Performance. Relationships.

MARSULEX

Ammonia WFGD Process

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



- For every pound of SO₂ 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

3. Typical FGD Processes

Typical WFGD Processes

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved

1. SO₂ Outlet Emissions

2. pH and Stoichiometry

3. Liquid-to-Gas Ratio

4. SO₂ Inlet Concentration

5. Residence Time

6. Mist Elimination

SO₂ Outlet Emissions

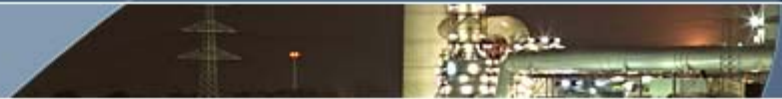
Copyright © 2008

Marsulex Environmental Technologies

All rights reserved



- Allowable SO₂ outlet emissions are based on either maximum outlet level or on overall system SO₂ removal efficiency
- Requirements dictated by environmental regulations
- Depending on requirements, absorbers may be designed to treat all or only a portion of flue gas



- 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 SO₂ removed.

Liquid-to-Gas Ratio

Copyright © 2008

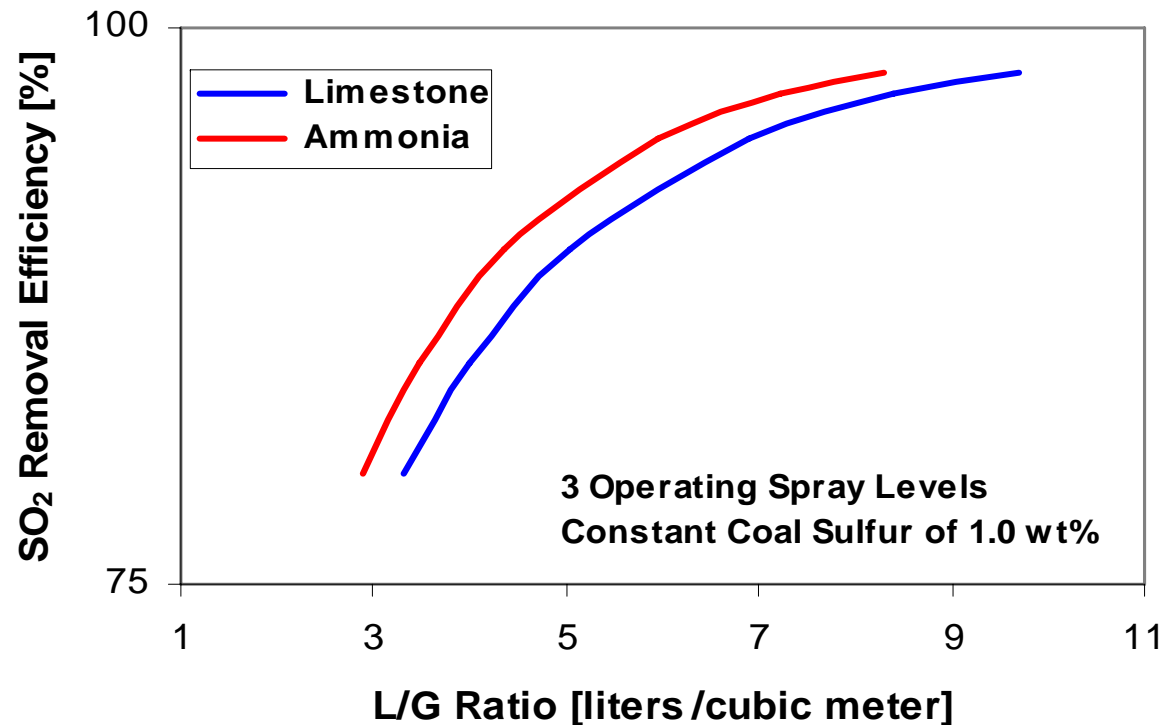
Marsulex Environmental Technologies

All rights reserved

- 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

Liquid-to-Gas Ratio

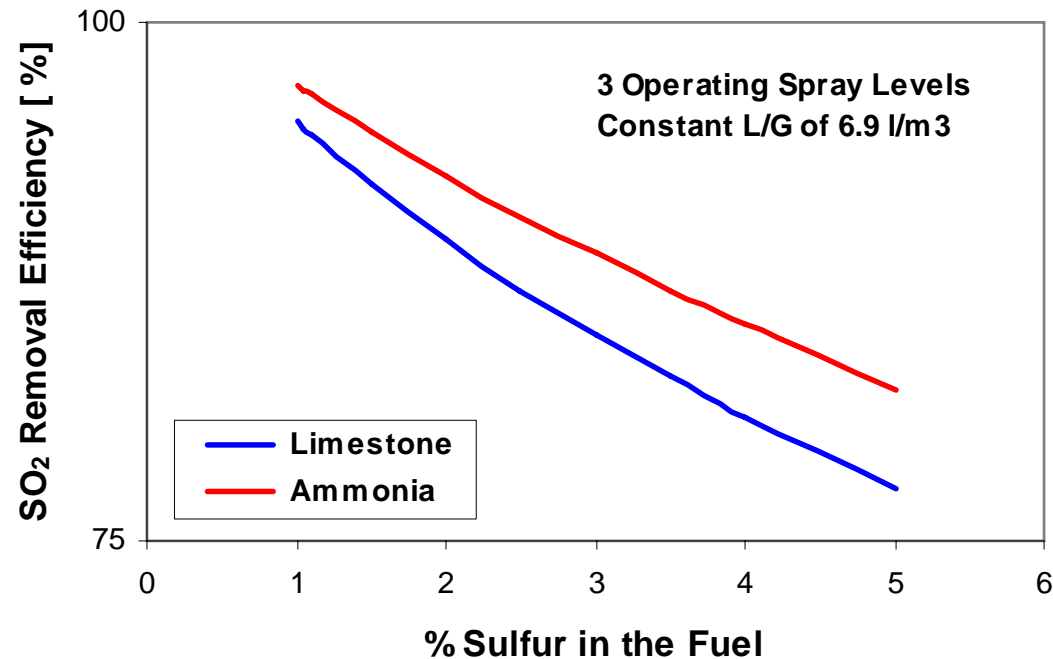
Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



The maximum flue gas velocity sets the absorber vessel diameters and impacts the ability of the mist eliminators to prevent droplet carryover.

SO₂ Inlet Concentration

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



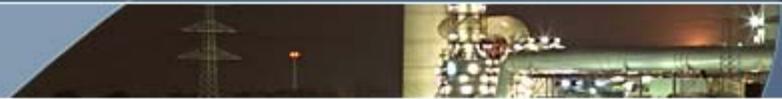
At constant operating conditions, increasing the concentration of SO₂ (increasing the sulfur content of the fuel) will decrease SO₂ removal. Increased SO₂ concentration causes an increased depletion of liquid phase alkalinity.

Residence Time

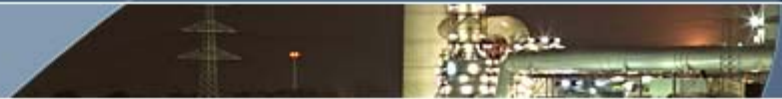
Copyright © 2008

Marsulex Environmental Technologies

All rights reserved



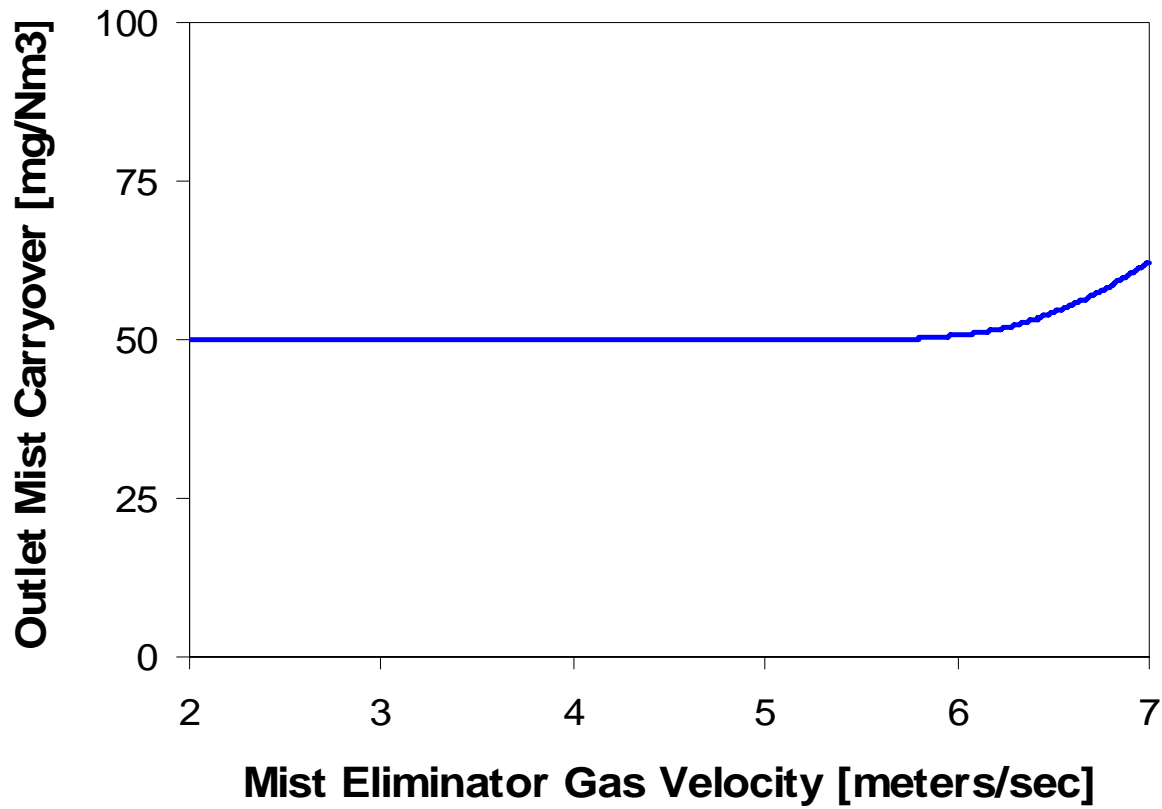
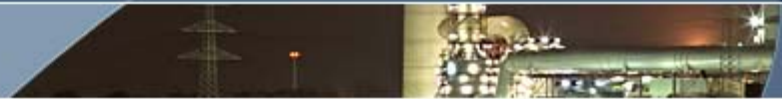
- Residence time - the time that slurry spends in the reaction tank before being recycled for further SO₂ absorption
- Residence time allows the liquid to desaturate and avoid scaling in lime/limestone systems
- Typically, for limestone systems, a residence time of 3-5 minutes is provided

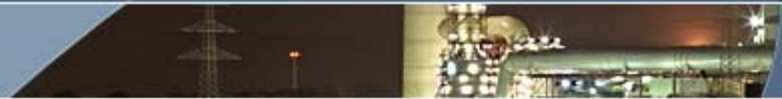


- Important to remove entrained liquid droplets in order to avoid carryover of the liquid into downstream ducts and stack.
- Good performance of mist eliminators depends on:
 - Operation of absorber at flue gas velocities below critical velocity at which re-entrainment of mist occurs
 - Proper washing techniques

Mist Elimination

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



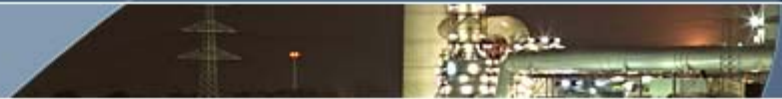


- Major parameters to be considered for proper mist eliminator washing include:
 - Wash water rate
 - Water quality
 - Timing sequence
 - Washing area coverage
 - Nozzle pressure
 - Nozzle spray angle

4. Major Components

Absorbers - Traditional Reagents

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



1. Spray Absorbers – Open Tower

2. Tray Towers

3. Packed Towers

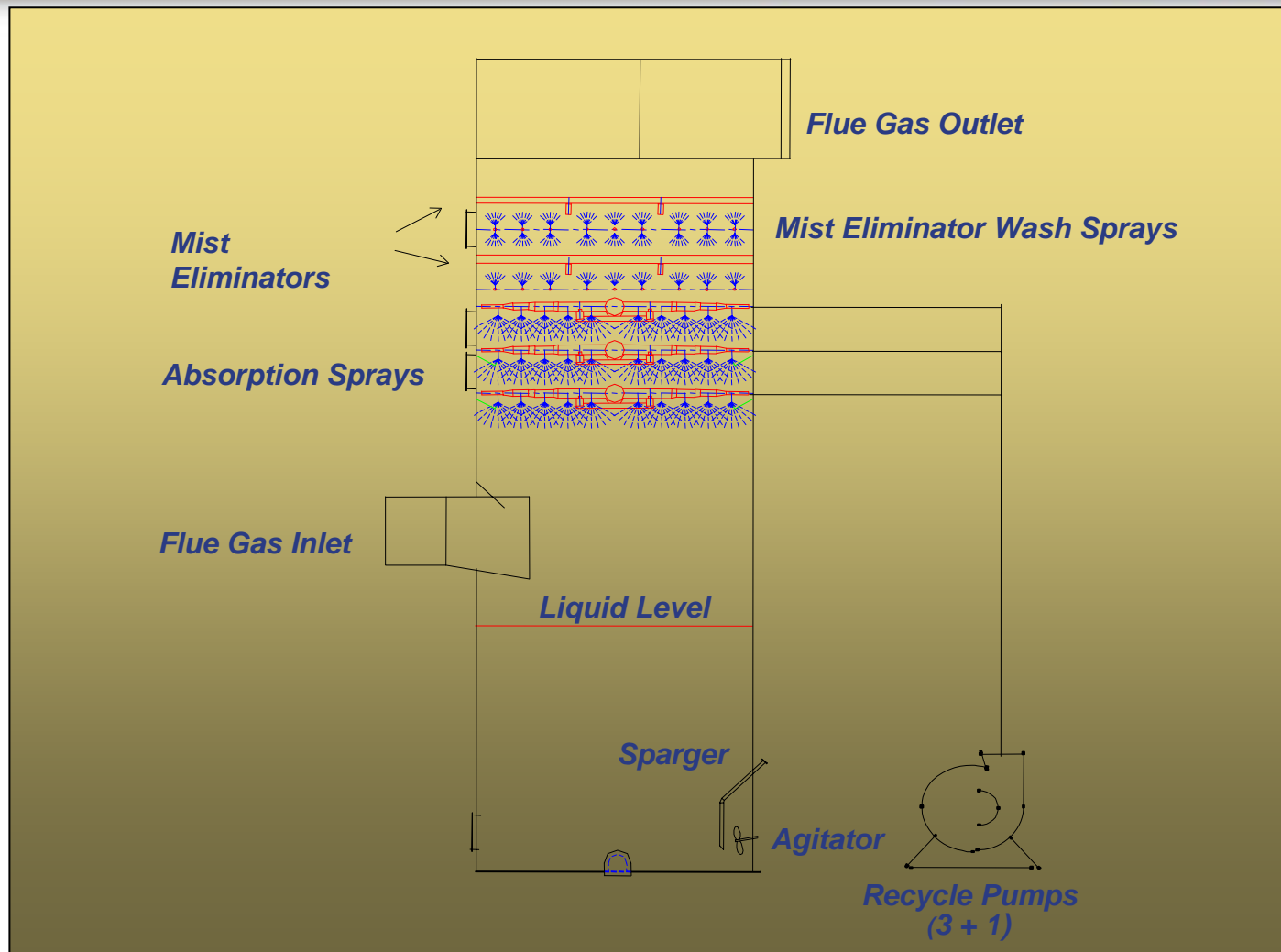
4. Jet Bubbling Reactors

5. Spray Dryers

6. Wulff Process

Spray Absorbers

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved

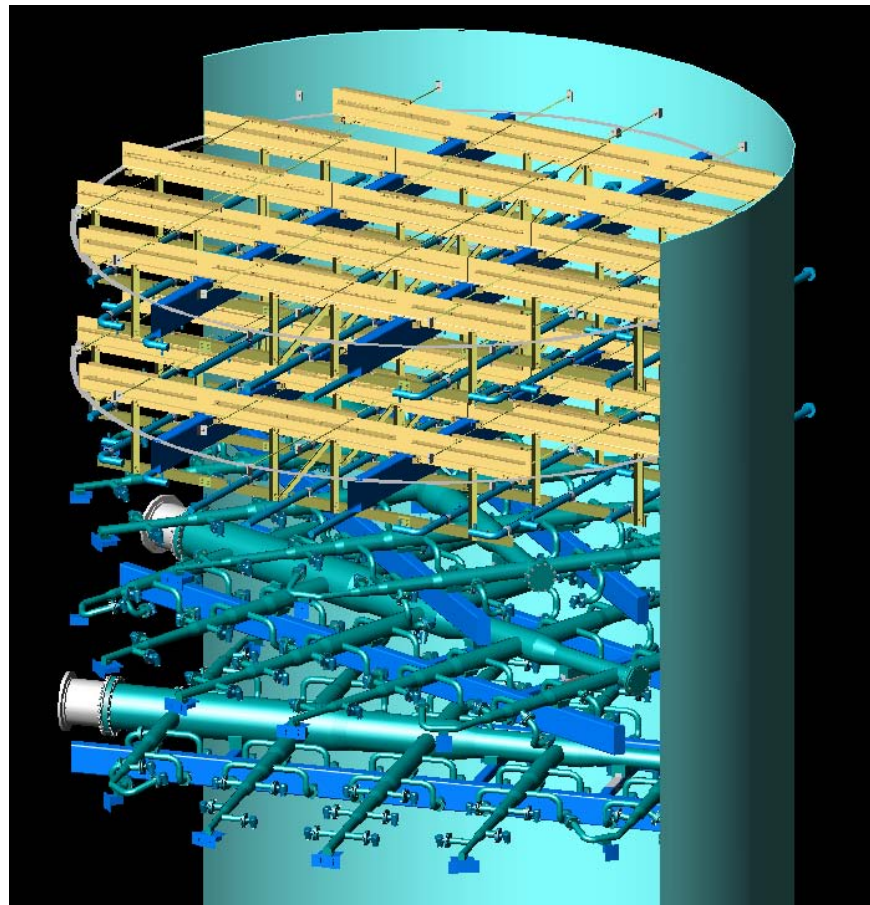


Solutions. Performance. Relationships.



Isometric of "Open" Spray Tower

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved

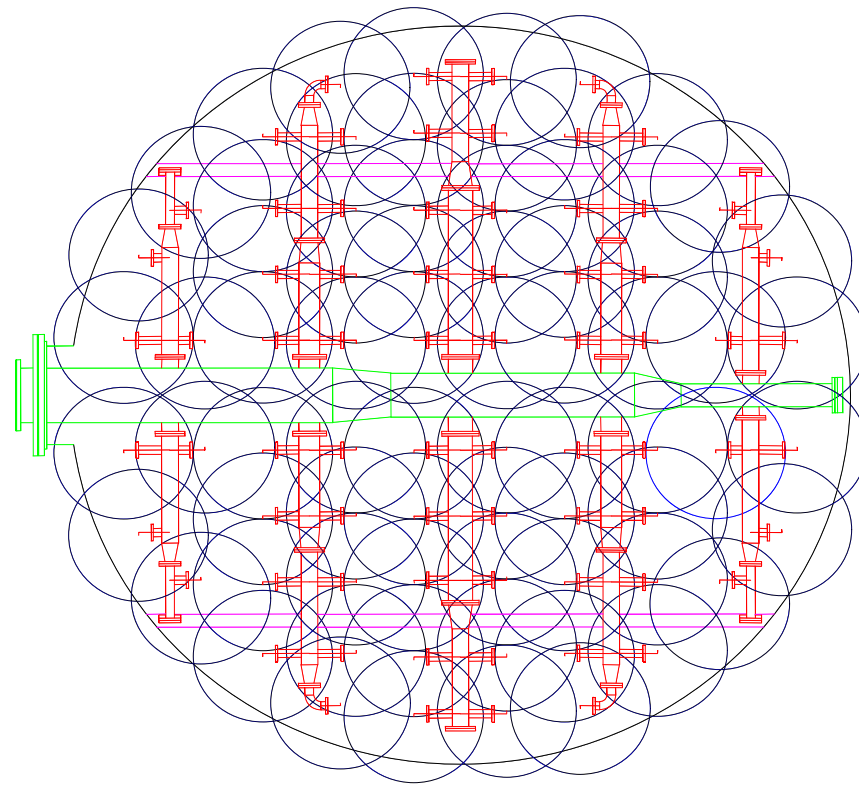


Solutions. Performance. Relationships.

MARSULEX
—————

Typical Spray Pattern

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved

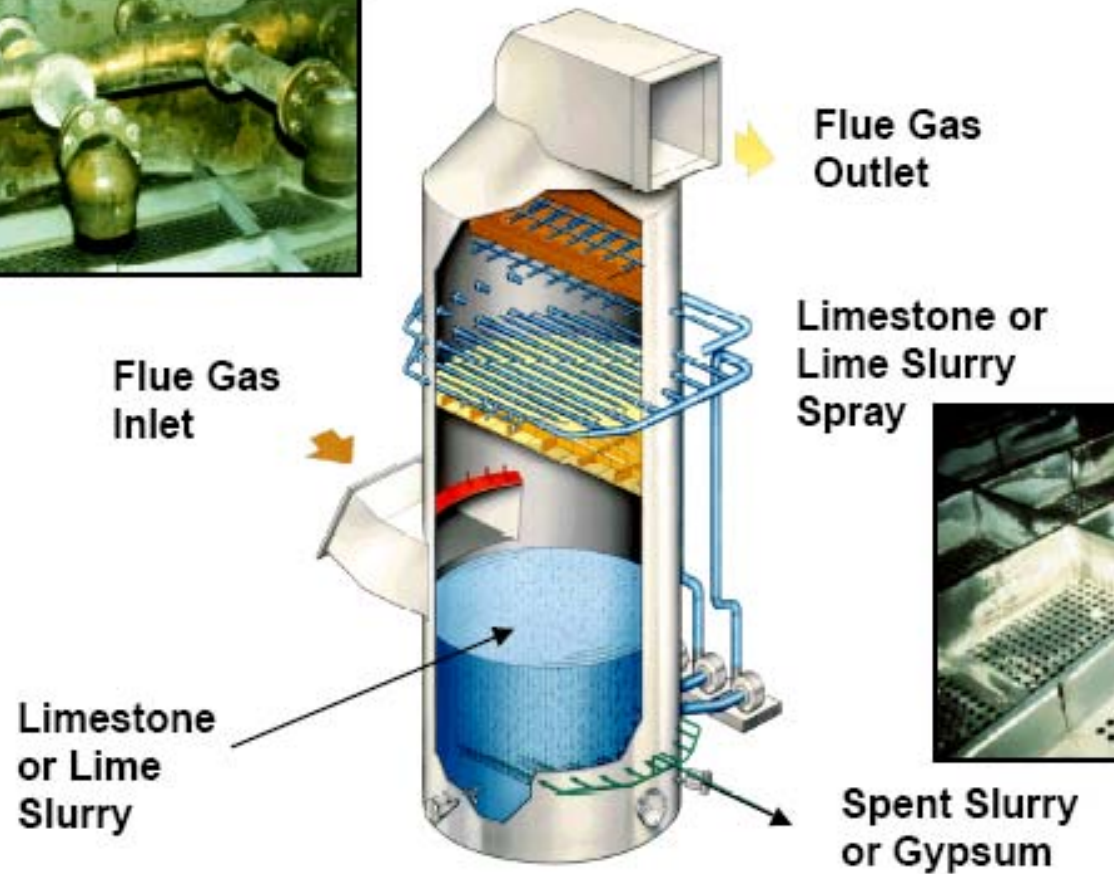


Solutions. Performance. Relationships.



Tray Towers

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



Solutions. Performance. Relationships.

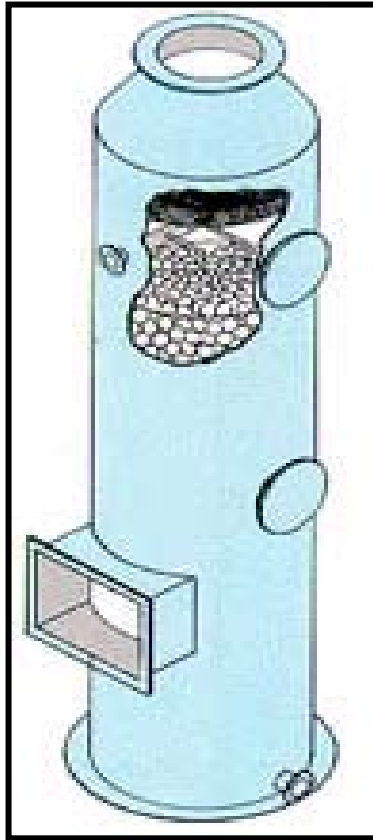


Packed Towers

Copyright © 2008

Marsulex Environmental Technologies

All rights reserved



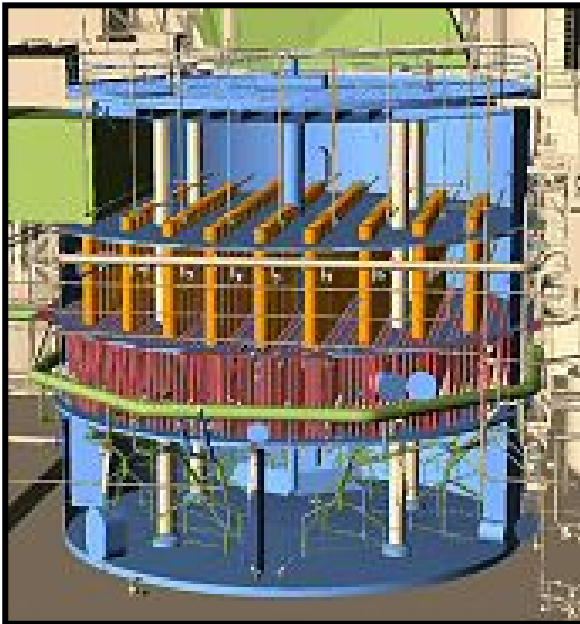
- Gas enters the base of the tower and passes up through the packing countercurrent to the scrubbing liquor which is introduced at the top of the tower
- The liquid is dispersed by means of inert, stationary or molded packings of various shapes and configurations designed to add surface area and thus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

Jet Bubbling Reactor

Copyright © 2008

Marsulex Environmental Technologies

All rights reserved



In one vessel combines concurrent chemical reactions of:

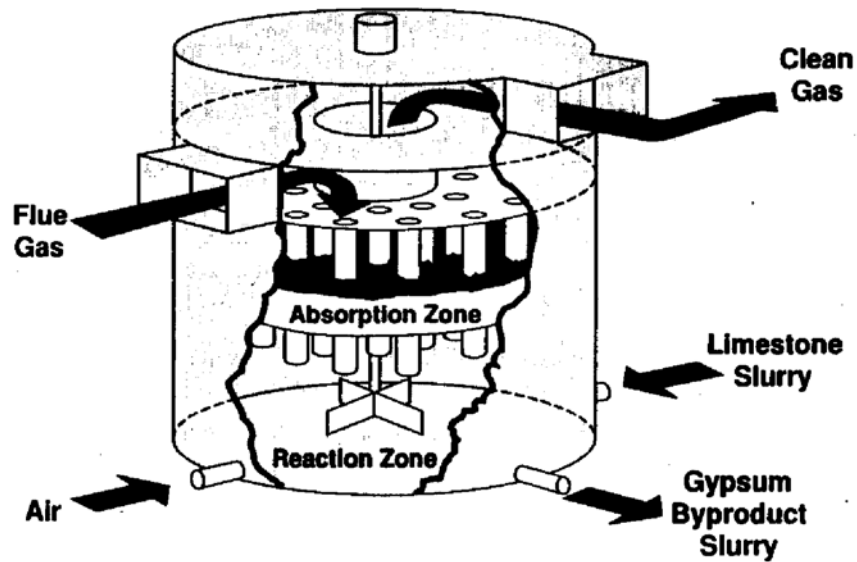
- Limestone dissolution
- SO₂ absorption
- Neutralization
- Sulfite oxidation
- Gypsum precipitation
- Gypsum crystal growth

Jet Bubbling Reactor

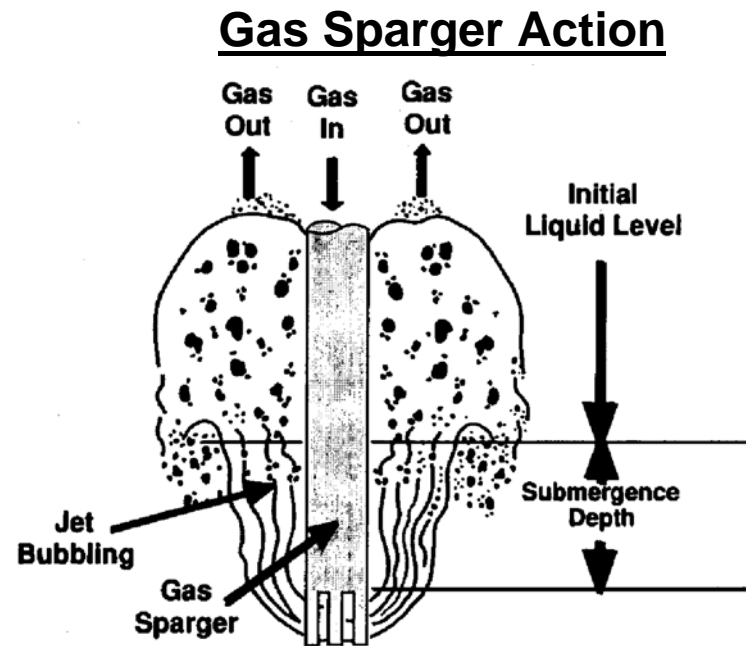
Copyright © 2008

Marsulex Environmental Technologies

All rights reserved



Cut-Away of JBR



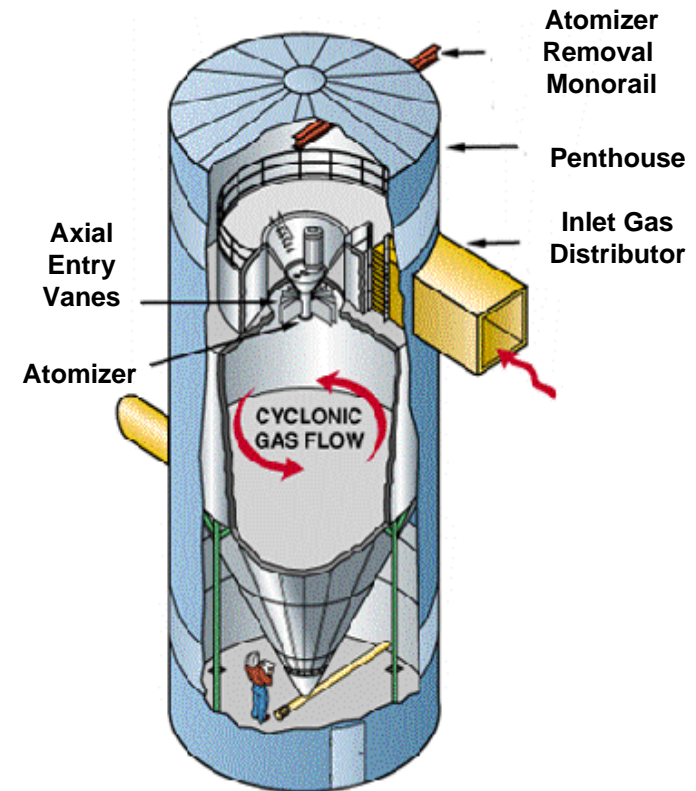
Spray Dryer Absorber

Copyright © 2008

Marsulex Environmental Technologies

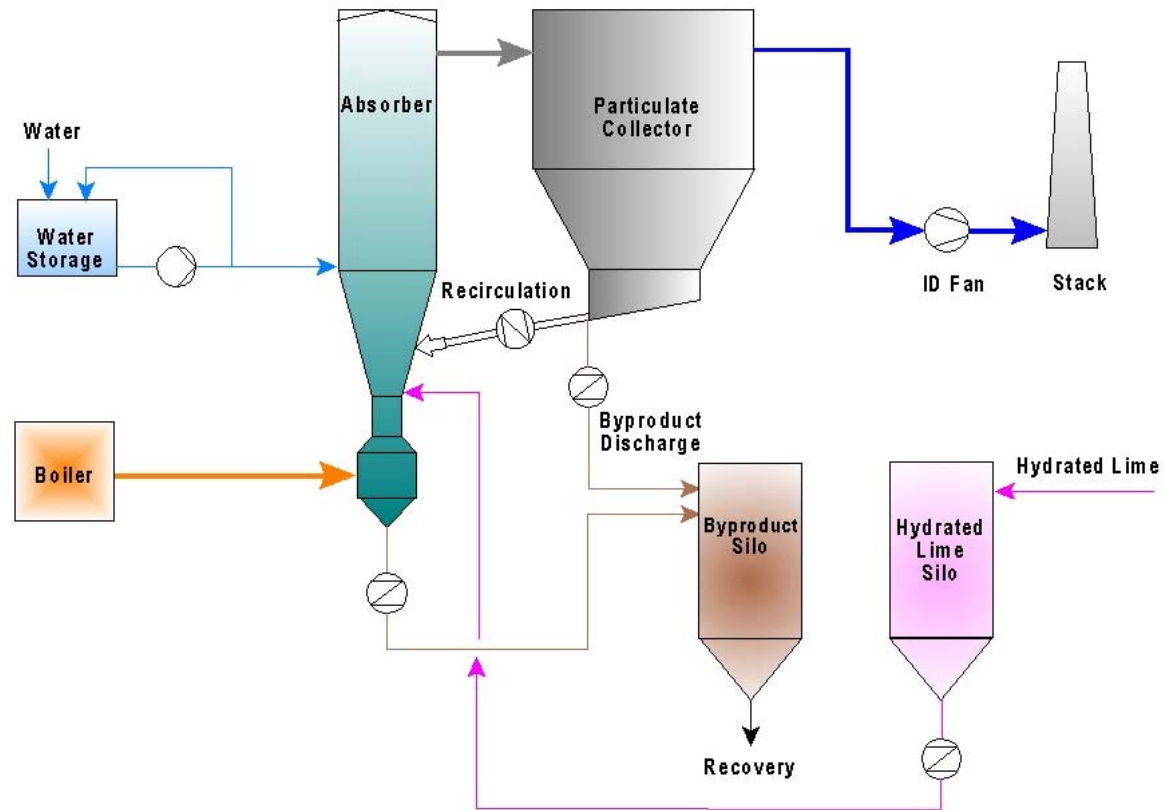
All rights reserved

- Rotary atomizer (shown) or dual fluid atomization
- Lime slurry or lime + recycle reagent
- ~95% SO₂ efficiency practical limit due to stoichiometry



Graf / Wulff Fluidized Bed

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



Reflux Circulating Fluid Bed Technology

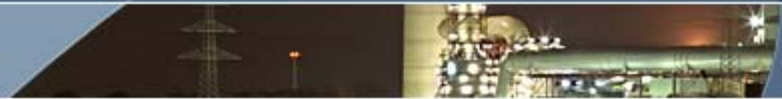
Solutions. Performance. Relationships.



4. Dry FGD vs. Wet FGD

Dry FGD vs Wet FGD

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



	<u>WET</u>	<u>DRY</u>
Capital Cost	Higher	Lower
Reagent Cost	Lower	Higher
% SO ₂ Efficiency	High 90's	Mid 90's (Spray Dryer Stoichiometry Limits) High-90's (CDS)
Water Usage	Higher	Lower (Approx 40% less)
Overall Operating \$'s (Normalized)	Lower	Higher
Coal % Sulfur preference	> 2%	<2%
By-Product Usage	Possible	Rare
SO ₃ Emissions	Yes	NIL

Dry FGD vs Wet FGD

Copyright © 2008

Marsulex Environmental Technologies

All rights reserved

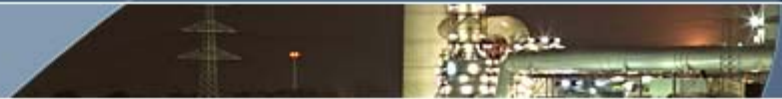
Decision

- % 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
- SO₃ emission requirements may drive economics to dry FGD in some cases

5. Summary

By-product Values

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved



	(\$US/ton)
Gypsum	<i>-4 to +4</i>
Sulfuric Acid (100% basis)*	<i>60 to 88</i>
Elemental Sulfur*	<i>50 to 80</i>
Ammonium Sulfate*	<i>110 to 196</i>

**Source: Green Markets*

Lower Colorado River Authority

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved

2x600 MW, Units 1 & 2

Wet FGD retrofit awarded to MET in 2006



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:	2010

- Wet Limestone FGD for low-sulfur PRB Coal
 - “Rules of Thumb” do not always dictate decision
 - Site-specifics...
 - Permit % SO₂ efficiency
 - Existing Wet FGD plant on Unit 3
 - By-product disposal issues
 - Reagent costs
- ... can trump the % sulfur in coal in the decision to go Wet

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

Copyright © 2008
Marsulex Environmental Technologies
All rights reserved

	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

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.

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

Solutions. Performance. Relationships.

