
**FOSSIL POWER PLANT CHEMISTRY
COURSE OUTLINE**

1. WATER CHEMISTRY CONCEPTS

1.1. *The Atoms, 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. Non-metals

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 Nomenclature and 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 Reaction 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*

2. 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 Concentrations*
 - 2.1.3.2. *Percent by Weight*
 - 2.1.3.3. *Diversity, 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 Weight*
- 2.1.4. **Preparing Solutions**
- 2.1.5. **Gas Concentrations**
- 2.2. ***pH and Conductivity of Solutions***
 - 2.2.1. **Introduction**
 - 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 of 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*
 - 2.2.5.5. *Cation Conductivity*

3. CORROSION AND CORROSION CONTROL

- 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*
 - 3.1.2.4. *Exfoliation*
 - 3.1.2.5. *Selective Leaching*
 - 3.1.3. **Localized Corrosion: Microscopic Attack**
 - 3.1.3.1. *Integrular Corrosion*
 - 3.1.3.2. *Stress-Corrosion Cracking*
 - 3.1.4. **Corrosion Resistant Alloys Used in Plants**
 - 3.1.4.1. *The Stainless Steels*

4.1.5.1. Base Load Operation

4.1.5.2. Cycling Operation

4.1.5.2.1. Effect on Feedwater Cycle Chemistry

4.1.5.2.2. Effect on Boiler Water Chemistry

4.1.5.2.3. Hot Start-up

4.1.5.2.4. Cold Start-up

4.1.5.3. Wet Lay-up

4.1.5.4. Dry Lay-up

4.1.6. System Chemistry

4.1.6.1. Action Level Concept

4.1.6.1.1. Action Levels Defined

4.1.6.1.2. Response Guidelines for Out-of-Normal Chemistry

4.1.6.2. System Chemistry Specifications

4.1.6.2.1. Make-up System

4.1.6.2.2. Condensate Chemistry

4.1.6.2.3. Feedwater Chemistry

4.1.6.2.4. Boiler Drum Water

4.1.6.2.5. Silica Control in Boiler Water and Steam

4.1.6.3. Main Steam Chemistry

4.1.6.4. Closed Cooling Water Systems

4.1.6.5. Circulating Water Systems

4.1.6.5.1. Deposit Control

4.1.6.5.2. pH Control

4.1.6.5.3. Biocide Treatment

4.1.7. Corrective Actions

4.2. Summary

5. WATER TREATMENT METHODS AND ION EXCHANGE THEORY

5.1. Introduction

5.2. Terms Used in Water Treatment

5.2.1. pH

5.2.2. Conductivity

5.2.3. Free Mineral Acidity

5.2.4. Alkalinity

5.2.5. Hardness

5.2.6. Carbonate Chemistry

5.2.7. Langelier Index and Ryzner Index

5.3. Clarification and Filtration in Water Treatment

5.3.1. Introduction

5.3.2. Clarifiers

5.3.2.1. Applications

5.3.2.2. Principle of Operation

5.3.2.3. Conditions for Successful Coagulation-Flocculation

5.3.2.4. Coagulant Chemicals

5.3.2.4.1. Inorganic Coagulants

5.3.2.4.2. Polymers and Polyelectrolytes

5.3.2.5. Sedimentation, Blowdown, and Backflush

5.3.2.6. Out-of-Specification Conditions

5.3.3. Filtration

5.3.3.1. Basis for Filtration

5.3.3.2. Bed Filters

5.3.3.2.1. Types of Bed Filters

5.3.3.2.2. Gravity Filters

5.3.3.2.3. Pressure Filters

5.3.3.2.4. Upflow Filters

5.3.3.3. Cartridge Filters

5.3.3.4. Out-of-Specification Conditions

5.4. Ion Exchange

5.4.1. Introduction

5.4.2. The Ion Exchange Process

5.4.2.1. Ion Exchange resins in Water Treatment

5.4.2.2. Cations and Exchange on Resins

5.4.2.3. Anions and Exchange on Resins

5.4.3. Classes of Ion Exchange Resins and Their Structure

5.4.3.1. Classes of Resin

5.4.3.2. Strong Acid Cation Resins

5.4.3.3. Weak Acid Cation Resins

5.4.3.4. Strong Base Anion resins

5.4.3.5. Weak Base Anion Resins

5.4.3.6. Gel and Macroporous Resins

5.4.4. The Ion Exchange Capacity of Resins

5.4.4.1. Ion Exchange Capability

5.4.4.2. Total Exchange Capacity of Resins

5.4.4.3. Operating Capacity

5.4.4.4. Column Capacity

5.4.5. Ion Exchange Equilibria

5.4.5.1. Reversible Nature of Ion Exchange

5.4.5.2. The Affinity Coefficient

5.4.5.3. Factors Affecting Ion Exchange Equilibria

5.4.6. Ion Exchange Kinetics

5.4.6.1. Exchange Rates

5.4.6.2. Film Diffusion Rate

5.4.6.3. Particle Diffusion Rates

5.4.6.4. Factors Which Affect Ion exchange Kinetics

5.4.6.4.1. Application Rates

5.4.6.4.2. Temperature

5.4.6.4.3. Organic Fouling

5.4.6.4.4. Resin Particle Size

- 5.4.7. Deep Bed Ion Exchange Types
 - 5.4.7.1. *Cation Resin Units*
 - 5.4.7.2. *Anion Resin Units*
 - 5.4.7.3. *Mixed Bed Units*
- 5.4.8. Resin Exhaustion and Regeneration
 - 5.4.8.1. *Resin Exhaustion*
 - 5.4.8.2. *Resin Regeneration*

5.5. *Summary*

6. **CHEMISTRY CONTROL SURVEILLANCE AND ANALYTICAL METHODS**

6.1. *Sampling*

- 6.1.1. Criteria for Sampling Frequency
- 6.1.2. General Considerations in Sampling
 - 6.1.2.1. *Sample Flow Rate*
 - 6.1.2.2. *Sample Conditioning*
 - 6.1.2.3. *Dead Legs*
 - 6.1.2.4. *Sampling to Eliminate Atmospheric Gases*
 - 6.1.2.5. *Density Corrections*
 - 6.1.2.6. *Sample Containers and Sample Preservation*
 - 6.1.2.7. *Purging Volumes*
 - 6.1.2.8. *Sample Temperature Adjustment*
- 6.1.3. Grab Sample Versus Composite or Inline Samples
- 6.1.4. Steam Sampling

6.2. *Common Power Plant Laboratory Analyses*

- 6.2.1. pH Measurements
- 6.2.2. Specific Conductance Measurements
- 6.2.3. Cation Conductivity Versus Specific Conductivity
- 6.2.4. Oxygen Analyses
 - 6.2.4.1. *The Indigo Carmine Dissolved Oxygen Method*
 - 6.2.4.2. *Winkler Dissolved Oxygen Method*
 - 6.2.4.3. *Dissolved Oxygen by Chemets*
 - 6.2.4.4. *Biological Oxygen Demand (BOD)*
- 6.2.5. Spectrophotometric Analyses
- 6.2.6. Chloride Determination
 - 6.2.6.1. *Spectrophotometric Chloride Determination*

- 7.1.2.1. *Calibration of Laboratory Conductivity Instrumentation*
- 7.1.2.2. *Maintenance of Laboratory Conductivity Instrumentation*
- 7.1.3. Selective Ion Electrodes (SIEs)
- 7.1.4. Spectrophotometric Analyses
- 7.1.5. Amperometric Titrator Operation and Maintenance
- 7.1.6. Analytical Balance Calibration and Maintenance
- 7.1.7. Documentation of Calibration and Maintenance
- 7.2. *Laboratory Quality Assurance/Quality Control*
 - 7.2.1. Purpose of Laboratory Quality Control Programs
 - 7.2.2. Reagent and Standard Solution Controls
 - 7.2.2.1. *Dry Chemicals, Acids, and Solvents*
 - 7.2.2.2. *Purchased Reagents and Solutions*
 - 7.2.2.3. *Prepared Reagents*
 - 7.2.2.4. *Reagent Standardization*
 - 7.2.2.5. *Purchased Standards*
 - 7.2.2.6. *Prepared Standards*
 - 7.2.3. Special Precautions for Trace Level Analyses
 - 7.2.3.1. *Facilities*
 - 7.2.3.2. *Reagents*
 - 7.2.3.3. *Sample and Standard Handling*
 - 7.2.4. Control of Analytical Performance
 - 7.2.4.1. *Purpose of Control Charts*
 - 7.2.4.2. *Preparation of Spiked Samples*
 - 7.2.4.3. *Calculation of Percent Recovery*
 - 7.2.4.4. *Construction of Accuracy Control Charts*
 - 7.2.4.5. *Duplicate Sample Analyses*
 - 7.2.4.6. *Calculation of Precision*
 - 7.2.4.7. *Construction of Precision Control Charts*
 - 7.2.4.8. *Use of Completed Control Charts*
 - 7.2.4.9. *Blind Sample Analysis*

7.3. Summary

8. DATA MANAGEMENT AND EVALUATION

8.1. Laboratory Data Logging

- 8.1.1. Recording Raw Laboratory Data
- 8.1.2. Reporting of Analytical Data
- 8.1.3. Daily Chemistry Logs
- 8.1.4. Instrument Log
- 8.2. *Data Review and Evaluation*
 - 8.2.1. Use of Acceptance Criteria
 - 8.2.2. Awareness of Plant Activities
 - 8.2.3. Correlation of Interrelated Parameters
 - 8.2.4. Trend Plotting of Critical Parameters
- 8.3. *Response to Abnormal Chemistry Conditions*
 - 8.3.1. Verification of Analytical Results
 - 8.3.2. Initiation of Corrective Actions
 - 8.3.3. Documentation of Corrective Actions
- 8.4. *Summary*

9. FOSSIL SCRUBBER CHEMISTRY

- 9.1. *Introduction*
- 9.2. *Process Descriptions*
 - 9.2.1. Calcium-Based Wet Scrubbing
 - 9.2.2. Magnesium-Based Wet Scrubbing
 - 9.2.3. Dual Alkali Wet Scrubbing
 - 9.2.4. Lime Spray-Drying
 - 9.2.5. Wellman Lord Process
- 9.3. *Summary*

10. LIME/LIMESTONE PROCESS CHEMISTRY

- 10.1. *Gas-Liquid Interactions*
 - 10.1.1. Gas Film Limited Mass Transfer
 - 10.1.2. Liquid Film Limited Mass Transfer

10.2. *Liquid-Liquid Interactions*

- 10.2.1. Acid Base Reactions**
- 10.2.2. Dissolved Alkalinity**
- 10.2.3. Buffered Systems and pH Effects**
- 10.2.4. Oxidation Reactions**

10.3. *Liquid-Solid Interactions*

- 10.3.1. Relative Saturation**
- 10.3.2. Solids Precipitation**
- 10.3.3. Reagent Utilization**

10.4. *Summary*

11. MONITORING PROCESS PERFORMANCE

11.1. *Flue Gas Measurements*

11.2. *Reagent Feed System Measurements*

11.3. *Slurry Measurements*

- 11.3.1. pH Measurement**
- 11.3.2. Slurry Solids Concentration Measurement**
- 11.3.3. Alkaline Reagent Utilization**
- 11.3.4. Ion Balance Calculations**
- 11.3.5. Liquid Phase Alkalinity**
- 11.3.6. Relative Saturation**

11.4. *Product Solids Measurements*

11.5. *Summary*

12. ACQUIRING AND HANDLING SAMPLES

12.1. Flue Gas Desulfurization System Samples

12.1.1. Reactive Samples

12.1.2. Non-Reactive Samples

12.2. Obtaining Representative Samples

12.2.1. Liquid/Slurry Stream Sampling

12.2.2. Tank Sampling

12.2.3. Gas Sampling

12.2.4. Solids Sampling

12.3. Sample Handling, Preservation, and Storage

12.3.1. Sample Preservation

12.3.2. Sample Processing and Storage

12.3.3. Dilution Factor

12.4. Summary

13. FOSSIL BOILER CHEMICAL CLEANING

13.1. Introduction

13.2. Boiler Deposits

13.2.1. Condenser Tube Leaks

13.2.2. Air Inleakage

13.2.3. Ion Exchangers

13.3. Materials of Construction

13.4. Summary

14. CHEMICAL CLEANING SOLUTIONS

14.1. Introduction to Chemical Cleaning Solutions

14.2. Chemical Cleaning Solutions

14.2.1. Mineral Acid Solvents

14.2.2. Organic Solvents

14.2.3. Other Solvents and Cleaning Solutions

14.2.4. Physical Factors in the Cleaning Process

14.2.5. Chemical Cleaning Solvent Additives

14.2.6. Rinsing, Neutralizing, and Passivating Solutions

14.3. Summary

15. FACTORS CONTROLLING CHEMICAL CLEANING

15.1. Safety

15.2. Post-Cleaning Inspection

15.3. Waste Treatment

15.3.1. Disposal Options

15.4. Summary

16. CHEMICAL CLEANING PROCESS

16.1. Isolation of the System

16.1.1. Hydrostatic Testing and Leak Detection

16.1.2. Superheater and Economizer Flushings

16.1.3. Preheating

16.1.4. Temperature Control

- 16.1.5. Solvent Injection and Leak Detection
- 16.1.6. Monitoring of the Cleaning Process
- 16.1.7. Solvent Circulation Control
- 16.1.8. Draining and/or Displacement of Solvent
- 16.1.9. Rinsing, Monitoring and Flushing After Solvent Removal
- 16.1.10. Neutralization of Residual Solvent
- 16.1.11. Passivation of Cleaned Surfaces
- 16.1.12. Inspection of the Cleaned System
- 16.1.13. Unit Lay-Up
- 16.1.14. Safety Procedures

16.2. Summary

17. FREQUENCY OF CHEMICAL CLEANING

17.1. Visual Inspection

17.2. Non-Destructive Inspections

- 17.2.1. The Turner Tube Scale Thickness Indicator
- 17.2.2. Adaptation of the Turner Indicator
- 17.2.3. Fiberscope or Boroscope Analysis
- 17.2.4. Chordal Thermocouples
- 17.2.5. Other NDI Methods
- 17.2.6. The Limitation of NDI

17.3. Physical Examination

- 17.3.1. Selection of Location

17.3.2. Method of Tube Removal

17.3.3. Tube Deposit Analysis

17.3.4. Determination of Deposit

17.4. *Cleaning Frequency*

17.5. *Solvent Selection*

17.6. *Summary*