西南交通大學
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Control of Sulfur Oxides

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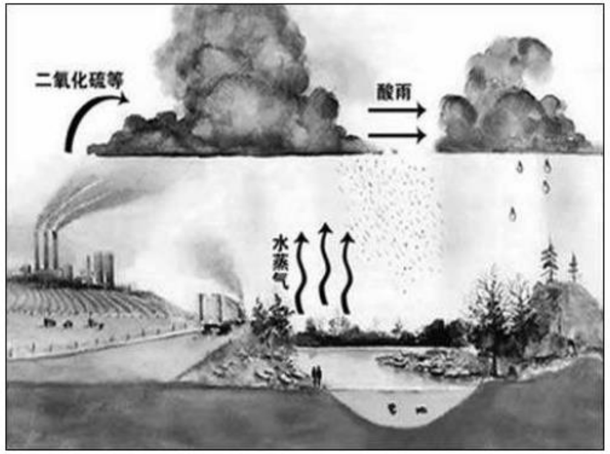
Contents

15.1 Introduction

- **Sulfur Oxides（SO_x）： SO_2 and SO_3**

- **Serious effects of emissions of SO_x to the atmosphere:**
  - Respiratory illnesses
  - Loss of chlorophyll in green plants
  - Acidic deposition



- **Emission sources in the U. S.**
  - Coal-fired power Plants
  - Industrial fuel combustion (petroleum refining)
  - Industrial processes (H_2SO_4 manufacturing, and smelting of nonferrous metals)

15.1 Introduction

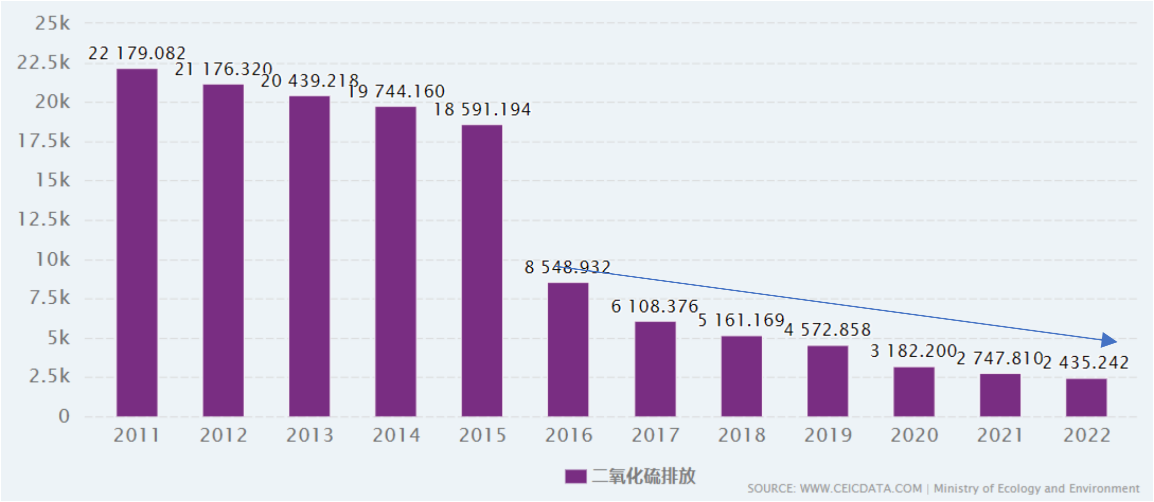
◆ Reductions in SO_x emissions

Trend in USA Emissions of SO_2 (1970-2023)

Source Category	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
FUEL COMB. ELEC. UTIL.	4,636	3,412	3,297	3,253	2,304	1,562	1,382	1,310	1,015	836	990	903
FUEL COMB. INDUSTRIAL	682	658	614	520	441	433	376	357	331	248	247	236
FUEL COMB. OTHER	219	210	196	120	112	52	44	43	44	28	29	29
CHEMICAL & ALLIED PRODUCT MFG	126	126	122	123	113	111	111	106	96	82	81	72
METALS PROCESSING	144	144	114	105	99	85	85	74	64	50	51	53
PETROLEUM & RELATED INDUSTRIES	122	120	94	86	84	101	86	95	91	189	195	194
OTHER INDUSTRIAL PROCESSES	188	188	186	167	153	139	146	145	136	125	131	127
SOLVENT UTILIZATION	0	0	0	0	0	0	0	0	0	0	0	0
STORAGE & TRANSPORT	9	9	7	3	1	4	1	1	1	1	1	1
WASTE DISPOSAL & RECYCLING	25	25	25	25	25	24	25	25	25	36	36	35
HIGHWAY VEHICLES	27	28	27	28	27	26	24	23	17	10	9	10
OFF-HIGHWAY	119	83	83	84	26	24	27	27	27	15	18	18
MISCELLANEOUS	130	112	85	85	117	135	201	205	118	224	281	176
Total	6,428	5,117	4,850	4,598	3,502	2,696	2,508	2,411	1,965	1,845	2,068	1,853
Wildfires	45	44	21	24	66	72	102	104	26	141	174	67
Total without wildfires	6,383	5,073	4,830	4,575	3,437	2,624	2,407	2,307	1,939	1,704	1,894	1,786
Miscellaneous without wildfires	85	67	64	61	52	63	100	101	92	83	107	109

Source: Air Pollutant Emissions Trends Data | US EPA

Trend in CHN Emissions of SO_2 (2011-2022)



Source：https://www.ceicdata.com.cn/zh-hans/china/industrial-waste-air-emission/cn-sulphur-dioxide-emission

15.2 Overview of Control Strategies

◆ Two basic approaches to controlling SO_x emissions

(1) Remove sulfur from fuel before it is burned

(2) Remove SO_2 from the exhaust gases

Main Option	Suboption	Examples of Processes
Do not create SO_2	Switch to a low-sulfur fuel Desulfurize the fuel	Convert to natural gas Oil desulfurization Coal cleaning
SO_2 scrubbing: Throwaway	Wet scrubbing	Lime Limestone Forced oxidation Inhibited oxidation Dual alkali Magnesium Enhanced Lime (MEL) Seawater
	Dry scrubbing	Lime spray drying Lime injection Trona Nahcolite Circulating fluidized bed
Regenerative	Wet processes	Absorption with water (smelters) Wellman-Lord MgO Citrate Carbonate Sulfite Forced oxidation (with gypsum sales)
	Dry processes	Activated carbon adsorption Copper oxide adsorption

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02 | Fuel Desulfurization

15.2.1 Fuel Desulfurization

◆ Oil desulfurization: diesel and gasoline for motor vehicle fuels (1-3% S)

- **Desulfurization units:** remove organic sulfur from oil via a catalytic reaction with hydrogen

$$R\text{–}S + H_2 \rightarrow H_2S + R \qquad \textbf{(15.1)}$$

where R represents any organic group.

When the H_2S was burned as part of the fuel gas, it produced SO_2

- **Recovery units (Claus process)**: part of the H_2S is burned to SO_2, and then the two compounds are combined over a catalyst to simultaneously oxidize and reduce each other.

$$H_2S + \frac{3}{2}O_2 \rightarrow H_2O + SO_2 \qquad \textbf{(15.2)}$$

$$2H_2S + SO_2 \rightarrow 2H_2O + 3S \qquad \textbf{(15.3)}$$

- Also for **Natural gas** (before the gas is admitted to pipelines)

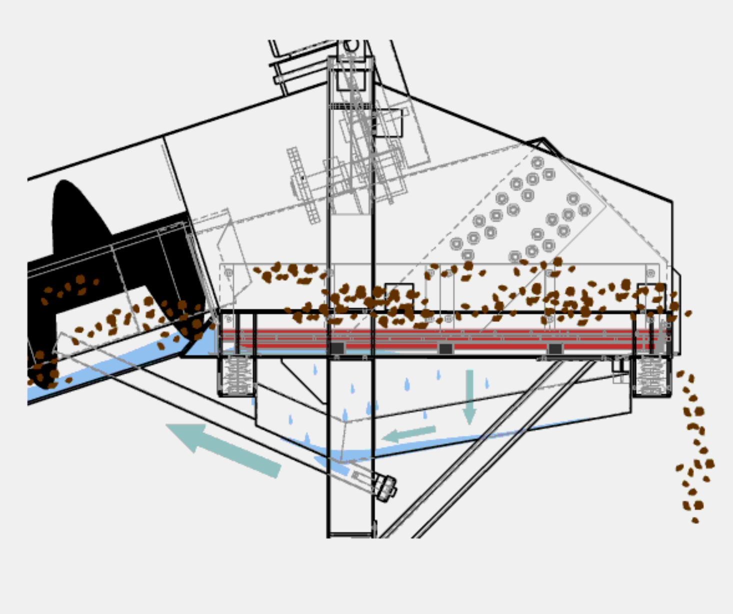
The elemental sulfur is separated in the molten state and sold as a by-product, and the emissions of either H_2S or SO_2 from a refinery are reduced substantially.

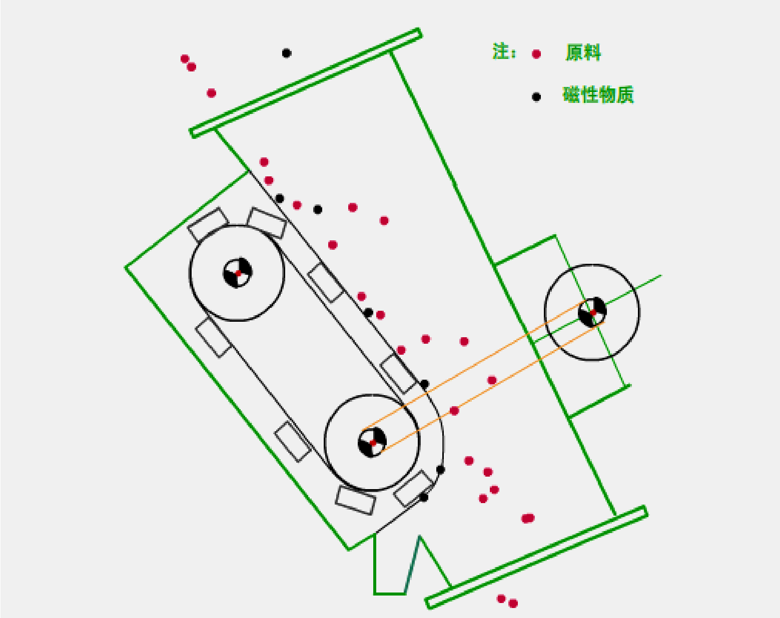
15.2.1 Fuel Desulfurization

◆ Coal cleaning (2%+ S)

- **Sulfur in mineral form (pyrites (FeS_2) or mineral sulfates):**

  removed relatively easily by washing or other physical cleaning processes





- **Organic sulfur:** Coal gasification and liquefaction processes

04 | Flue Gas Desulfurization

15.2.2 SO_2 Removal Techniques

(1) Remove sulfur from fuel before it is burned

(2) Remove SO_2 from the exhaust gases

- **Flue Gas Desulfurization**

  A stream of gas that is dilute in SO_2 (about 0.2% or 2000 ppm SO_2).

- **Absorption of smelter off-gases:**

  Oxidize the SO_2 to SO_3 gas, and then absorb the SO_3 in water to make H_2SO_4, which can be sold as a by-product.

  A concentrated stream of SO_2 (about 10% or 100,000 ppm SO_2)

Main Option	Suboption	Examples of Processes
Do not create SO_2	Switch to a low-sulfur fuel Desulfurize the fuel	Convert to natural gas Oil desulfurization Coal cleaning
SO_2 scrubbing: Throwaway	Wet scrubbing	Lime Limestone Forced oxidation Inhibited oxidation Dual alkali Magnesium Enhanced Lime (MEL) Seawater
	Dry scrubbing	Lime spray drying Lime injection Trona Nahcolite Circulating fluidized bed
Regenerative	Wet processes	Absorption with water (smelters) Wellman-Lord MgO Citrate Carbonate Sulfite Forced oxidation (with gypsum sales)
	Dry processes	Activated carbon adsorption Copper oxide adsorption

15.2.2 Flue Gas Desulfurization

The phase in which the
main reactions occur

◆ **Throwaway Processes**

The sulfur removed from the exhaust gas is discarded.

wet

- **Limestone scrubbing**
- **Lime scrubbing**
- **Forced oxidation/inhibited oxidation**
- **Dual alkali**

dry

- Lime-spray drying
- Dry injection

◆ **Regenerative Processes**

The sulfur is recovered in a usable form.

15.2.2 Flue Gas Desulfurization (wet)

◆ Limestone/lime Scrubbing

- **Principle:** a limestone/lime slurry is contacted with the flue gas in a spray tower. The sulfur dioxide is absorbed, neutralized, and partially oxidized to calcium sulfite and calcium sulfate.

$$CaCO_3(s) + H_2O + 2SO_2 \rightarrow Ca^{+2} + 2HSO_3^- + CO_2(g) \qquad \textbf{(15.4)}$$

$$CaCO_3(s) + 2HSO_3^- + Ca^{+2} \rightarrow 2CaSO_3 + CO_2 + H_2O \qquad \textbf{(15.5)}$$

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad \textbf{(15.6)}$$

$$SO_2 + H_2O \rightleftharpoons H_2SO_3 \qquad \textbf{(15.7)}$$

$$H_2SO_3 + Ca(OH)_2 \rightarrow CaSO_3 + 2H_2O \qquad \textbf{(15.8)}$$

$$CaSO_3 + \tfrac{1}{2}O_2 \rightarrow CaSO_4 \qquad \textbf{(15.9)}$$

*lime is a much more reactive reagent than limestone

Absorbent is abundant and inexpensive.

Scaling inside the tower, equipment plugging, and corrosion.

Better utilization of the reagent and more flexibility in operations.

High cost of lime relative to limestone.

Now, both lime and limestone systems can achieve efficiencies of 98–99%.

15.2.2 Limestone/lime Scrubbing

- **Net reaction**

$$CaCO_3 + SO_2 + 0.5H_2O \rightarrow CaSO_3 \cdot 0.5H_2O + CO_2 \uparrow \qquad CaO + SO_2 + 0.5H_2O \rightarrow CaSO_3 \cdot 0.5H_2O$$

1. **Dissolution of SO_2** (slow)

$$SO_2(气) + H_2O \rightarrow SO_2(液) + H_2O$$
$$SO_2(液) + H_2O \rightarrow H_2SO_3$$
$$H_2SO_3 \rightarrow H^+ + HSO_3^- \rightarrow 2H^+ + SO_3^{2-}$$

2. **Dissociation of limestone/lime** (key)

$$H^+ + CaCO_3 \rightarrow Ca^{2+} + HCO_3^-$$
$$H^+ + HCO_3^- \rightarrow H_2CO_3$$
$$H_2CO_3 \rightarrow CO_2 + H_2O$$

Influenced by pH (5.8-6.2)

$$CaO + H_2O \rightarrow Ca(OH)_2$$
$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$$
$$H^+ + OH^- \rightarrow H_2O$$

Lime dissociates more easily, regardless of pH

3. **Absorption**

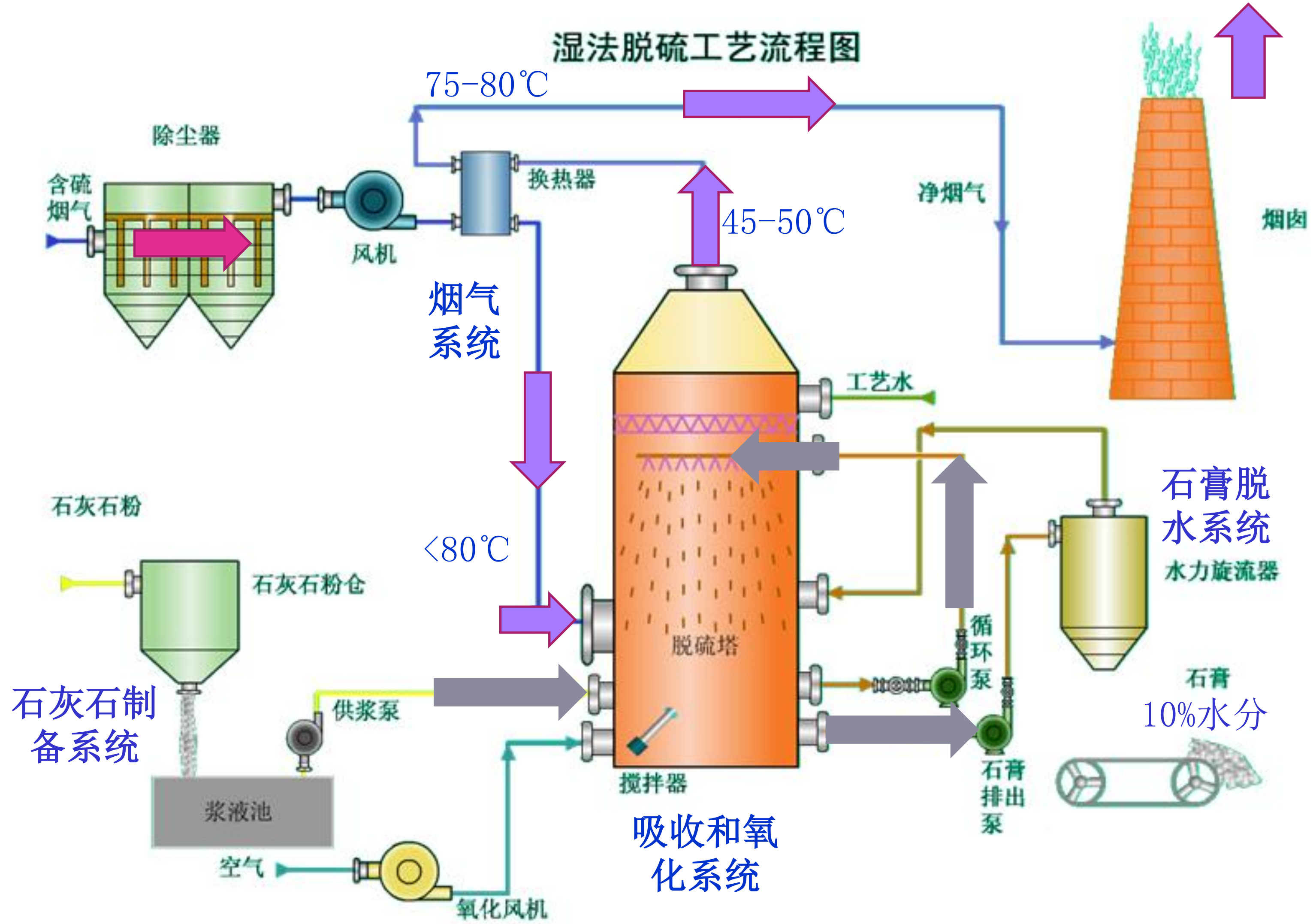
$$Ca^{2+} + SO_3^{2-} + 0.5H_2O \rightarrow CaSO_3 \cdot 0.5H_2O$$
$$Ca^{2+} + HSO_3^- + 2H_2O \rightarrow CaSO_3 \cdot 2H_2O + H^+$$

4. **Partially oxidization** (Excess oxygen)

$$CaSO_3 \cdot 0.5H_2O + O_2 + 3H_2O \rightarrow CaSO_4 \cdot 2H_2O$$

15.2.2 Limestone Scrubbing (wet)

Widely accepted by the coal-fired power industry: lower cost and simpler to operate



15.3 Process Chemistry

◆ **Maximize SO_2 removal**

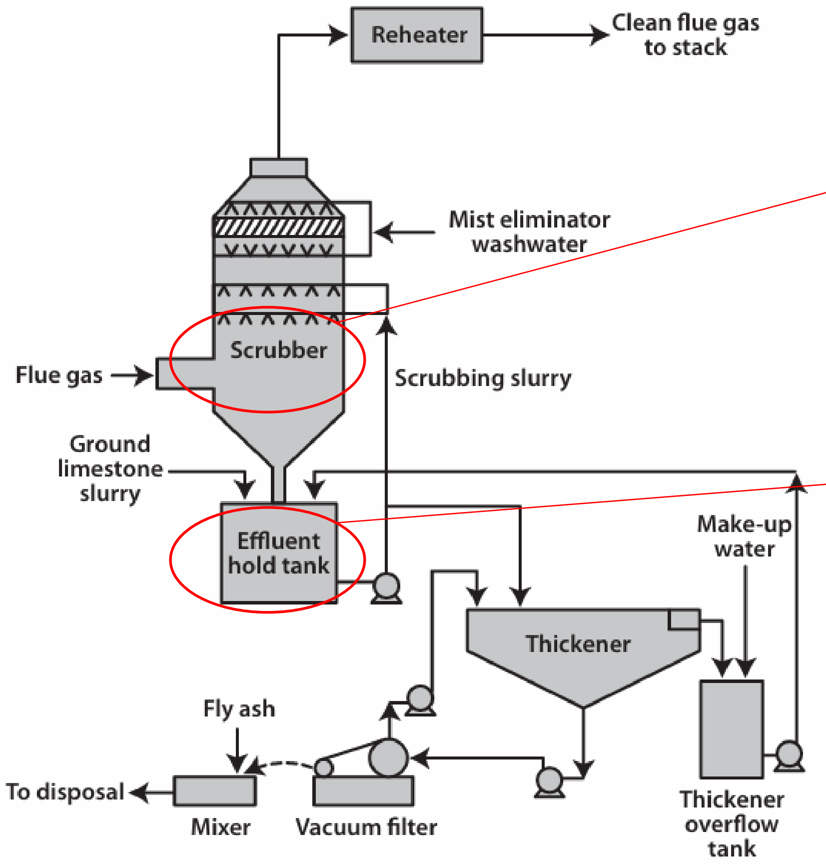


Figure 15.1
Schematic process flow diagram for a limestone-based SO_2 scrubbing system.
(Adapted from Henzel et al., 1981.)

➢ Avoid scaling

- Providing two separate working areas within the same vessel: the scrubber and the effluent hold tank

$$CaCO_3 + 2SO_2 + H_2O \rightarrow Ca^{+2} + 2HSO_3^- + CO_2 \qquad \textbf{(15.21a)}$$

If an excessive amount of $CaCO_3$ is input, the bisulfite ion will not be stable, and $CaSO_3$ will precipitate inside the scrubber (forming scale). If the pH is too low (less than about 4.5), SO_2 absorption will be adversely affected.

$$CaCO_3 + 2HSO_3^- + Ca^{+2} \rightarrow 2CaSO_3 + CO_2 + H_2O \qquad \textbf{(15.21b)}$$

➢ Maximize the utilization of the limestone

- Proper pH control
- Using finely ground limestone
- A sufficiently high liquid/gas ratio

Excess oxygen results in $CaSO_4$ (gypsum). Maintain a high liquid/gas ratio can prevent Gypsum precipitation in the scrubber

15.2.2 Flue Gas Desulfurization (wet)

◆Dual Alkali System (wet)

Use two reagents and two process loops to eliminate scaling and plugging inside the scrubbing tower encountered with limestone/lime scrubbing

Principle:

1. A solution of sodium sulfite (Na_2SO_3)/sodium hydroxide (NaOH) provides the absorption/neutralization of SO_2 inside the tower.

$$NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$$

Both sodium sulfite (Na_2SO_3) and sodium sulfate (Na_2SO_4) are soluble in water, no precipitation occurs inside the scrubber.

Reduce scaling and plugging and lower maintenance costs.

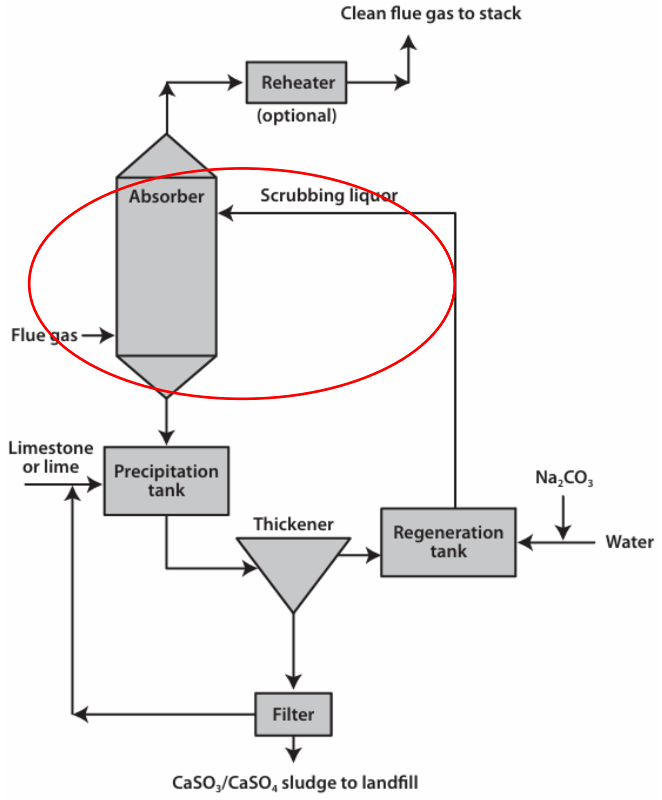


Figure 15.2
Schematic process flow diagram for a dual alkali FGD system.

15.2.2 Dual Alkali System (wet)

Disposal of large volumes of Na_2SO_3/Na_2SO_4 solution would pose a water pollution problem.

2. Lime or limestone is added to the scrubber effluent to simultaneously precipitates the sulfite/sulfate ions and regenerates the sodium hydroxide in a separate vessel.

$$Ca(OH)_2 + 2HSO_3^- \rightarrow SO_3^{2-} + CaSO_3 \cdot 2H_2O$$

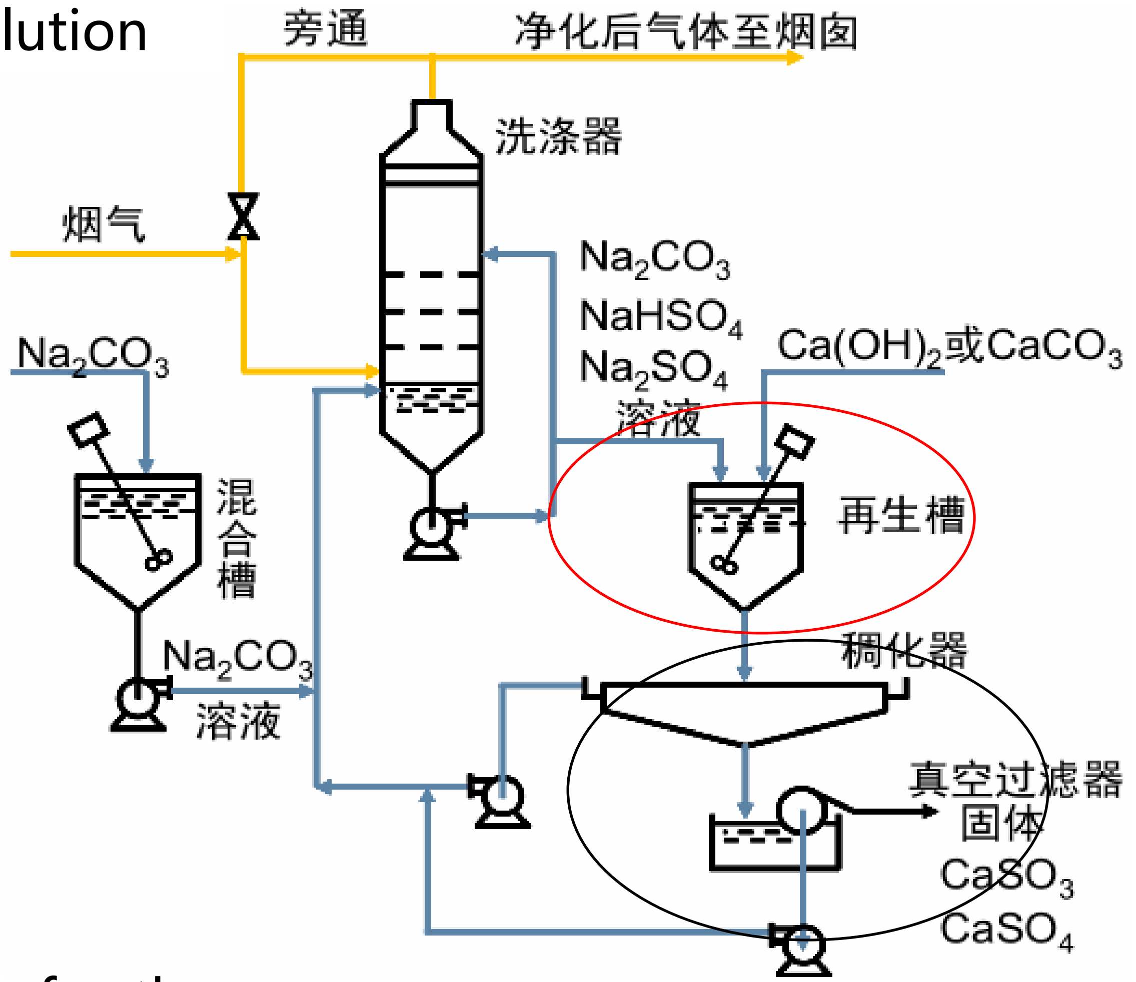
$$Ca(OH)_2 + SO_3^{2-} + 2H_2O \rightarrow 2OH^- + CaSO_3 \cdot 2H_2O$$

$$Ca(OH)_2 + SO_4^{2-} + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + 2OH^-$$

$$CaCO_3 + 2HSO_3^- + 2H_2O \rightarrow SO_3^{2-} + CaSO_3 \cdot 2H_2O^- + CO_2$$

$$(x+y)CaCO_3 + xSO_4^{2-} + (x+y)HSO_3^- + 2H_2O \rightarrow$$

$$(x+y)HCO_3^- + xCaSO_4 \cdot yCaSO_3 \cdot 2H_2O^- + xSO_3^{2-}$$



Need an elaborate treatment or disposal system for the soluble sodium salts; great sodium consumption.

15.2.2 Flue Gas Desulfurization (wet)

◆ Forced Oxidation (external) System

- **Principle:** Conventional limestone + $CaSO_3/SO_4$ waste slurry is oxidized (via excess air contact in a separate tank) to a gypsum sludge.

👍 The oxidized waste is more easily de-watered and is more stable in sludge disposal ponds.

👎 high pumping costs and is prone to plugging and scaling.

◆ Inhibited Oxidation System

- **Principle:** Adding a fine water emulsion of elemental sulfur/a small amount of EDTA to inhibit the oxidation of SO_2 to sulfate.

👍 Prevents scaling, requires less operating power/maintenance, and uses less fresh water than forced oxidation.

15.3 Operational Factors

➢ Chemical Parameters

$$\frac{N}{A} = K_g\left(\bar{P}_{SO_2} - H_{SO_2}C_{SO_2}\right) \quad \mathbf{(15.26)}$$

where K_g = overall gas phase transfer coefficient

In Eq. (15.26), K_g is given by

$$\frac{1}{K_g} = \frac{1}{k_g} + \frac{H_{SO_2}}{\phi k_l} \quad \mathbf{(15.27)}$$

$\frac{N}{A}$ = flux of SO_2, mol/s-cm^2

k_g = local mass transfer coefficient, mol/(s-cm^2-atm)

$\bar{P}_{SO_2}$ = partial pressure of SO_2 in the bulk gas, atm

H_{SO_2} = Henry's law constant, atm/(mol/L)

k_l = local mass transfer coefficient, mol/(s-cm^2-mol/L)

C_{SO_2} = concentration of SO_2 in the bulk liquid, mol/L

ϕ = an enhancement factor to account for chemical reactions that permit SO_2 to diffuse through the liquid film as bisulfite or sulfite species as well as SO_2

$$SO_2 + H_2O \rightleftharpoons H^+ + HSO_3^- \quad \mathbf{(15.28)}$$

$$SO_2 + SO_3^{-2} + H_2O \rightleftharpoons 2HSO_3^- \quad \mathbf{(15.29)}$$

Table 15.4 SO_2 Scrubber Chemical Parameters and Their Effects on the Enhancement Factor, ϕ

Parameter	Effect on ϕ
Gas composition	ϕ decreases as SO_2 concentration increases; for example, at pH 5.8, $\bar{P}_{SO_2}$, ppm / ϕ: 500 / 10 1000 / 7.5 2000 / 5.8
Bulk liquid sulfite and bisulfite concentrations	ϕ increases as $C_{SO_3^{-2}}$ increases; ϕ decreases as $C_{HSO_3^-}$ increases
pH	ϕ increases as pH increases. (Note: because the solution tends to be in equilibrium with $CaSO_3$ solids, $C_{HSO_3^-}$ decreases as pH increases; thus, the effect of pH is essentially that of $C_{HSO_3^-}$)
Alkali additives	ϕ increases as alkali species increase
Buffer additives (organic acids)	ϕ increases as buffer additives increase (ϕ values of 20–30 are achieved with as little as 10–15 milli-mol/L of adipic acid)

15.3 Operational Factors

➢ Physical Factors

- **liquid/gas ratio (L/G):** the greater the L/G ratio, the greater the SO_2 absorption efficiency. (40 to 100 gal/1000 acf)
- **Proper gas and liquid flow distribution:** prevent scaling and promote good gas–liquid contact.
- **Finely ground limestone** (90% passing a 325-mesh screen)
- **Gas velocity:** mass transfer increases as gas velocity increasers. But too high a flow rate will cause a decrease in contact time and incomplete absorption
- ……

15.2.2 Flue Gas Desulfurization

◆ **Throwaway Processes**

wet

- Limestone scrubbing
- Lime scrubbing
- Forced oxidation/inhibited oxidation
- Dual alkali

dry

- **Lime-spray drying**
- **Dry injection**

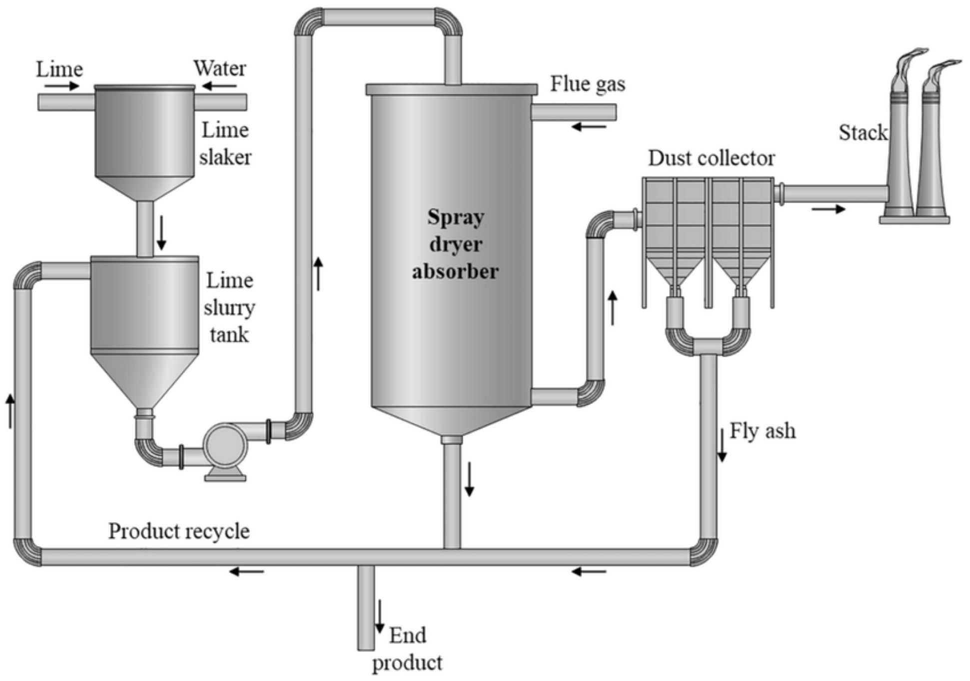
◆ **Regenerative Processes**

15.2.2 Flue Gas Desulfurization (wet/dry)

◆ Lime-Spray Drying

Principle:

- A lime slurry is sprayed into the absorption tower, and SO_2 is absorbed by the slurry, forming $CaSO_3/CaSO_4$.
- The water evaporates before the droplets reach the bottom of the tower.
- The dry solids are carried out with the gas and collected in a baghouse with the fly ash.



👍 Few maintenance problems, low energy usage, and low capital and operating costs.

👎 The potential to blind the fabric if the temperature of the flue gas approaches the dew point.

15.2.2 Flue Gas Desulfurization (dry)

◆ Dry Injection

Principle:

- The pulverized lime or limestone is injected into the flue gas.
- Dry sorption occurs and the solid particles are collected in a baghouse.
- Further SO_2 removal occurs as the flue gas flows through the filter cake on the bags.

👍 Low capital costs and low maintenance requirements, can collect mercury emissions.

👎 High reagent costs and possible waste disposal problems.

15.2.3 Flue Gas Desulfurization

◆ Throwaway Processes

◆ Regenerative Processes

wet

- **Wellman-lord (W-L) process**
- **Magnesium oxide**
- **Citrate scrubbing**

dry

- Activated carbon adsorption
- Copper oxide adsorption

15.2.3 Flue Gas Desulfurization (wet)

◆ Wellman-Lord (W-L) process

(1) Flue gas pretreatment

- remove most of the remaining particles as well as any existing SO_3 and HCl
- cool and humidifies the flue gas

(2) SO_2 absorption

- The flue gas is contacted with aqueous sodium sulfite and the SO_2 is absorbed and reacted to form sodium bisulfite.

$$Na_2SO_3 + SO_2 + H_2O \rightarrow 2NaHSO_3 \qquad \textbf{(15.10)}$$

(3) Purge treatment

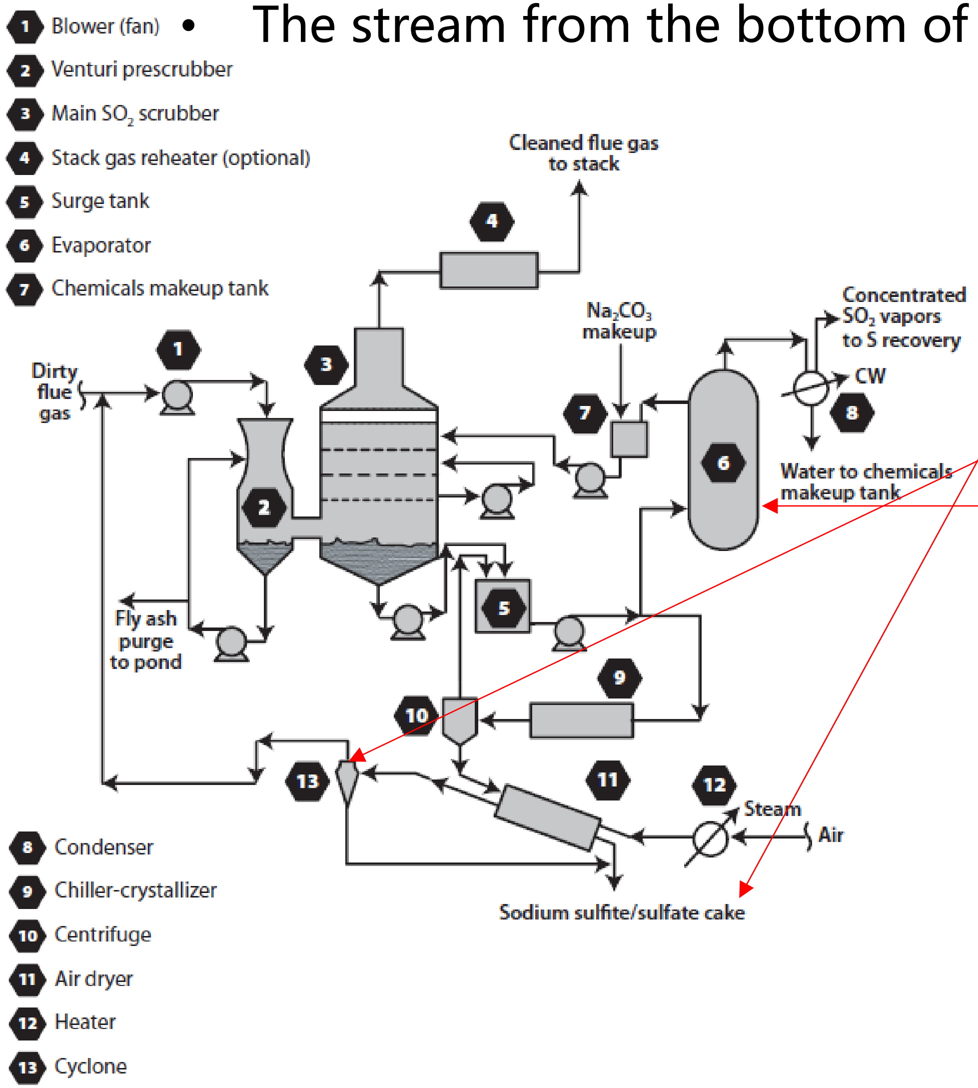
- Some of the sulfite is oxidized to sulfate by oxygen.
- SO_3 that passes through the prescrubber results in aqueous sulfate.

$$Na_2SO_3 + 1/2\ O_2 \rightarrow Na_2SO_4 \qquad \textbf{(15.11)}$$

$$2Na_2SO_3 + SO_3 + H_2O \rightarrow Na_2SO_4 + 2NaHSO_3 \qquad \textbf{(15.12)}$$

- The sodium sulfate does not contribute to further SO_2 absorption and must be removed.

- The stream from the bottom of the absorber is rich in bisulfite and is routed for further processing.



(4) Sodium sulfite regeneration

- The slurry is centrifuged: the solids are dried and discarded, the centrifugate (rich in bisulfite) is returned to the process.
- SO_2 is liberated and sodium sulfite crystals are regenerated.

$$2NaHSO_3 \xrightarrow[heat]{} Na_2SO_3 + SO_2 + H_2O \qquad \textbf{(15.13)}$$

- The water vapor is condensed and recovered, producing a concentrated stream of SO_2 gas.

15.2.3 Wellman-Lord (W-L) process

(5) Processing to a marketable product

- The concentrated stream of SO_2 gas can be reduced to elemental sulfur or oxidized to sulfuric acid either on-site or at a nearby chemical plant.

***Make-up:** some of the sodium is removed from the process via the sodium sulfate purge, soda ash (Na_2CO_3) is added to provide make-up sodium.

$$Na_2CO_3 + SO_2 \rightarrow Na_2SO_3 + CO_2 \qquad \textbf{(15.14)}$$

15.2.3 Flue Gas Desulfurization (wet)

◆ Magnesium Oxide (MgO) Process

- **Principle:** a slurry of $Mg(OH)_2$ produces $MgSO_3/MgSO_4$ solids. The solids are then calcined, generating SO_2 and regenerating MgO.

👍 Little solid waste, Flue gas pretreatment,

👎 A high-temperature calciner is needed.

◆ Citrate-Scrubbing Processes

Principle:

- The citrate ions in solution increase the effective solubility of SO_2 by binding some of the hydronium ions created when SO_2 absorbs into water.

$$SO_2(g) + H_2O \rightleftharpoons H_2SO_3 \tag{15.15}$$

$$H_2SO_3 \rightleftharpoons H^+ + HSO_3^- \tag{15.16}$$

$$Ci^{-3} + H^+ \rightleftharpoons HCi^{-2} \tag{15.17}$$

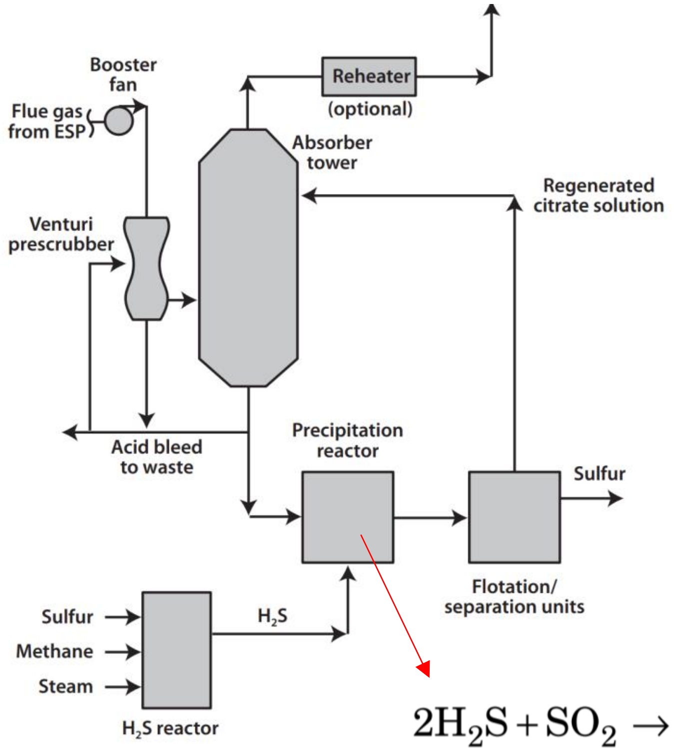
$$HCi^{-2} + H^+ \rightleftharpoons H_2Ci^- \tag{15.18}$$

- As the citrate ions react with and remove hydronium ions in solution, the equilibria of Reactions are shifted to the right, promoting further SO_2 absorption.

15.2.3 Citrate-Scrubbing Processes

➢ **Regenerating the solution/recovering the SO_2**

- **U.S. Bureau of Mines process:** the SO_2 is reduced with H_2S to elemental sulfur.



$$2H_2S + SO_2 \rightarrow 2H_2O + 3S$$

Figure 15.5
Simplified schematic diagram of the U.S. Bureau of Mines citrate FGD process.

- **Flakt–Boliden process:** heating and steam-stripping the SO_2-loaded citrate solution, resulting SO_2-rich stream.

$$SO_2(g) + H_2O \rightleftharpoons H_2SO_3 \quad \textbf{(15.15)}$$

$$H_2SO_3 \rightleftharpoons H^+ + HSO_3^- \quad \textbf{(15.16)}$$

15.2.3 Flue Gas Desulfurization

- Throwaway Processes
- **Regenerative Processes**

wet

- Wellman-lord (W-L) process
- Magnesium oxide
- Citrate scrubbing

dry

- **Activated carbon adsorption**
- **Copper oxide adsorption**

15.2.3 Flue Gas Desulfurization (dry)

◆ Activated Carbon Adsorption

Principle：

- The carbon catalyzes the reaction of SO_2 to H_2SO_4, thus preventing desorption of the SO2.

$$SO_2 + H_2O + 1/2\ O_2 \xrightarrow[150\text{–}300\ ^\circ F]{\text{Activated Carbon}} H_2SO_4 \qquad \textbf{(15.19)}$$

- The carbon can be regenerated by water washing, producing a dilute sulfuric acid stream that often is neutralized and discarded.

Westvaco process:

- SO_2 is adsorbed onto carbon.
- The carbon flows to the next vessel, where the sulfuric acid is reacted with hydrogen sulfide, resulting in adsorbed elemental sulfur.

$$H_2SO_4 + 3H_2S \xrightarrow[300\ ^\circ F]{\text{Activated Carbon}} 4S + 4H_2O \qquad \textbf{(15.20)}$$

- ¼ Sulfur is vaporized and recovered. The remainder reacted with H_2 to generate the H_2S needed by Reaction (15.20) to regenerate the carbon.
- The regenerated carbon is then recycled back to the start.

15.2.3 Flue Gas Desulfurization (dry)

◆ Copper Oxide Adsorption

Principle：

- SO_x adsorption and reaction occurs at 750 °F to form copper sulfate.
- The bed is regenerated with a reducing gas (H_2 or H_2 + CO) to form a concentrated stream of SO_2.
- The bed is reduced to copper, but is later oxidized to copper oxide when in the adsorption mode.

One of the few processes that can control both SO_2 and NO_x.

15.4 Mercury control

- **Wet flue gas desulfurization has been shown to be able to remove some of the mercury.**
- The actual removal percentage depends on the percent of the mercury that is in the oxidized state: 50 to 80% of the oxidized mercury, none of the elemental mercury.
- The total removal percentage for FGD systems: 20 to 60% as the percent of oxidized mercury at the scrubber inlet goes from 15% to about 80%

- **Activated carbon injected into the flue gas upstream of a baghouse achieves a higher mercury removal percentage**

Cost Estimates

- **Factors have affected the costs of FGD systems**

• Size of plant
• Type of FGD process
• Type of project (new or retrofit)
• Percentage of sulfur in the coal
• Degree of removal required
• Access to and costs of raw materials(e.g., trona, limestone, steel, concrete, etc.)

- An FGD scrubber represents a huge investment for a coal-fired power plant: as much as 20% of the total capital investment of the power plant.

Conclusions

Flue Desulfurization

- Convert to natural gas
- Oil desulfurization
- Coal cleaning

Flue Gas Desulfurization

Throwaway Processes

Wet

- Limestone scrubbing
- Lime scrubbing
- Forced oxidation /inhibited oxidation
- Dual alkali

Dry

- Lime-spray drying
- Dry injection

Regenerative Processes

Wet

- Wellman-lord (W-L) process
- Magnesium oxide
- Citrate scrubbing

Dry

- Activated carbon adsorption
- Copper oxide adsorption

Quiz

	Principle	Advantages	Disadvantages
Limestone/ lime			
Dual Alkali			
Dry Injection			
Wellman-Lord			
Activated Carbon			