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# FLUE GAS DESULFURIZATION THEORY & OPERATION

## Course Outline

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                         Chemistry Applications  
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## 1.0 WATER CHEMISTRY CONCEPTS

- 1.1 The Atom, Atomic Structure, and Chemical Periodicity
  - 1.1.1 Introduction
  - 1.1.2 The Atom and Atomic Structure
    - 1.1.2.1 Atomic Structure
    - 1.1.2.2 The Electron Structure of Atoms
  - 1.1.3 Elements, Chemical Symbols, and Avogadro's Number
    - 1.1.3.1 Symbols for Elements
    - 1.1.3.2 Atomic Number
    - 1.1.3.3 Atomic Weight
    - 1.1.3.4 Avogadro's Number
    - 1.1.3.5 Isotopes
  - 1.1.4 The Periodic Table
    - 1.1.4.1 Chemical Periodicity
    - 1.1.4.2 The Periodic Table of the Elements
      - 1.1.4.2.1 Organization of the Periodic Table
      - 1.1.4.2.2 Electron Structure and Chemical Properties
    - 1.1.4.3 Classes of Elements in The Periodic Table
      - 1.1.4.3.1 Metals
      - 1.1.4.3.2 Nonmetals
      - 1.1.4.3.3 Metalloids
      - 1.1.4.3.4 Noble Gases
- 1.2 Compounds, Compound Formation, and Chemical Reactions
  - 1.2.1 Introduction
  - 1.2.2 Compound Formation and the Chemical Bond
    - 1.2.2.1 Stable Electron Structure: The Octet Rule
    - 1.2.2.2 Valence: Combining Power of Elements
    - 1.2.2.3 Chemical Formulas for Representing Compounds
    - 1.2.2.4 The Ionic Bond
      - 1.2.2.4.1 Ionization and Ions
      - 1.2.2.4.2 Properties of Ionic Compounds
    - 1.2.2.5 The Covalent Bond
    - 1.2.2.6 Molecules
    - 1.2.2.7 Radicals
    - 1.2.2.8 Chemical Formulas
  - 1.2.3 Chemical Reactions and Stoichiometric Calculations
    - 1.2.3.1 Chemical Reactions
    - 1.2.3.2 Reason for Chemical Reactions
    - 1.2.3.3 Energy Changes Associated with Chemical Reactions
    - 1.2.3.4 Chemical Reactions versus Physical Changes
    - 1.2.3.5 Conservation of Mass in Chemical Reactions
    - 1.2.3.6 Conservation of Atoms in Chemical Reactions
    - 1.2.3.7 Chemical Equations
  - 1.2.4 Stoichiometric Calculations
    - 1.2.4.1 The Mole and Weight Relationship in Chemical Reactions
    - 1.2.4.2 Molecular Weights and the Law of Definite Composition

#### 1.2.4.3 The Mole

### 1.3 Summary

## 2.0 WATER CHEMISTRY CONCEPTS - CONTINUED

- 2.1 Solutions in Power Plant Chemistry
  - 2.1.1 Introduction
  - 2.1.2 Solutions: Solvent and Solutes
    - 2.1.2.1 Definition of a Solution
    - 2.1.2.2 Dispersions and Suspensions
    - 2.1.2.3 Polar and Non-Polar Solvents
    - 2.1.2.4 Water as a Solvent
    - 2.1.2.5 Ionic Solutions in Water
    - 2.1.2.6 Solubility
    - 2.1.2.7 Effect of Temperature and Pressure on Solubility
  - 2.1.3 Concentration of Solutions
    - 2.1.3.1 General Terms for Expressing Concentration
    - 2.1.3.2 Percent by Weight
    - 2.1.3.3 Density, Specific Gravity, and the Baume` Scale
    - 2.1.3.4 Percent by Volume
    - 2.1.3.5 Parts per Million (ppm) and Parts per Billion(ppb)
    - 2.1.3.6 Molar and Molal Solutions
    - 2.1.3.7 Normal Solutions and Equivalent Weights
  - 2.1.4 Preparing Solutions
  - 2.1.5 Gas Concentrations
- 2.2 pH and Conductivity of Solutions
  - 2.2.1 Introductions
  - 2.2.2 Acids and Bases
    - 2.2.2.1 Properties of Acids and the Hydronium Ion
    - 2.2.2.2 Properties of Bases and the Hydroxide Ion
  - 2.2.3 Neutralization Reactions and Salt Formation
  - 2.2.4 The Definition of pH and the pH Scale
    - 2.2.4.1 The Ionization of Water
    - 2.2.4.2 The pH Scale and Other Logarithmic Functions
    - 2.2.4.3 The Effect of Temperature on pH
  - 2.2.5 Conductivity
    - 2.2.5.1 Equivalent Conductance
    - 2.2.5.2 Solvent Effects: The Conductivity of Pure Water
    - 2.2.5.3 Temperature Effects on Conductivity
    - 2.2.5.4 Power Plant Conductivity Measurements
- 2.3 Summary

### **3.0 CORROSION AND CORROSION CONTROL**

- 3.0.1 Introduction
- 3.1 Overview of Corrosion Mechanisms and Types of Corrosion
  - 3.1.1 Uniform Corrosion
  - 3.1.2 Localized Corrosion: Macroscopic Attack
    - 3.1.2.1 Galvanic Corrosion
    - 3.1.2.2 Erosion Corrosion
    - 3.1.2.3 Pitting Corrosion
  - 3.1.3 Localized Corrosion: Microscopic Attack
    - 3.1.3.1 Intergranular Corrosion
    - 3.1.3.2 Stress-Corrosion Cracking
  - 3.1.4 Corrosion Resistant Alloys Used in Plants
    - 3.1.4.1 The Stainless Steels
    - 3.1.4.2 Copper Based Alloys
    - 3.1.4.3 Specialty Materials
- 3.2 Chemistry Aspects of Corrosion
  - 3.2.1 Oxidation and Reduction
  - 3.2.2 Passivity
  - 3.2.3 Effects of pH
  - 3.2.4 Specific Chemical Effects
    - 3.2.4.1 Chemisorption
    - 3.2.4.2 Chloride Stress-Corrosion Cracking
    - 3.2.4.3 Concentrated Caustic Cracking
    - 3.2.4.4 Underdeposit Corrosion
- 3.3 Summary

### **4.0 FOSSIL SCRUBBER CHEMISTRY**

- 4.1 Introduction
- 4.2 Process Descriptions
  - 4.2.1 Calcium-Based Wet Scrubbing
  - 4.2.2 Magnesium-Based Wet Scrubbing
  - 4.2.3 Dual Alkali Wet Scrubbing
  - 4.2.4 Lime Spray-Drying
  - 4.2.5 Wellman Lord Process
  - 4.2.6 Alstom Seawater FGD
- 4.3 Summary

### **5.0 LIME/LIMESTONE PROCESS CHEMISTRY**

- 5.1 Gas-Liquid Interactions
  - 5.1.1 Gas Film Limited Mass Transfer
  - 5.1.2 Liquid Film Limited Mass Transfer
- 5.2 Liquid-Liquid Interactions
  - 5.2.1 Acid Base Reactions
  - 5.2.2 Dissolved Alkalinity
  - 5.2.3 Buffered Systems and pH Effects
  - 5.2.4 Oxidation Reactions

- 5.2.4.1 Inhibited Oxidation
- 5.3 Liquid-Solid Interactions
  - 5.3.1 Relative Saturation
  - 5.3.2 Solids Precipitation
  - 5.3.3 Reagent Utilization
- 5.4 Summary

## **6.0 LIMESTONE SCRUBBER PROCESS CONSIDERATIONS**

- 6.1 Introduction
- 6.2 Reagent Selection
  - 6.2.1 Limestone
  - 6.2.2 Slaked Lime
  - 6.2.3 Magnesium Enhanced Lime Slurry
- 6.3 Reagent Size Reduction and Classification
- 6.4 Reagent Feed
- 6.5 Absorber Designs
  - 6.5.1 Wet Scrubbers
    - 6.5.1.1 Inhibited/Partial Oxidation
    - 6.5.1.2 Forced Oxidation
    - 6.5.1.3 Mitsubishi Double Contact Double Flow (DCDF)
    - 6.5.1.4 Babcock and Wilcox Tray Tower
    - 6.5.1.5 Alstom FLOWPAC Turbo Bed Reactor
    - 6.5.1.6 B & V/Chiyoda CT-121 Absorber
  - 6.5.2 Dry Scrubbers
    - 6.5.2.1 Alstom Flash Dryer Absorber (FDA) Process
    - 6.5.2.2 B&W/Niro Spray Dry Absorber
    - 6.5.2.3 Lurgi/Lentjes Circulating Fluidized Bed
- 6.6 Absorber Additives
  - 6.6.1 Scale Inhibitors
  - 6.6.2 SO<sub>2</sub> Removal Efficiency Enhancers
- 6.7 Recycle Streams
- 6.8 Reject Stream
  - 6.8.1 Solids Classification
  - 6.8.2 Solids Separation and Dewatering
  - 6.8.3 Chloride Removal
- 6.9 Product Gypsum
- 6.10 Waste Handling
  - 6.10.1 Coagulation-Flocculation-Filtration
  - 6.10.2 Organic Removal/Bioreactors
  - 6.10.3 Wetlands
  - 6.10.4 Zero Liquid Discharge
- 6.11 Summary

## **7.0 MONITORING PROCESS PERFORMANCE**

- 7.1 Flue Gas Measurements
- 7.2 Reagent Feed System Measurements
  - 7.2.1 % Loss on Ignition
  - 7.2.2 Calcium and Magnesium Content
- 7.3 Slurry Measurements
  - 7.3.1 pH Measurement
  - 7.3.2 Slurry Solids Concentration Measurement
  - 7.3.3 Slurry Particle Size Distribution
- 7.4 Alkaline Reagent Utilization
  - 7.4.1 Calcium and Magnesium Content
  - 7.4.2 Total Sulfur and Carbonate by TGA
- 7.5 Ion Balance Calculations
  - 7.5.1 Other Cation and Anion Analytical Methods
- 7.6 Liquid Phase Alkalinity
- 7.7 Relative Saturation
- 7.8 Product Solids Measurements
- 7.9 Product Solids Characterization
  - 7.9.1 Gypsum Quality-Calcium Sulfite, Unreacted Reagent, % Gypsum
  - 7.9.2 Gypsum Quality – Free Moisture
  - 7.9.3 Gypsum Quality – Chloride Content
  - 7.9.4 Gypsum Quality – Particle Size
- 7.10 Summary
  - Appendix 7-1
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## **8.0 ACQUIRING AND HANDLING SAMPLES**

- 8.1 Flue Gas Desulfurization System Samples
  - 8.1.1 Reactive Samples
  - 8.1.2 Non-reactive Samples
- 8.2 Obtaining Representative Samples
  - 8.2.1 Liquid/Slurry Stream Sampling
  - 8.2.2 Tank Sampling
  - 8.2.3 Gas Sampling
  - 8.2.4 Solids Sampling
- 8.3 Sample Handling, Preservation, and Storage
  - 8.3.1 Sample Preservation
  - 8.3.2 Sample Processing and Storage
  - 8.3.3 Dilution Factor
- 8.4 Summary