SCADA for Water and Wastewater Operations

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SCADA for Water and Wastewater Operations

MMS-9520

7 Contact hours

9 CC10 hours

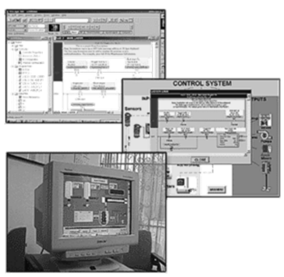
Supervisory Control and Data Acquisition (SCADA) are highly distributed control systems used for geographically dispersed stations or assets, normally scattered over large areas. This course is designed to show the participants how SCADA systems can be used to get the best performance out of water and sewer systems at the least cost. It will cover the components of a SCADA system and show how they function and relate back to a treatment plant. At the end of this course, operators, technicians, mechanics and engineers will have a working overview of SCADA, its importance, architecture, advantages and disadvantages, terminology and the overall process control and connectivity.

1. Identify the importance and architecture of SCADA systems.
2. Describe the advantages and disadvantages of SCADA systems.
3. Define key terminology in SCADA.
4. Explain the SCADA control process and connectivity.

Agenda:

8:00 am – 8:30 am:	Overview of key Terminology
8:30 am – 9:30 am:	SCADA System Architecture
9:30 am – 10:30 am:	Review the application of SCADA in water and wastewater
10:30 am – 11:30 am:	Review the advantages, disadvantages, and major components of SCADA
11:30 am – 12:30 pm:	Lunch
12:30 pm – 1:30 pm:	SCADA Software types and description
1:30 pm – 2:00 pm:	SCADA security concerns
2:00 pm – 2:30 pm:	What is in the future for SCADA?
2:30 pm – 3:00 pm:	Role of operators, technicians and engineers in process control
3:30 pm – 4:00 pm:	Post-Test

SCADA for Water and Wastewater Operations



Process Training Sessions

<u>Before class </u>starts, please:

- –**Sign in** on Attendance Sheet
- –**Fill out** Registration Form, if appropriate

<u>During class</u>, please:

- –**Asks questions**
  - – Feel free to get up and leave the classroom at any time (i.e., rest rooms, phone calls, etc.)
- –**Answer questions** on post test

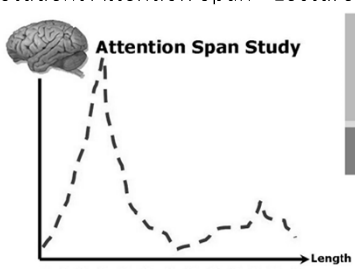
Housekeeping

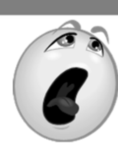
- 1–day class
- Start class – 6:30 am
- 10-minute Breaks – every hour
- Lunch ~ 10:00 am – 10:30 pm
- End class ~ 2:00 – 2:30 pm

Instructor Expectations

- Begin and end class on time
- Be interactive – participate at your own comfort level
- Share experiences and needs
- Less lecture, more discussions
- Keep it simple
- ***<u>Make this an enjoyable and informative experience!</u>***

Student Attention Span - Lectures





Source: based on a study by Richard Mayer

How this Class is Structured

- This 1-day class will be lecture and class discussion
- The class will be structured around three teaching components:
  - Establishing rapport (Trainer as facilitator)
  - Stimulating student interest (Trainer as motivator)
  - Structuring classroom experiences (Trainer as designer)

SCADA Systems 7

Discussions

- Student involvement in class discussions is encouraged:
  - To keep students attentive
  - To help students retain information

SCADA Systems 8

The Guiding Expectation

"Things should be made as simple as possible -- but no simpler."

Albert Einstein

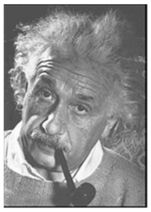


image source: www.physik.uni-frankfurt.de/~jr/physpiceinstein.html

SCADA Systems 9

Ground Rules

- Discussion is encouraged; share experiences
- Use terms we all can understand
- Everyone is different, so please show respect for others in the room
- Express opinions - of things,
  not people
- Maintain confidences

Class time, note taking, testing - these are all *"NO CELL PHONE"* activities!

Ice Breaker

- Before we start, let's introduce ourselves.
  - Name,
  - What do you know about SCADA?
  - What do you know about instrumentation and automation?

Introduction

Objectives, Focus, and Agenda

Objectives

- To discuss SCADA systems used for monitoring and process control at WWTP's
- To discuss the fundamentals of instrumentation control
- To discuss the interaction between:
  - Plant processes and operator work stations
  - Remote facilities and plant work stations
  - Setpoints, process variables, and loop controls
  - Process sensors, analyzers, and PLCs

Agenda

- SCADA – monitoring and process control
- SCADA elements:
  1. SCADA workstation
  2. Operator workstations
  3. PLC's/RTU's
  4. Communications
  5. Sensors/Analyzers
- Loop control fundamentals
- Examples of automation
- Summary and conclusions

Learning Objectives

- Objective 1 - To discuss use of common instrumentation and automation systems for process monitoring and control:
  - SCADA systems
  - Computers
  - Sensors
  - Controllers
- Objective 2 –to discuss programmable controller devices
  - Operator Work Stations
  - PLC's
  - RTU's

Learning Objectives

- Objective 3 - to discuss fundamentals of loop control:
  - Feedback
  - Feedforward
  - Combined

Objectives

- To discuss importance of SCADA systems and instrumentation controls in a wastewater treatment system
- To discuss performances of:
  - PLCs and loop controls
  - Sensors and controllers
  - Set points and process variables
  - Processes and "disturbances"

Participant Focus

- What information can you use at your work location?
  - SCADA
  - Current **instrumentation technologies**
  - Loop controls – Feedback and Feedforward; combined
- What information can you contribute to the discussion?
  - Problems with **plant automated controls**

PROCESS CONTROL LAWS

- **FIRST LAW**: The best control system is the simplest one that will do the job
- **SECOND LAW**: A process must be understood before it can be controlled
- **THIRD LAW**: Automated control is difficult if mathematical models and/or algorithms can not be developed

Instructor's Rules

- Rule # 1 – Automation is all around you
- Rule # 2 – Automation doesn't come to you …you go to it
- Rule # 3 – "There's no one trick pony"
- Rule # 4 – "There's no cure for the uninspired"

Automation Drivers

- Advancements in instrumentation
  - More accuracy and precision
- Increasingly more stringent water quality standards (Nutrients):
  - Clean Water Act
  - Chesapeake Bay
- Improve process performance (and cost efficiencies):
  - Internal Recycle (Power, pumping)
  - Aeration (Power)
  - Chemicals (Chemical and sludge costs)

Introduction

Definitions and Acronyms

Acronyms

- PCS – Process Control System
- DCS – Distributed Control System
- SCADA – Supervisory Control and Data Acquisition system
- IC&A – Instrumentation Control and Automation
- PLC – Programmable Logic Controller
- RTU- Remote Terminal Units
- CMMS – Computerized Maintenance Management System
- LIMS – Laboratory Information Management System

Definitions

- **Input Variable** – This variable shows the effect of the surroundings on a process and normally refers to factors that influence the process
  - *Manipulated inputs:* variable in the surroundings that can be controlled by an operator or the control system in place
  - *Disturbances:* inputs that can not be controlled by an operator or control system; measurable and immeasurable disturbances exist

Definitions

- **Output variables**- Also known as *control variables,* are variables that are outputs of the process
- **Setpoint** is a value for a process variable that is desired to be maintained
- **Closed control loop** exists where a process variable is measured, compared to a setpoint, and action is taken to correct any deviation from that setpoint

Definitions

- **Error** is the difference between the measured variable and the setpoint
- **Algorithm** is a step-by-step (usually involving math) procedure used in automating process control, processing data, and reasoning

Instrumentation Terms

- Range: The values that the instrument can read, minimum to full scale.
- Span: The currently set upper range limit of the instrument.
- Turndown:
  - The ratio between the maximum value (full scale) and the set upper range limit of the span, or
  - The range of values it can accurately read.

SCADA Systems 28

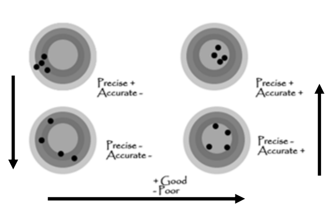
Instrumentation in the Water Industry

- Want to know basic information about the system
- Eliminate manual measurements
- Transmit information for use in controlling the system
- Save time, save money, and increase efficiency
- Allows us to operate facilities at the limits of technology

SCADA Systems 29

Instrumentation Terms

- Accuracy: How close is it to the actual reading?
- Precise/Repeatability: Does it provide the same answer each time?



SCADA Systems 30

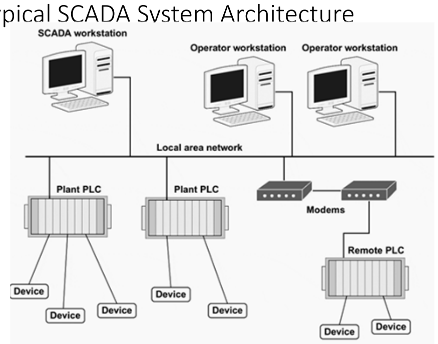
Introduction

SCADA Systems

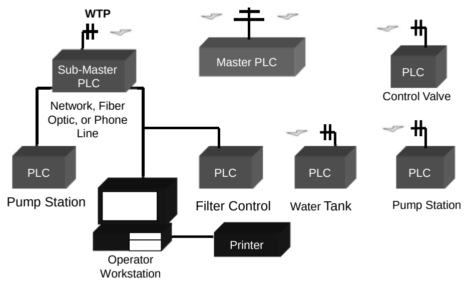
SCADA Defined

- What is SCADA?
  - **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition
  - One Supervisory Control Master
  - Multiple Sub-Controllers
  - Possible Sub-Master Controllers

Typical SCADA System Architecture



SCADA System Architecture - Water



SCADA System Architecture

- Goals:
  - Graphical Representation of Entire System
  - Continuous Information at Operator Workstations
  - Automatic Control
  - Remote Control
  - Alarming/Paging
  - Trending/Reporting
  - Easily Expandable

SCADA Economic Advantages

- Greater Speed, Accuracy, and efficiency
- Increased Reliability
- Reduced Maintenance
- Safety and Security

Typical Hardware – PLC's

- Programmable Logic Controllers (PLC's) - Standardized on Allen-Bradley and Micrologix controllers

PLC's/RTU's

- Each process area identified within a SCADA system will require its own programmable process controller
- The PLC/RTU can be programmed to
  - **Monitor all of the signals within the process area**
  - **To effect control over the process equipment**, based upon the design of the program.

PLC's/RTU's

- A field controller, commonly referred to as a PLC, is typically programmed in a language called **Ladder Logic**, which resembles the electrical control circuitry used before the PLC came into being
- Today, most PLCs allow for a variety of programming languages to meet the application requirements.

SCADA Software

- Drives the I/O
- Runs the control algorithms
- Generates control outputs
- Displays graphics and monitored values
- Senses alarm statuses
- Stores monitored data in a series of files that can be:
  - Archived
  - Recalled at a later time for analysis

Today's SCADA Software

- Intellution (Fix 32)
- Iconics (Genesis32 v7.0)
- Wonderware (InTouch)
- Citect (CitectSCADA 5.42)
- National Instruments (Lookout SCADA)

SCADA Systems

- SCADA systems involve two major activities:
  - **Supervisory control** of equipment or a process
  - **Data acquisition** (monitoring) of equipment or a process
- Complete automation of a process can be achieved by automating the monitoring and control actions

SCADA Systems

- SCADA – **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition
- Supervisory control by:
  - Operators
  - Supervisors
  - Engineers
- Data Acquisition
  - Acquire data from equipment or processes
  - Signals can be analog or digital

SCADA Systems 43

Why SCADA?

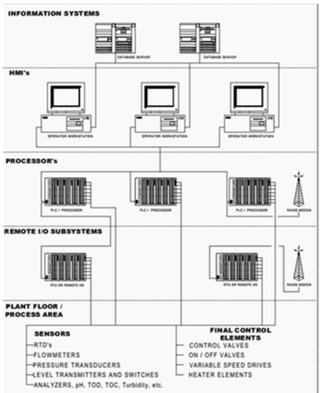
- Reliable
  - Close control of equipment and processes
- Saves time and money
  - Less travel time for workers
  - More efficient control of complex operations
  - Saves energy costs

SCADA Systems 44

SCADA Levels

- Level IV – Enterprise
  - LAN; firewall for remote users; security
- Level III – SCADA/MTU
  - HMI's; operator workstations; data logging
- Level II – Communications
  - Analog/digital/radio; protocols
- Level I – Field
  - RTU's/PLC's
  - Sensors; devices

SCADA Systems 45



Elements of SCADA

- SCADA Server/Workstation/Central Processing Unit
  - Backup server
  - I/O (Input/Output) subsystems
  - HMI (Human Machine Interface) computer/software
- Operator workstations/video monitors
- RTU's – Remote Terminal Units
- PLC's – Programmable Logic Controllers
- Communication network
- Control devices – Field sensors and actuators

HMI Computer

- HMI – Human Machine Interface Computer
- Access to the SCATA server
- Operator interface
- User friendly software

SCADA Server Computers

SCADA Systems 49

SCADA Server Computer

- The server computer performs **all of the communications with the PLC's and RTU's on the SCADA network**
- Each RTU/PLC maintains and collects data pertaining to its process areas
- Process area data is then retrieved by the server computer to update the current process and the historical databases

SCADA Systems 50

SCADA Server Computer

- Another purpose of the SCADA server computer is to provide an interface to other facilities, typically through the Internet, **using Firewalls and SQL interface calls**
- It is important that outside access cannot interfere with the internal operations of the SCADA system, so the server computer often provides a secure interface

SCADA Systems 51

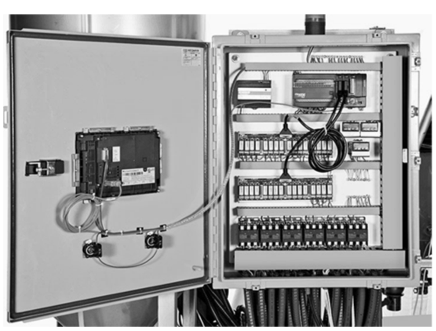
SCADA Server Computer

- Other departments and users may require data collected by the SCADA system, and so a means of accessing this data can be provided through the SCADA server computer, with the appropriate security measures in place

SCADA Server Computer

- Communications to the SCADA server is configured to poll or otherwise collect data values from the PLCs/RTUs
- Commands and adjustments from the operations workstations are sent out to the PLCs and/or RTUs via the server computer

SCADA Automation Panel



Local SCADA Workstation

SCADA Systems 55

Network SCADA Workstation

SCADA Systems 56

Operator Workstation

- The SCADA workstations present **the process graphic displays with operator interaction**, such as controlling equipment and requesting information
- The software at this level involves:
  - The creation of the process control displays
  - Historical trend and historical report displays alarm and event summary displays
  - The process database.

SCADA Systems 57

Operator Workstation

RTUs and PLCs

- In SCADA systems, RTUs and PLCs perform the majority of on-site control
- RTUs and PLCs acquire site data, which includes meter readings, pressure, voltage, or other equipment status
- Both perform local controls and transfer data to the central SCADA system

RTUs and PLCs

- In practice, the typical PLC usage model revolves around localized fast control of discrete variables
- RTU usage focuses on remote monitoring with control, but with a higher demand for application communications and protocol flexibility

Programmable Logic Controller (PLC)

- Microprocessor-based controller that executes a program of instructions to implement logic, sequencing, counting, and arithmetic functions to control equipment and processes
- Introduced around 1970 to replace electromechanical relay controllers
- Today's PLCs perform both discrete and continuous control

What is an RTU?

- RTU - **R**emote **T**erminal **U**nit
- Sometimes called a:
  - Remote Telemetry Unit, or
  - Remote Telecontrol Unit
- An RTU is a microprocessor-based device that monitors and controls field devices that connect to plant control/SCADA systems

Remote Terminal Unit (RTU)

- A direct interface between field sensors, actuators, and a central control unit
- A device to control multiple processes, without direct intervention from a controller or master

RTU's

- **RTU's serve as the eyes, ears and hands of a SCADA system**
- The RTU:
  - Acquires all the field data from different field devices
  - Processes the data
  - Transmits the relevant data to the master station
- At the same time, it distributes the control signals received from the master station to the field devices

SCADA RTU Panel

Sensors

- Flow meters
- Pressure gauges
- Level indicators
- Water quality:
  - Temperature
  - Dissolved oxygen probes
  - Nutrient probes/analyzers (NH_3, NO_X, PO_4)
  - Chlorine residual probe
  - ORP/pH probe

Actuators

- Motorized valves
- Pumps
- Motors (VFDs - Variable Frequency Drives)

LAN

- The in-plant equipment, programmable process controllers and SCADA user workstations, are typically interconnected via a **Local Area Network (LAN)**, using Ethernet or other high-speed communication system
- Some SCADA systems may extend outside the physical building into remote sites; these sites require some form of communication back to the host facility, e.g., radio signals

Field Signals

- Field devices may be signal transmitters, **such as level or pressure transmitters**
- They could be discrete signals, such as a valve's open or closed status, or a motor's running status
- Some devices may actually provide multiple signals, such as a water quality unit which provides both chlorine residual and water pH

Field Signals

- All field signals must be identified for each process area sensor
- Field sensors/devices are wired into the various PLCs/RTUs, which in turn process the signals

Field Signals

- Field devices, which are represented by discrete and analog signals, are connected to the various input and output modules of the PLC/RTU
- The PLC/RTU processes the input signals and effects control through the output signals, based upon the programming in the PLC/RTU

Field Signals

- Analog input signals may include:
  - Levels
  - Flowrates
  - Motor speeds
  - Voltage and current from power monitors
  - Water quality signals
  - Temperatures and pressures

Field Signals

- Analog output signals may include:
  - Motor speed controls for Variable Speed Drives (VSDs) on variable speed motors
  - Valve positioning signals for modulating valves
  - Analog display devices.

Field Signals

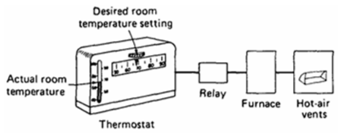
- Since field signals, such as levels, flows, and water quality parameters may be used by the program to control the operation of plant equipment, the **Programmable Logic Controller (PLC)** is key to monitoring and controlling every process area in a SCADA system

Field Signals

Signal Transmission Techniques

Signal-Transmission Techniques

- Analog
- Digital
- Telemetric



Home heating control system.

Analog Signal Transmission

- A continuous and proportional output converted to another form
- Pre-electronic forms:
  - Pneumatic and hydraulic transmission system converted mechanical displacement to pressure
- Electronic analog transmission systems
  - Low voltage/low amperage
  - Continuous signal proportional to sensor output

Analog Signal

- Continuous range of values
- Have a scale (gpm, psi, feet, pH, %, etc.)
- Current-based 4-20 mA signal
- Signal carried by a twisted pair of wires with a shield

Digital Signal Transmission

- Process information like computers…binary number system
- Numerical data: combinations of zeros and ones; electrically, presence or absence of electrical voltage
- To transmit analog data, analog-to-digital converters are used
- Large amounts of data can be processed at high speeds

Telemetry

- Both analog and digital signal transmission techniques link remote facilities (lift stations) to centralized facilities
- Telemetry systems use radio, telephone, microwaves, or lasers as communication media
- Typically combined with computers

Typical Hardware – Radio Communication

- MAS/MDS radios and modems for Radio Communication

Typical Hardware – Phone Line Communication

- Mille Research modems for Phone Line Communication

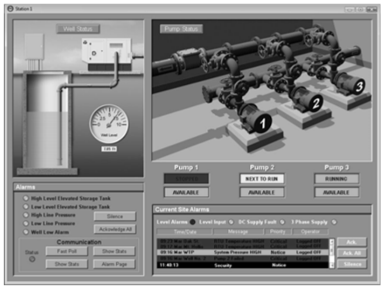
Typical Software

- Standardized on Rockwell Software:
  - RSLogix for programming
  - RSLinx for communications
  - RSView for Operator Interface
  - RSMessenger for Alarm Paging
- LapLink Software allows connection to operator workstation from a remote computer through a dial-up modem

Pumping Station Operation

- For example, a pumping station may use two or three pumps, **operating in a lead/lag/standby mode**
- The automation program in the controller is configured to operate the pumps based upon operator-entered set-points and duty assignments

Video Monitor - Pumping Station



SCADA Systems 85

Video Dashboards

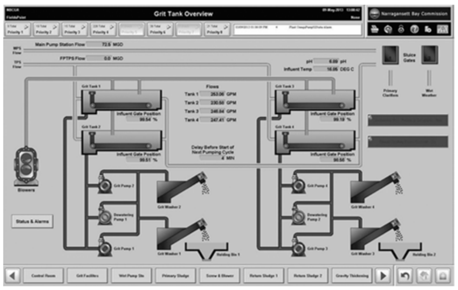
- Used for process overviews
  - Plant wide
  - Process specific

SCADA Systems 86

Video Monitor - WWTP

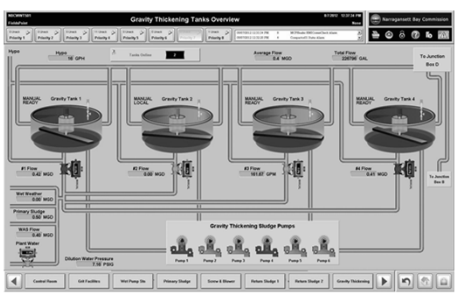
SCADA Systems 87

Video Monitor - Grit Removal



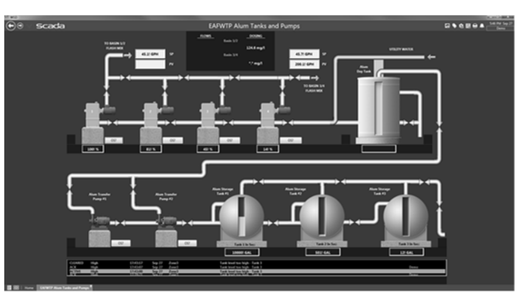
SCADA Systems 88

Video Monitor - Gravity Thickeners



SCADA Systems 89

Video Monitor - Chemical Feed



SCADA Systems 90

Remote Access to SCADA Systems

Process Monitoring

Typical Control Variables

Before You Can Control a Process Variable, You Must be able to Monitor It with Reliable Sensors

Process Control Fundamentals

- Focus is on the process
- Dynamic behavior of individual processes and the plant as a whole needs to be understood
- Best to utilize the simplest control system that will achieve desired objectives
- Process control design determines how well it will respond dynamically and how it can be controlled

Process Control

- Three physical properties are typically monitored in wastewater:
  1. Liquid flow: Influent/effluent, recirculation, return activated sludge (RAS), sludge wasting quantities, chemical addition
  2. Constituent Concentrations: DO, MLSS, BOD_5, TSS, nutrients, sludge solids
  3. Gas volumes: air, digester gas

Common Controlled Variables

- Aeration
- BOD_5 and TSS loadings
- Ammonia, Nitrate, and Phosphate loadings
- Chemical Addition
- Internal Recycles (MLE processes)
- Low water level and fill level during fill stage (SBR)
- Sludge Wasting Rates

Common Controlled Variables

- Aeration
  - Set DO levels in different sections of process
  - Control aeration time (cyclic aeration)
- BOD_5 and TSS loadings
  - Maximize removal of BOD_5 and TSS before nitrification/denitrification
- Ammonia, Nitrate, and Phosphate mass loadings
  - Avoid overloading unit processes

Common Controlled Variables

- Chemical Addition
  - Methanol, Ferric/Alum, alkalinity feed rates
- Internal Recycles (MLE processes)
  - Set recycle flow rates based on process conditions
- Low water level to fill level (SBRs)
- Sludge Wasting Rate
  - Control Solids Retention Time – One of the most important parameters for advanced BNR

Nitrification-Related Process Instruments and Parameters

- Temperature
- Flow meters
- Flow rates:
  - Influent/Effluent
  - WAS
- Solids ret. time (SRT)
- pH/alkalinity
- ORP
- Airflow distribution
- DO probe(s)
- DO conc., mg/L
- Ammonia probe(s)
- Ammonia conc., mg/L
- Nitrate probe(s)
- Nitrate conc., mg/L

Denitrification-Related Process Instruments and Parameters

- Temperature
- Flow meters
- Flow rates
  - Inflows
  - Internal Recycle
- pH/alkalinity
- ORP
- DO probe(s)
- DO conc., mg/L
- Nitrate probe(s)
- Nitrate conc., mg/L

Phosphorus-Related Process Instruments and Parameters

- Flow meters
- Flow rates:
  - Influent/Effluent
  - WAS
- pH/alkalinity
- ORP
- Phosphate analyzers
- Phosphate conc., mg/L

What does a Control System do?

Control: To maintain desired conditions in a process by adjusting selected variables in the system.

In control Systems:

- A specific value or range is used as a desired value for the controlled variable
- The conditions of the system are measured
- Each system has a **control calculation or algorithm**
- The results of calculation are implemented by a final control element

Why is Control Necessary?

Two reasons for control:

1. To maintain the measured variable at its desired value when disturbances occur
2. To respond to changes *in t*he “desired value” set point

Desired values are determined by control objectives

SCADA Systems 103

How is Control Achieved?

- A process can be controlled manually by operators or automatically with instrumentation (Sensors, controllers, and control elements)
- Most automatic control is implemented with electronic equipment which uses levels of current or voltage to represent values of variables to be communicated
- Sensors should be calibrated and accurate

SCADA Systems 104

How is Control Achieved?

- Generally the plant never operates on “automatic pilot” and an operator is always present:
  - to perform tasks not automated
  - to optimize operations
  - to interfere with situations when an unusual or dangerous situation occurs

SCADA Systems 105

Process Control Design

- Key factors in automated process control systems:
  - Responsiveness
  - Ability to deal with disturbances
- "A responsive control system" means the controlled variable responds quickly to adjustments in the manipulated variable
- Frequency and magnitude of disturbances should be minimum

Sensors

- Selection and location of sensors in process is critical
- "one can control only what is measured"
- Sensors measure important variables rapidly, reliably, and with sufficient accuracy

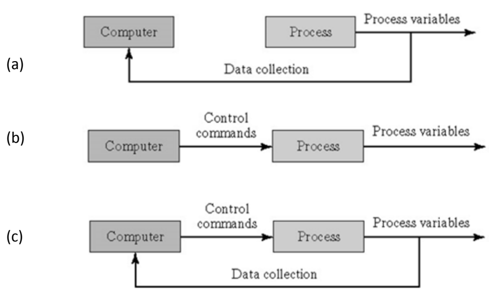
Introduction

Programmable Controls

Computer Use Milestones

- 1950's to 1960's - Origins
  - Mainframe computers – slow and expensive
  - Set point control
  - 1962 - Direct digital control (DDC) systems
- Late 1960's - Minicomputers introduced
- Early 1970's - Microcomputers introduced
  - Programmable logic controllers (PLC) introduced for discrete process control
  - Distributed control starting around 1975
- Early 1990's - PCs for process control

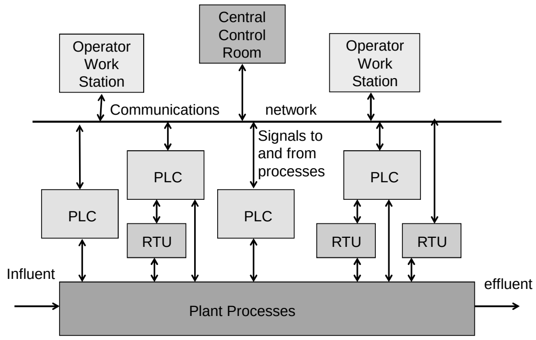
Computer Use Milestones



PCs in Process Control

1. Operator interface – PC is interfaced to one or more PLCs or other devices that directly control the process
   - PC performs certain monitoring and supervisory functions, but does not directly control process
2. Direct control – PC is interfaced directly to the process and controls its operations in real time
   - Traditional thinking is that this is risky

Distributed Control System

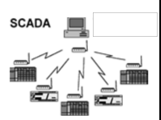


Supervisory Control

Denotes a control system that manages the activities of a number of integrated unit operations

A control system that directs and coordinates the activities of several interacting pieces of equipment

- SCADA
- CMMS - Avantis



Process Control

Loop Control

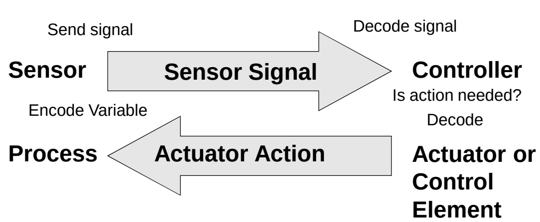
Process Control “Loops”

- Monitoring and control of a process
- WWTP relies on four building blocks:
  - A process model concept
  - Monitoring and control strategies
  - Sensors that provide on-line data to controllers
  - Actuators or control elements that implement controller output

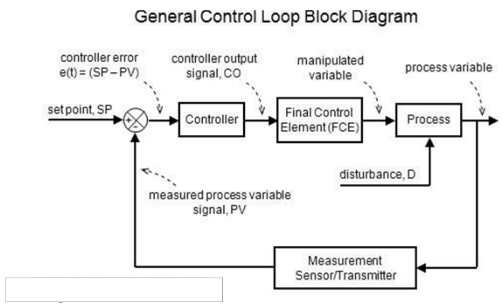
Control Types

- **Feedback Control**: uses direct measurements of the controlled variables to adjust the values of the manipulated variables
- **Feedforward Control**: uses direct measurement of the disturbances to adjust the values of the manipulated variables
- **Compound Control**: different combinations of the two types
- Control objective - to keep control variables at desired levels

Simple Communication Loop



Feedback Process Control "Loop"

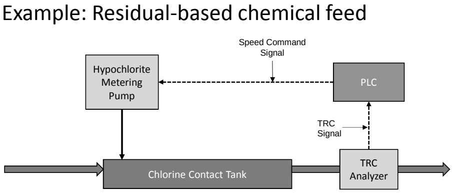


Feedback Process Control "Loop"

- Feedback control is a common control strategy; its simplicity accounts for its popularity.
- The feedback controller works with minimum knowledge of the process; it needs only to know which direction to move
- How much to move is usually adjusted by trial and error

Feedback Control Loop

- Measurement is after the mechanical action (e.g., pump speed change)
- Example: Residual-based chemical feed



Feedback Process Control "Loop"

- Disadvantage of feedback control: it compensates for a disturbance only after the controlled variable has deviated from the set point
- Disturbance must propagate through the entire process before the feedback control scheme can initiate action to compensate

SCADA Systems 121

Feedforward Control

- Objective - anticipate the effect of disturbances that will upset the process by sensing and compensating for them before they affect the process
- If applied correctly, the controlled variable deviation would be minimum
- Mathematical model captures the effect of the disturbance on the process

SCADA Systems 122

Feedforward Control

- Complete compensation for disturbances is difficult due to variations, imperfections in mathematical models, and imperfections in the control actions
  - Usually combined with regulatory control
- Regulatory control and feedforward control are more closely associated with water and wastewater utilities

SCADA Systems 123

Control Concepts

- Manual
- Feedback
- Feedforward
- Compound
- Advanced Control

SCADA Systems 124

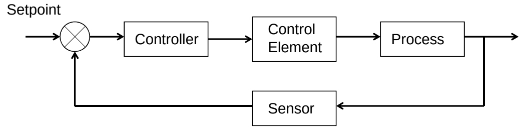
Manual Control

- Operator observes problems and takes corrective action
- Sometimes, nothing more than a guess
- "Open-loop" control
  - No direct connection between desired output (setpoint) and process variable
  - Operator may have to constantly observe and change manipulated variable to ultimately correct problem

SCADA Systems 125

Feedback Control

- Output information is used to adjust process controls
- Feedback controller receives sensor output on process variable and compares it to setpoint



SISO – Single-input single-output

SCADA Systems 126

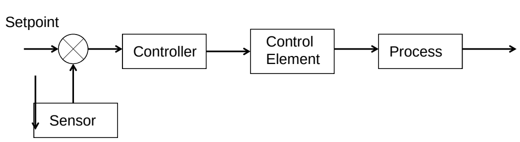
Feedback Control

- Limitations on feedback control:
  - Feedback control is after the fact, not predictive
  - Requires operators to change set points to optimize system
  - Changes can bring instability into system
  - Optimization of many input and output variables are difficult
  - Most processes are non-linear and change according to process environment

SCADA Systems 127

Feedforward Control

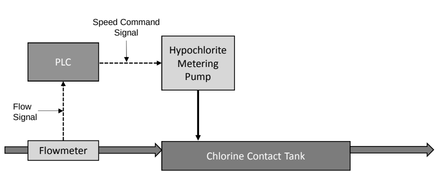
- Input information is used to adjust process controls
- Controller receives sensor output on process variable and compares it to setpoint



SCADA Systems 128

Feedforward Control Loop

- Measurement comes before the mechanical action (e.g., pump speed change)
- Example: Flow-paced chemical feed



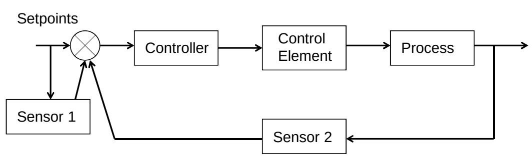
SCADA Systems 129

Feedforward Control

- Feedforward control avoids delays of feedback control
- Input disturbances are measured and accounted for before they have time to affect the system
- Difficulty with feedforward control:
  - Effects of disturbances on process must be anticipated
  - No surprises

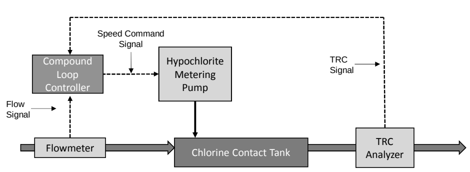
Compound Control

- Input and output information is used to adjust process controls
- Controller receives sensor outputs on process variables and compares it to setpoints



Feedback/Feedforward Control Loop

- Measurement is made before mechanical action but adjusted based upon measurement downstream of the mechanical action
- Combination feed forward (FF) and feed back (FB) control



Compound Control

- Benefits of feedback control:
  - Controlling unknown disturbances
  - Not having to know exactly how a system will respond
- Benefits of feedforward control:
  - Responding to disturbances before they can affect process

Cascade control – Feedback as primary with a feedforward secondary loop

Advanced Control

- Use of computers and microprocessors
- Control logic (algorithms) includes feedforward and feedback control concepts
- Compare process conditions with pre-programmed conditions
- Best applied where multiple, parallel treatment units are used
- Monitors dozens of sensors
- Manipulates several pieces of equipment

Advanced Control

- Most complex processes have many control variables
- To control multiple variables, multiple control loops are used
  - Example: bioreactor with at least three control loops: Carbon feed, D.O., and flow splitting
  - Multiple control loops often interact causing process instability
- Multivariable controllers account for loop interaction
- Models can be developed to provide feedforward control strategies applied to all control loops simultaneously

Data Issues

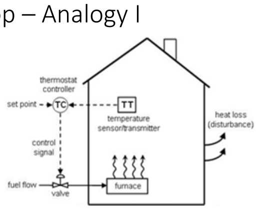
- Inputs to advanced control systems require accurate, clean, and consistent process data
  - “Garbage in-garbage out
- Many key process parameters cannot be measured on-line requiring laboratory or maintenance analyses
  - LIMS
  - CMMS
- Sensors may have to be filtered to attenuate noise
- With many variables to manipulate, control strategy is critical to limit control loop interaction

Analogies

- Before discussing instrumentation and sensor details, let’s look at two familiar feedback process control loops:
  - Home heating system
  - Car cruise control

Feedback Control Loop – Analogy I

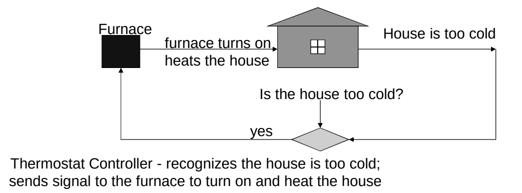
Heating your home



- Temperaturere of the room is determined by a thermostat
- Temperature is compared with a desired temperature
- If the temperature falls below desired amount, furnace turns on; if the temperature is above, the furnace turns off

Feedback Control Loop – Analogy I

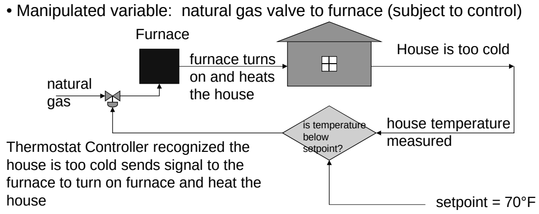
- Process control loop: control component monitors desired output results and changes input variables to obtain the result.
- Example: thermostat controller



SCADA Systems 139

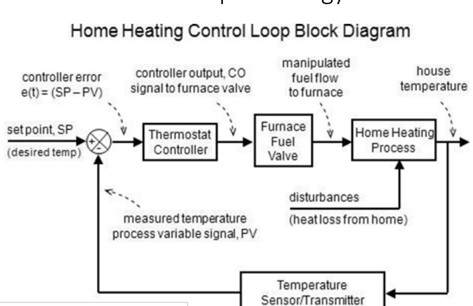
Feedback Control Loop – Analogy I

- Controlled variable: temperature (desired output)
- Input variable: temperature (measured by thermometer in theromostat)
- Setpoint: user-defined desired setting (temperature)
- Manipulated variable: natural gas valve to furnace (subject to control)



SCADA Systems 140

Feedback Control Loop – Analogy I



SCADA Systems 141

Feedback Control Loop – Analogy I

- As the furnace turns on and off, home temperature increases or decreases
- Feedback loops are operative
- Elements of a home heating control system:
  - Control Objective: *maintain house temperature at SP in spite of disturbances*
  - Process Variable: *house temperature*
  - Measurement Sensor: *thermistor; or bimetallic strip coil on analog models*
  - Measured Process Variable (PV) Signal: *signal transmitted from the thermistor*

Feedback Control Loop – Analogy I

- More elements of home heating controls:
  - Set Point (SP): *desired house temperature*
  - Controller Output (CO): *signal to fuel valve actuator, furnace blower, furnace burner*
  - Final Control Element (FCE): *solenoid valve for fuel flow to furnace*
  - Manipulated Variable: *fuel flow rate to furnace*
  - Disturbances (D): *heat loss from doors, walls and windows; changing outdoor temperature; sunrise and sunset; rain...*

Feedback Control Loop – Analogy II

- Cruise control in a car
  - Cruise control is enabled with a push button on the car steering wheel
  - Once on the open road and at a desired cruising speed, a second button switches the controller from manual mode (where car speed is adjusted by our foot) to automatic mode (where car speed is adjusted by the controller)
  - Cruise control monitors transmission drive shaft rotation, not vehicle speed…!

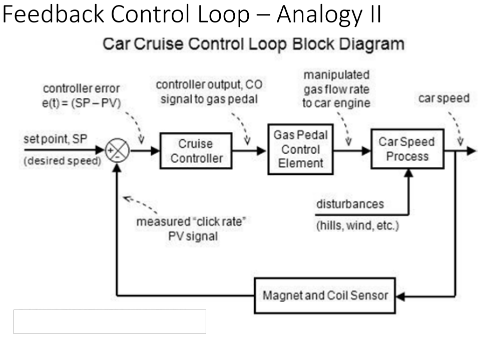
Feedback Control Loop – Analogy II

- Elements of cruise control:
  - Control Objective: *maintain car speed at SP in spite of disturbances*
  - Process Variable: *car speed*
  - Measurement Sensor: *magnet and coil to clock drive shaft rotation*
  - Measured Process Variable (PV) Signal: *"click rate" signal from the magnet and coil*

Feedback Control Loop – Analogy II

- Other elements of cruise control:
  - Set Point (SP): *desired car speed, recast in the controller as a desired transmission click rate*
  - Controller Output (CO): *signal to actuator that adjusts gas pedal (throttle)*
  - Final Control Element (FCE): *gas pedal position*
  - Manipulated Variable: *fuel flow rate*
  - Disturbances (D): *hills, wind, curves, passing trucks…*

Feedback Control Loop – Analogy II



Driver for IC&A

Improved BNR/ENR Process Performances and Cost Efficiencies

SCADA Systems 1

Process Automation - What's Needed?

- Strategies:
  - Process control fundamental and/or "models" for TN and TP removal
  - Automation (loop) controls:
    - On-off
    - Proportional-Integral (PI) algorithms
    - Proportional-Integral-Derivative (PID) algorithms
    - With feed forward and/or feed back control loops

SCADA Systems 2

Process Automation - Strategies

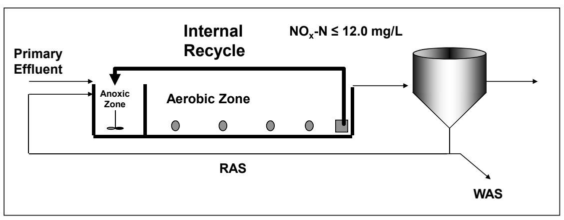
- Optimize internal recycle
- Optimize aeration
- Optimize addition of supplemental carbon

SCADA Systems 3

BNR/ENR

Internal Recycle

Let's Focus on Internal Recycle



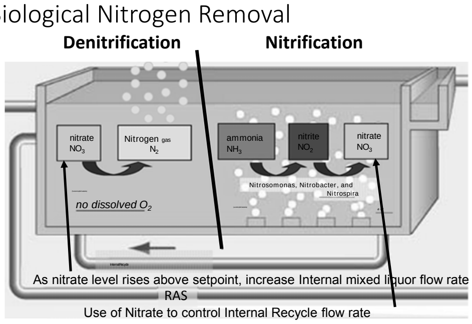
Internal Recycle

- Internal recycle flow rates determine nitrate concentrations in BNR process effluent
  - The higher the recycle flow rate, the lower the effluent nitrate concentrations
  - Process effluent nitrate concentration "set points" can be used to control internal recycle flow rates

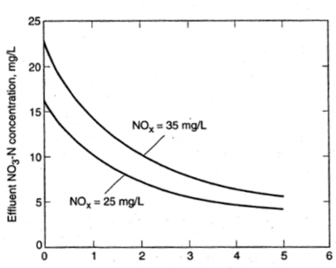
Nitrate-Based Internal Recycle Control

- As nitrate concentrations increase above set point in the nitrification zone (e.g., excess effluent nitrates)
  - Increase internal recycle from nitrification to denitrification
  - To decrease nitrates in nitrification effluent
  - To fully denitrify

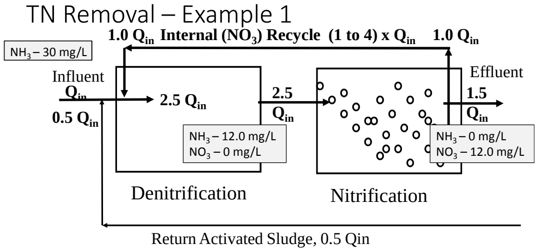
Biological Nitrogen Removal



Impact of Internal Recycle on BNR Effluent TN

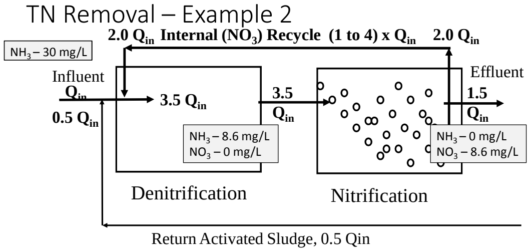


TN Removal – Example 1



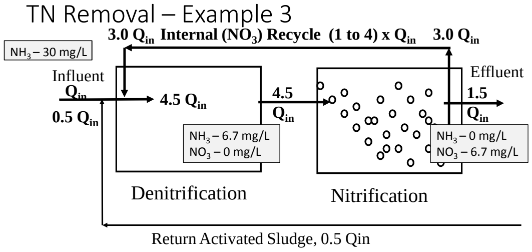
Assume all NO_3–N returned to Denitrification is converted to N_2
Assume all NH_3-N is converted to NO_3-N in Nitrification.
What is the NH_3-N concentration in Denitrification? $NH_3\text{-N} = \frac{30 \text{ mg/L}}{2.5/1} = 12.0 \text{ mg/l}$

TN Removal – Example 2



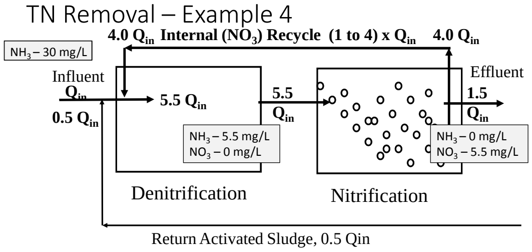
Assume all NO_3-N returned to Denitrification is converted to N_2
Assume all NH_3-N is converted to NO_3-N in Nitrification.
What is the NH_3-N concentration in Denitrification? $NH_3\text{-N} = \frac{30 \text{ mg/L}}{3.5/1} = 8.6 \text{ mg/l}$

TN Removal – Example 3



Assume all NO_3-N returned to Denitrification is converted to N_2
Assume all NH_3-N is converted to NO_3-N in Nitrification.
What is the NH_3-N concentration in Denitrification? $NH_3\text{-N} = \frac{30 \text{ mg/L}}{4.5/1} = 6.7 \text{ mg/l}$

TN Removal – Example 4

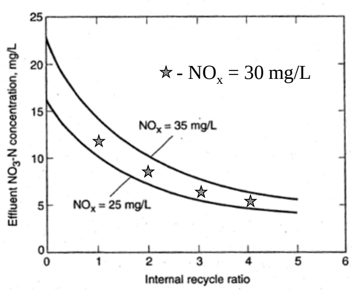


Assume all NO_3-N returned to Denitrification is converted to N_2

Assume all NH_3-N is converted to NO_3-N in Nitrification.

What is the NH_3-N concentration in Denitrification? $NH_3\text{-N} = \frac{30\text{ mg/L}}{5.5/1} = 5.5\text{ mg/l}$

Impact of Internal Recycle on BNR Effluent TN



Denitrification

Note: (Almost) all nitrates returned to the pre-anoxic zone are denitrified

The “goal” NO_3-N concentration in the effluent from the pre-anoxic zone should be between 0 and 0.5 mg/L.

BNR/ENR

Aeration

SCADA Systems 16

Let's Focus on Aeration

SCADA Systems 17

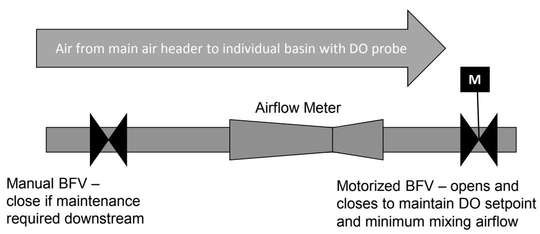
Aeration

SCADA Systems 18

DO-Related Process Controls

- Main header pressure
- Blower speed
- Number of blowers
- DO control valve positions
- DO probes
- Ammonia probe(s) (optional)

DO Control: Opening or Closing a MOV to Maintain a DO Setpoint

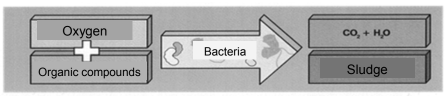


Aeration

- Purpose of aeration:
  - To dissolve oxygen into wastewater so that microorganisms can utilize it to break down organic material
- Aeration is also used for mixing the activated sludge process and to enhance biological growth

Aeration

- Oxygen is used for growth of suspended and attached biomass to remove:
  - Soluble Organics (cBOD, COD)
  - Organic Solids (TSS, VSS)
  - Nutrients
    - Nitrogen
    - Phosphorus



Aeration

- Conventional biological processes are aerobic
- Many organisms in the activated sludge and fixed film processes need free oxygen (O_2) to convert food into energy for their growth
- Typical Dissolved Oxygen (DO) concentrations:
  - BOD removal - normal 1 to 2 mg/L
  - "Nitrification" - 2 to 4 mg/l

Aerobic Processes

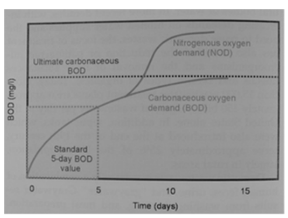
- Aerobic processes require O_2 for removal of organics (BOD) and conversion of ammonia-N to Nitrate-N (nitrification)
- Oxygen can be supplied by air or pure O_2
- Oxygen can be delivered through mechanical (surface) or diffused aerators

Aeration

- BOD Removal
- Nitrification – convert NH_3 to NO_3

Oxygen Requirements

- Biological treatment:
  - cBOD removal – from organic matter and suspended solids
  - nBOD removal – Nitrification, convert ammonia nitrogen to nitrate nitrogen (before denitrification)



Air Demand Requirements, lbs/day

Treatment	Equation	lb O_2/lb oxidized
Organic Removal	$BOD_{oxidized} = BOD_{inf} - BOD_{eff}$	1.0 – 1.2
Nitrification	$TKN_{oxidizable} = TKN_{inf} - TKN_{assimilated}$ $TKN_{oxidized} = TKN_{oxidizable} - TKN_{eff}$	4.6

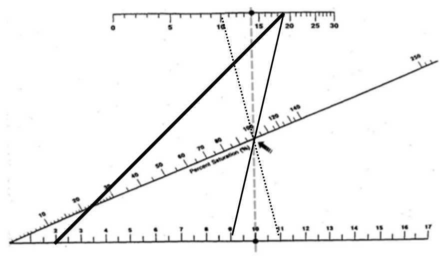
NPDES Effluent Requirement	OTR Equation
BOD5 Limit	1.2 * BODoxidized
BOD5 + NH3-N Limit	1.2 * BODoxidized + 4.6 * TKNoxidized

Importance of Dissolved Oxygen

- Oxygen is sparingly soluble in water
- DO is a growth-limiting substrate
- C*ritical oxygen concentration* is about 10% to 50% of DO saturation in water
  - 10% minimum saturation (~ 1.0 mg/l DO) for BOD removal to less than 15 mg/L
  - 20% minimum saturation (~ 2.0 mg/l DO) for complete nitrification

D.O. - Percent Saturation in Water

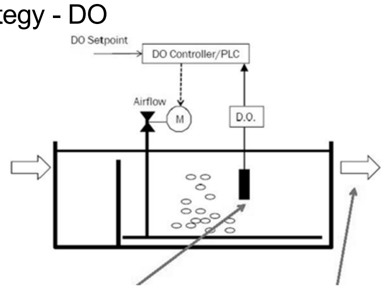
Water Temperature in Degrees Celsius



Oxygen in mg/L

Source: Department of Fisheries and Aquatic Sciences, University of Florida

Typical MLE Aeration Basin Control Strategy - DO



DO setpoint chosen to minimize historical NH_3 breakthrough

New Aeration Basin Control Strategies

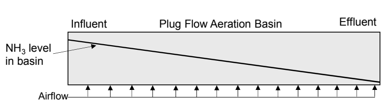
- Ammonia-based DO control
- Nitrate-based DO control

Objective of Ammonia-Based Aeration Control

- Aeration options:
  - Full nitrification
  - **Incomplete nitrification**
  - Reduce effluent ammonia peaks
- Potential benefits of incomplete nitrification include:
  - Decreased energy expenses (for aeration)
  - Possibly increased denitrification with less supplemental carbon addition
  - Possibly improved Bio-P removal

Ammonia-Based DO Control

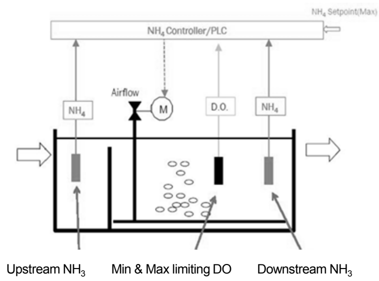
- Operator selects effluent ammonia setpoint
  - Complete nitrification, NH_3-N ~ 0.1 mg/L
  - Incomplete nitrification, NH_3-N ≤ 1.0 to 2.0 mg/L



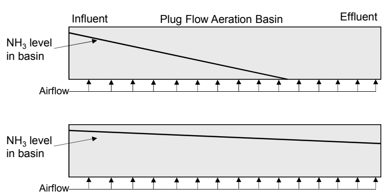
Just right

- When effluent ammonia is greater than setpoint, controller increases DO
- When effluent ammonia is below setpoint, controller decreases DO

Ammonia Feed Forward – Feedback Control



Ammonia-Based DO Control



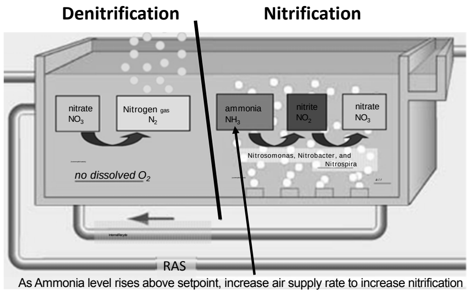
Too much air

Not enough air

Ammonia-Based DO Control

- As ammonia concentration increases above set point in the nitrification zone (e.g., ammonia breakthrough)
  - Increase aeration
  - To increase nitrification
  - To decrease ammonia concentration

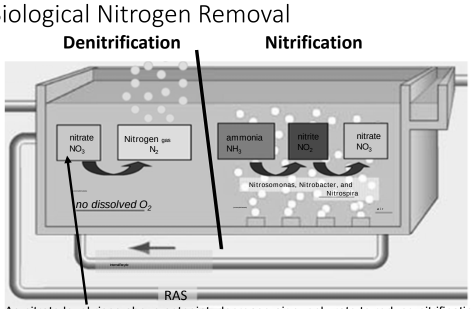
Biological Nitrogen Removal



Nitrate-Based DO Control

- As nitrate concentration increases above set point in the denitrification zone (e.g., incomplete denitrification)
  - Decrease aeration in nitrification
  - To decrease nitrification
  - To decrease nitrate concentration in recycle flow
  - To fully denitrification

Biological Nitrogen Removal



Process Control

Sensors and Analyzers

What are sensors?

- Devices which measure a target variable
- Two components
  - Sensing Element
    - Tracks the variable being measured
    - Sends signal to transmitter
  - Transmitter
    - Converts signal for use on local display
    - Sends signal to controller/SCADA

Sensor image from:
http://www.capitolscientific.com/core/media/media.nl?id=51573&c=1250437&h=767af71ece59e1f9ec11

Why are Sensors important?

- Automate data collection
- Monitor performance when no one is looking
- **<u>Optimize process performance</u>**
- **<u>Minimize energy use and chemical consumption</u>**
- Sensors can be paired with calibrated process models to enhance operations

IC&A Drivers

- Collect and record data for creating reports, profiling process performance, and storing data
- Reduce costs:
  - Operating costs, e.g. chemicals, energy (for aeration), labor
  - Capital costs, e.g., increase nutrient removal capacity by 10% to 30%; possibly reduce future system investments by another 20% to 50%

Sensors – Calibration and Validation

- Example: side-by-side grab sampling with immediate filtration/analysis and comparing grab value with instrument value
- Typically conducted three times per week dependent on plant and sensor

Physical-Chemical Analyzers

- Specific chemical ion analyzers
  - DO, pH, ammonia, ORP
- Group of chemical analyzers
  - Total chlorine, total oxidized nitrates
- Type of substance analyzers
  - TSS, SS, PO_4
- Effect analyzers
  - BOD, COD

Sensors

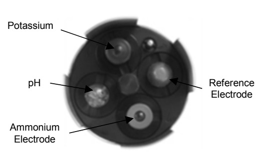
- Flow measurement
- Pressure measurement
- Level
- Temperature
- Weight
- Speed
- Proximity sensors
- Physical-chemical analyzers
- Solids concentration

Three Main Chemical Sensor Types

- Ion Selective Electrode (ISE) probes
- Wet Chemistry (Colorimetric) analyzers
- Optical (UV) probes

Ion Selective Electrode (ISE)

- Probe-type sensors that use an ISE probe and reference electrode



Images Courtesy of S::CAN


Images Courtesy of WTW

Detection by ISE Probe

- Specific ions adhere to membrane on measurement electrode
- Those ions do not affect reference electrode
- Measure potential (voltage) difference
- Replace cartridge ~ 6-12 months

Nutrient ISE Probes

Brand	Model
YSI	VARiON (IQ SensorNet)
Hach	AN ISE sc
Endress & Hauser	ISEmax

Wet Chemistry (Colorimetric) Analyzers

- Utilize a colorimetric method for measuring a constituent in a sample
- Withdraw a sample from the wastewater flow and pump it to a nearby analyzer

Images Courtesy of HACH®

http://www.capitalh2o.com/image/page_photos/chemscan_front.jpg

Optical (UV) Probes

- Utilize an ultraviolet (UV) light source to measure an absorbance and/or transmittance of UV light waves passing through a sample
- Similar to UV light absorbance spectrophotometers in a lab

UV
Transmittance
Path

SCADA Systems 52

Optical (UV) DO Probes

Brand	Model
YSI	FDO (IQ SensorNet)
Hach	LDO Model 2
Endress & Hauser	Oxymax
Insight IG	Model 1000
ATI	Q45D

SCADA Systems 53

FLOW MEASUREMENT

SCADA Systems 54

Flow Measurement Uses - Wastewater

- Influent/effluent flow measurement
- Flow distribution
- Reactor control
  - Aeration air flow
  - RAS rate
  - WAS rate
- Flow pacing of chemicals
- Digester gas flow

Flow Measurement Uses - Water

- Water supply, production, & delivery
- Flow pacing of chemicals
- Customer billing
- Check pump efficiency
- Monitor for leaks
- Help control or limit water delivery

Flow Measurement Basics

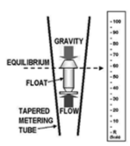
- To measure flow, must know:
  - Velocity
  - Area
  - $Q = V \times A = ft/sec \times ft^2 = ft^3/sec$
- To know mass flow, multiply by specific weight
  - $\gamma \times Q = lb/ft^3 \times ft^3/sec = lb/sec$
- In an open channel or partially full pipe, must measure both or have a device that compensates for this

Flow Measurement Basics

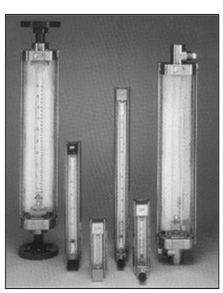
- Incompressible fluids
  - Volume doesn't change with pressure
  - Water
  - Liquid chemicals
  - We get to simplify our flow equations
- Compressible fluids
  - Volume changes with pressure
  - Gas flow (air, steam, etc.)
  - PV = nRT (ideal gas law)
  - Must measure temperature and pressure to get accurate mass flow

Variable Area Flow Meters

- Generally called rotameters
- Fluid velocity moves shaped float within tapered tube
- Read flow via graduations on clear tube
- Magnetically-coupled pointer on solid tubes
- Often used for:
  - Chlorination gas flow
  - Seal water flow
  - Bubbler air flow

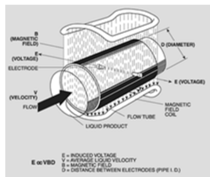


Rotameters



Magnetic Flow Meters

- Any conductor moving within an electromagnetic field will have an induced voltage in that conductor
- The magnitude of the voltage (volts) is proportional to the speed of the movement.



SCADA Systems 61

Magnetic Flow Meters

- Used for liquids and sludge in closed pipes
- No obstruction to flow
  - No head loss
  - Unaffected by solids
- Must be conductive fluid

SCADA Systems 62

Magnetic Flow Meters

- Highly accurate – 0.25%
- Wide flow range – >10:1 turndown
- Good immunity to flow line distortion
- Needs full pipe flow

SCADA Systems 63

Flow Measurement

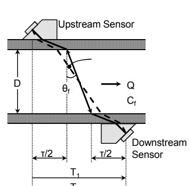
- Open-channel flow
  - Parshall flume
- Closed-pipe flow
  - Venturi meters
  - Magnetic flow meters
  - Ultrasonic

Magmeters

- Magnetic flow metering is based on Faraday's law of electromagnetic induction
- Magmeters can detect the flow of conductive fluids only

Ultrasonic Flowmeters

- Doppler Effect Ultrasonic Flowmeter
- Transit Time Difference Ultrasonic Flowmeter



PRESSURE MEASUREMENT

Pressure Measurement

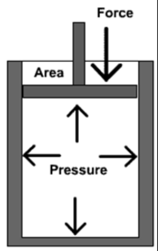
- Mechanical pressure gauges
- Pneumatic pressure transmitters
- Electronic pressure transmitters
- Differential pressure transmitters

Pressure Measurement Uses

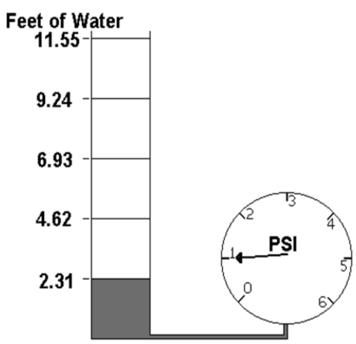
- Pump/blower performance
- Force main pressure
- Aeration system header pressure
- Differential pressure for flow measurement, filter status
- Level measurement
- Distribution system pressures
- Pressure in tanks, etc.

Pressure Measurement Basics

- Pressure = force per unit area
- Measured in:
  - pounds per square inch – lbs/in^2
  - kilonewtons per square cm – kN/cm^2 (kPa)
- Can also express as height of liquid:
  - feet of water – ft w.c.
  - inches of water – in w.c.
  - millimeters of mercury – mm Hg

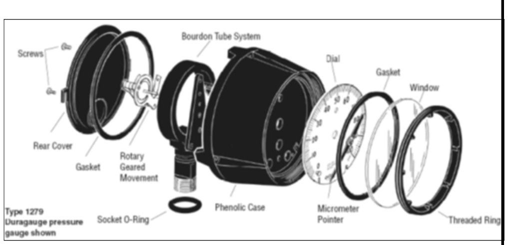


Water Column to PSI



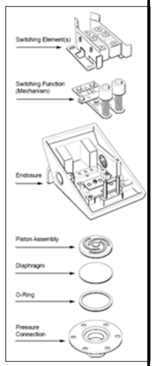
Pressure Gauges

- Simple pressure indication
- Bourdon tube geared to pointer
- Liquid fill and/or snubber for vibration/pulsation



Pressure Switches

- Tells us of high or low pressure
- Diaphragm/spring operated snap action switch
- Deadband: Amount of pressure change before switch releases

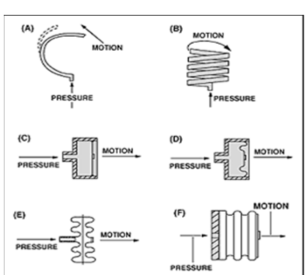


Pressure Transmitters

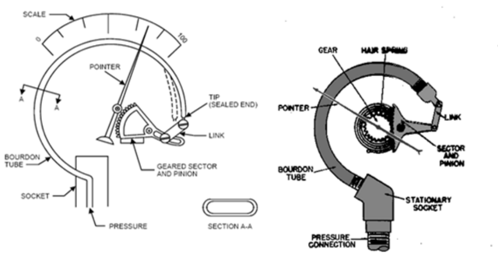
- Continuous pressure readings
- Transmit analog signal
- Loop powered
- Gauge/differential pressure, flow or level
- Incredibly accurate: 0.04% or 0.025%

Pressure Sensing Units

A. C- shaped Bourdon tube
B. Helical Bourdon tube
C. Flat diapragm
D. Convoluted diaphragm
E. Capsule
F. Bellows

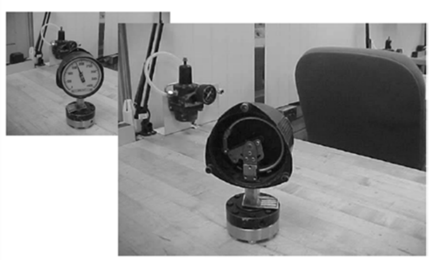


Bourdon Tube



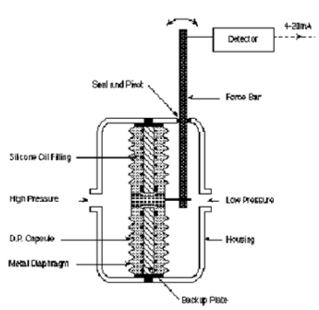
SCADA Systems 76

Bourdon Tube



SCADA Systems 77

Differential Pressure Cell



SCADA Systems 78

LEVEL MEASUREMENT

SCADA Systems 79

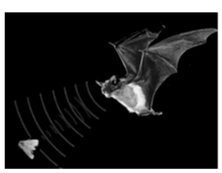
Level Measurement

- Floats
- Ultrasonic
- Electrical methods
- Head pressure
  - Bubbler tube system
  - Diaphragm bulb system

SCADA Systems 80

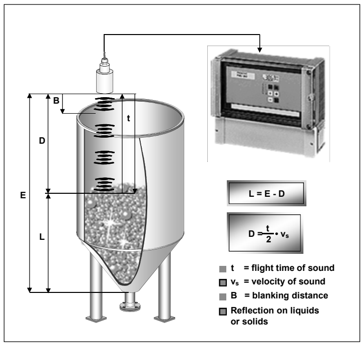
Ultrasonic Level Instruments

- Accurate and reliable
- Non-contacting
- Must eliminate interferences
  - Obstructions
  - Surface scum/ice/foam
  - Wind
  - Air temperature must be compensated



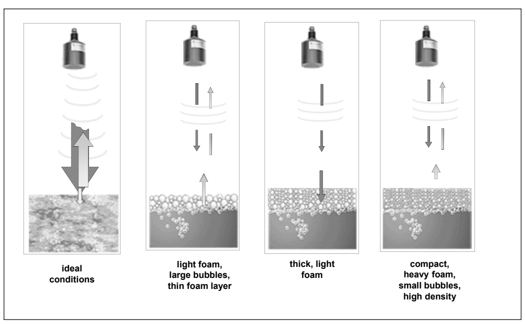
SCADA Systems 81

Ultrasonic Level Measuring Principle



SCADA Systems 82

Effects of Foam



SCADA Systems 83

Radar Level Instruments

- Uses electromagnetic wave propagation
- Depends on dielectric constant of material surface – water is fine
- Eliminates interference by wind, temperature, and <u>some</u> foam

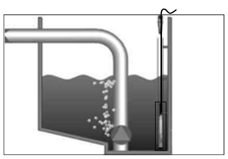
SCADA Systems

Types of Radar Level Instruments

- Free Space
  - Frequency Modulated Continuous Wave (FMCW)
  - Pulse Time-of-Flight (similar principle to ultrasonic)
- Guided Wave Radar (GWR)
  - “Radar on a rope” or Time Domain Reflectometry (TDR)
  - Time pulse along cable or rod

Submersible Pressure-Type Level Instruments

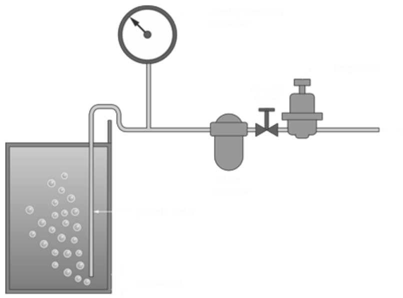
- Cheap – $500-1,000
- Accurate – 0.2%
- Works in tight spaces
- Must be secured in PS’s



Bubbler Level Measurement

- Components
  - Gas Compressor & Receiver Tank
  - Flow Regulator
  - Tube into Water
  - Pressure Instrument(s)
- Good for Tight Quarters
- Moving Parts Can Fail
- Widely Used

Bubbler Tube Level Measurement



Float Level Switches

- Classic pump control solution
- Used to be mercury switches, now mechanical switches
- Contacts open or close on rising or falling water
- Can be fouled in wet wells or damaged by scum layer

Ultrasonic Level Measurement

- Time of Flight Technology
- Short ultrasonic impulses emitted from transducer
- Bursts are created from electrical energy applied to piezeo electric crystal inside the transducer
- The transducer creates sound waves (mechanical energy)
- With longer measuring ranges a lower frequency and higher amplitude are needed to produce sound waves that can travel farther
- The longer the measuring range the larger the transducer must be

TEMPERATURE MEASUREMENT

SCADA Systems 91

Temperature Measurement

- Thermal bulb
- Thermocouple
- Resistance temperature detectors
- Thermistors

SCADA Systems 92

Temperature Measurement Uses

- Wastewater influent/effluent temperature
- Digester sludge temperature
- Raw/finished water temperature
- Motor bearing/winding temperature
- Air temperature for mass air flow measurement

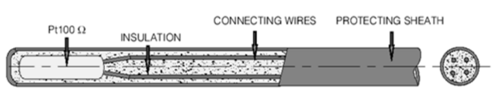
SCADA Systems 93

Temperature Sensors

- Thermometers
  - Liquid or capillary
  - Bimetallic
- RTDs
  - Pure metal - stable, accurate, repeatable
  - Most often used
- Thermocouples
  - Versatile
  - Good for temps > 800 C (engine exhaust)
- Thermistors
  - Like RTDs but made of ceramic or polymer
  - Most sensitive – low stability but fast response

Temperature Transmitters

- Need a measuring device (RTDs, etc.)
- Generally use a transmitter to give us a 4-20 mA signal
- Protect element with thermowell



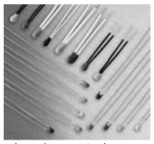
RTD – Resistance Temperature Detector

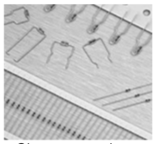
Thermocouple Applications

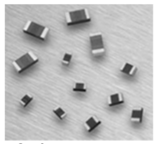
- Plastic injection molding machinery
- Food processing equipment
- Deicing
- Semiconductor processing
- Heat treating
- Medical equipment
- Industrial heat treating
- Packaging equipment

Thermistors
THERMal resISTORS

- •A thermistor is a type of resistor used to measure temperature changes, relying on the change in its resistance with changing temperature
- •Thermistor is a combination of the words thermal and resistor.


Leads, coated


Glass encased

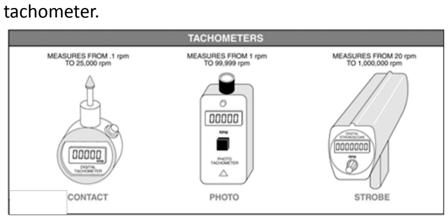

Surface mount

Speed Measurement

- Tachometer generations
- Noncontact frequency generators

Tachometers

- The speed of a rotating object can be measured using a contact tachometer, photo tachometer, or strobe tachometer.



Weight Measurement

- Weigh beam
- Hydraulic load cell
- Strain gauge

SCADA Systems 100

PROCESS ANALYZERS

SCADA Systems 101

Physical-Chemical Analyzers

- Ion-selective electrodes
  - Dissolved Oxygen
  - pH
  - Ammonia
  - ORP
- Group chemical analyzers
  - Total Chlorine
  - Total NO_x - Nitrate and Nitrite

SCADA Systems 102

pH/ORP Analyzers

- pH = negative log of H^+ concentration (acid/base)
- ORP = oxidation-reduction potential
- Two methods – differential and combination
  - Differential electrodes
    - Longer lasting
    - Replaceable parts
    - Resists poisoning

Typical ORP Probes

Several typical ORP probes. The one on the left is designed for high chlorine applications.

NOTE: Each has a thin glass bulb or membrane at the tip. These are VERY fragile.

pH/ORP Analyzer Uses

- Each process has its own favorable range
- Wastewater process contains many oxidation-reduction reactions
- BNR process changes pH and ORP

ORP Ranges for Processes

Biochemical Reaction	ORP, mV
Nitrification	+100 to +350
cBOD degradation with air (O_2)	+50 to +250
Denitrification	+50 to -50
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400

Residual Chlorine Analyzers

- "Chemist in a Box"
- Measures either free **or** combined chlorine
- Uses colorimetric measurement process
- Replace reagents monthly
- Latest amperometric devices use no reagents, but have limitations

Chlorine Measurement Uses

- Control chemical addition
- Ensure disinfection residual in distribution system
- Confirm dechlorination

Dissolved Oxygen Analyzers

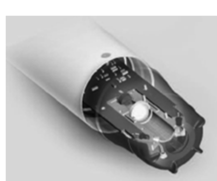
- Historically problems with membrane probes
- Zullig electrode probes solved some of these but had high O&M
- Improved membrane probes worked reasonably well
- New optical units are much better

DO Analyzer Uses

- DO is most important W/W process monitor
- Maintain aerobic conditions for biological treatment
- Automatically control aeration systems
  - Save energy
  - Save money

Optical Dissolved Oxygen Sensor

- End cap coated w/ luminescent material
- LED emits blue light
- Coating gets excited
- Emits red light
- Measure time to disappear
- More O_2 - “quenches” faster
- Red LED for reference



Optical DO is Not Perfect

- Optical device in wastewater
- Requires clean surface
- Wipe end cap as maintenance
- Use air blast cleaning - maybe

Chemical Analysis

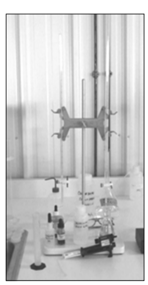
Test Kits and Colorimeters

Chemical Analysis - Alkalinity

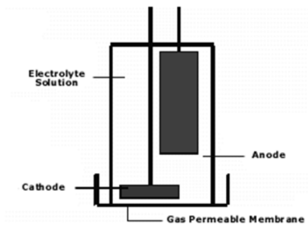
Titration Method

Titration with 0.02 N Sulfuric Acid
with methyl orange indicator end point (4.5 pH)

1 ml titrant equals 10 mg/L $CaCO_3$.



DO Probe



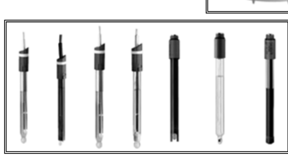
SCADA Systems 115

Measurements - pH

Both laboratory and field instruments readily available

SCADA Systems 116

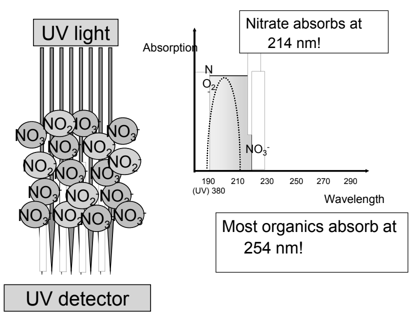
Measuring pH using ion selective electrodes (ISE)



Chemical Analysis – Ammonia, Nitrite and Nitrate

Ammonia:	colorimetric Nesslerization ion specific electrodes
Nitrite:	colorimetric
Nitrate:	reducing to nitrite with cadmium catalyst, measure nitrite. ion specific electrode

NO_3 Absorption measurement



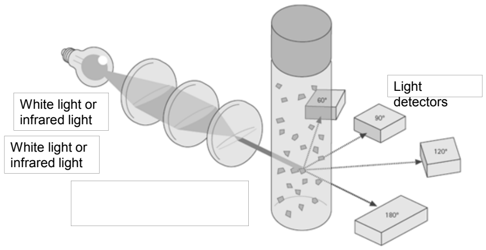
Solids Concentrations

- Nephelometers
- Turbidimeters
- Ultrasonic solids meters
- Sludge blanket sensors

MEASUREMENT OF POLLUTANTS IN WATER

Optical methods

Nephelometry



Ultrasonic sludge blanket level

Primary clarifiers / Thickeners

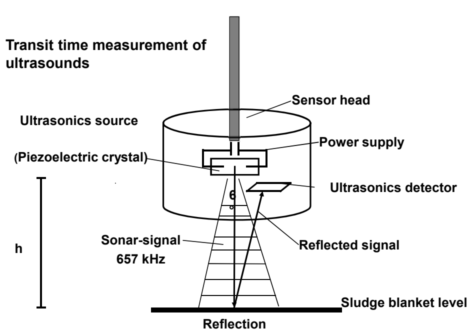
- Ultrasonic detection
- To moniter blanket level
- Prevent sludge overflow

Sand Filter

- Bed expansion during backwash

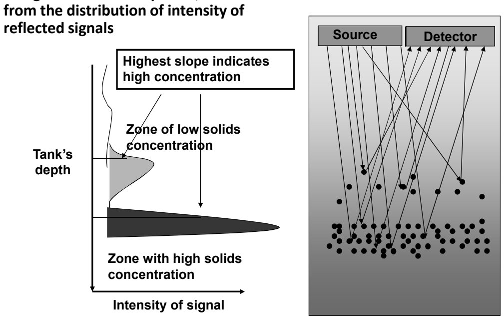
Measuring principle

- **Transit time measurement of ultrasounds**



Measuring principle

- **Sludge concentration profile, derived from the distribution of intensity of reflected signals**



SCADA Systems 124

Summary

Helpful Hints/Conclusions

SCADA Systems 125

Conclusions

- All SCADA systems are different in structures, but all have a common purpose – to supervise process control and collect data
- Communication is the key to successful SCADA systems
- Power and communication systems are vulnerable to hackers and need security protection

SCADA Systems 126

Questions?

Thank You

"Anyone who can solve the problems of water will be worthy of two Nobel prizes – one for peace and one for science."

- John F. Kennedy

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