Instrumentation, Control, and Automation (ICA) in Wastewater Treatment
Wastewater treatment, how it began...

First sewage systems in cities of ancient civilizations:

- 6000 B.C. Ephesus (today Turkey)
- 3000 B.C., Mesopotamia (today area of Turkey, Syria, Iraq)
Romans 400 B.C. improved sewage systems

„Cloaca maxima“

image source: http://de.wikipedia.org

waste was mainly dumped untreated in rivers/lakes/sea
All knowledge was lost during the “dark” middle age

(Schrader, 2003)
“Unlimited self-purification potential of the environment”

Epidemics (e.g. Cholera) triggered start of building sewage systems in big cities

- Berlin: 1830
- London: 1830
- Hamburg: 1842
Sewage farm Berlin 1900

Trickling waste water on irrigation fields
Drivers

• Meet regulatory requirements, e.g. flow, composited samples
• Improve process performance – BNR requires effective DO control (enough but not too much)
• Record data and create reports – collect, access, store
• Reduce:
  – Operating costs, e.g. chemicals, energy, labor
  – Capital costs
    • ICA has increased capacity by 10% to 30% and is predicted to reduce total system investment by another 20% to 50%
  – Risks, e.g. violations, odors
• Get good sleep
Enablers

- Computing power - virtually free
- Process Knowledge – desktop WWTP simulators
- Actuators – precise control, e.g. VFD
- **Digital technology** – sensors, controllers, communications, actuators
- **Sensors** – Old technologies evolve / new technologies arrive
Digital Sensors w/ signal processing

• Calibration stored in the sensor – calibrate in lab, take to field
• Self-diagnostics
• Model calculations, e.g. compensation
Digital Controllers (a.k.a. analyzers/transmitters)

- Multiple channels
- Plug and play
- A field computer to display, chart, and combine measurements
Digital Communications

• High signal stability → convenient location of sensors / transmitters

• Less cabling, e.g. point-to-point connections not required, wireless

• 2-way communications
Single Measurement Systems (analog) compared to digital Sensor Network System

11 x power cable
11 x comm cable

1 x power cable
1 x com cable
Connectivity

- Serial – RS-422 or RS-485
  - Common, inexpensive
  - Slow, costly to install for large networks
- Fieldbus – Profibus
  - Less wiring, better signal resolution
  - System-specific, support
- Ethernet – (copper, fiber optic, WiFi)
  - Universal, inexpensive, fast, web-enabled
  - Security, noise, connectors not industrial-grade
Wireless Communication

1.2.3 Application examples

**Fig. 1-4** Example 1: Basin with rotating scraper bridge

**Fig. 1-5** Example 2: Basin with rotating scraper bridge
Sensors - Optical measurements

- D.O., Nitrate, TSS, BOD/COD
- Direct measurement
- No reagents
- Multiple detectors per sensor
- Stable – less frequent calibration
Dissolved Oxygen – Optical Measurement

- Detector
- Filter
- Optical insulation

Reference channel
Measuring channel
Gas selective membrane with fluorescence dye
LED Light Source

Reference LED

Excitation LED

Reference channel

Measuring channel
**Step 1:** Excitation flash

**Step 2:** Fluorescence duration and intensity depend on $O_2$ concentration

**O$_2$ Detection**
May 18, 2012: Luminescence approved for CWA analysis and sampling

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>46. Oxygen, dissolved, mg/L.</td>
<td>Electrode Luminescence Based Sensor.</td>
<td>4500–O G–2001</td>
<td>D888–09 (B)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D888–09 (C)</td>
</tr>
</tbody>
</table>
## Online Optical DO Market

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>$t_{90}$, Sensor Cap Warranty, cleaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>YSI</td>
<td>FDO (IQ SensorNet)</td>
<td>150 s ; 2 yrs. ; manual w/air cleaning option</td>
</tr>
<tr>
<td>Hach</td>
<td>LDO Model 2</td>
<td>40 s ; 2 yrs. ; manual</td>
</tr>
<tr>
<td>Endress &amp; Hauser</td>
<td>Oxymax</td>
<td>60 s ; &gt; 2 yrs. (Lifetime) ; manual w/air cleaning option</td>
</tr>
<tr>
<td>Insight IG</td>
<td>Model 1000</td>
<td>60 s ($t_{95}$) ; ?? ; manual</td>
</tr>
<tr>
<td>ATI</td>
<td>Q45D</td>
<td>150 s ; ?? ; built-in air cleaning</td>
</tr>
</tbody>
</table>
Suspended Solids – Optical measurement

Optical measuring principle:
Intensity of scattered light

particles: absorb, reflect, scatter light
Total Suspended Solids

Scattered light measurement at < 90° angle

or back scatter

Angle depends on manufacturer
Measurements at 3 different angles

- **90° (DIN, ISO, US EPA)**
- **60°**
- **180° (back scatter)**
## Online TSS Market

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Optics, cleaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>YSI</td>
<td>ViSolid (IQ SensorNet)</td>
<td>60°, 180°, Ultrasonic + air cleaning option</td>
</tr>
<tr>
<td>Hach</td>
<td>SOLITAX</td>
<td>90°, 140° + 2-beam pulsed light, built-in wiper</td>
</tr>
<tr>
<td>Endress &amp; Hauser</td>
<td>Turbimax</td>
<td>90°, 135° + 4-beam pulsed light, air clean option</td>
</tr>
<tr>
<td>Insight IG</td>
<td>Model 1500</td>
<td>??, jet clean option</td>
</tr>
</tbody>
</table>
Spectrometry – BOD/COD, nitrate

Waterproof, miniaturized UVVIS spectrophotometer:

Measuring of total spectrum from ultraviolet (UV) to visible (VIS) light

200 nm  720 nm
Absorbance depends on:

- Concentration of the sample
- Optical path length
- Transmission characteristics of the sample

Light gets absorbed/weakened by a sample.
Type of parameter and concentration

Most organic compounds absorb UV-light

Example of a wastewater UVVIS-spectrum

[spectrum fingerprint = qualitative information]

[spectrum integral = quantitative information]
Spectra differ…
from process stage to process stage
from application to application, from site to site
Calculating the concentration

Models are stored in the instruments based on correlations with reference measurements.

Measurement procedure:
1. Recording spectra
2. Calculation of concentrations according to algorithms

mathematics \[\text{COD, TOC, BOD, NO}_3\text{-N, TSS}\] \(\text{mg/l}\)
# Online UV-Vis Market

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Optics, cleaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>YSI</td>
<td>Carbovis (IQ SensorNet)</td>
<td>200-720 nm, Ultrasonic + air cleaning option</td>
</tr>
<tr>
<td>s::can</td>
<td>Spectrolyzer</td>
<td>220-720 nm, built-in air cleaning</td>
</tr>
</tbody>
</table>
Highly selective for Ammonium / Nitrate

\[ \Delta E = mV \rightarrow \text{calculation of mg/l according to Nernst Equation} \]

ISE technology improvements

Constant potential, no interferences
Interference w/ competing ions

For 0.1 mg/l NH₄-N:

<table>
<thead>
<tr>
<th>Potassium contents</th>
<th>Ammonium value increased by approx.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mg/l</td>
<td>0.7 mg/l</td>
</tr>
<tr>
<td>50 mg/l</td>
<td>3.4 mg/l</td>
</tr>
</tbody>
</table>

Compensation needed:
- ammonium - potassium
- nitrate - chloride
**NH₄-N: Influence by pH**

Ammonium-Ammonia-Equilibrium

\[ \text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O} \]

**Compensation:**

- pH < 8.5 \(\rightarrow\) not needed
- pH > 8.5 \(\rightarrow\) needed
ISE System: Influence of Matrix effect

Matrix effect caused by all free ions in waste water

Responsible for change of physical/chemical character of ions (e.g. ionic strength)

- Ions do not act according to their concentration
- mV signal will be influenced
- erroneous measurement

Compensation of matrix effect

- Matrix adjustment = in situ 1-pt calibration
- Matrix effect is unique from site to site
## Online Nutrient ISE Market

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>$t_{90}$, Electrode Warranty, pH range</th>
</tr>
</thead>
<tbody>
<tr>
<td>YSI</td>
<td>VARiON (IQ SensorNet)</td>
<td>&lt; 20 s ($t_{95}$)</td>
</tr>
<tr>
<td>Hach</td>
<td>AN ISE sc</td>
<td>&lt; 3 min, 12 months (typ. Lifetime), 5 - 9</td>
</tr>
<tr>
<td>Endress &amp; Hauser</td>
<td>ISEmax</td>
<td>&lt; 2 min., 6 months (typ. Lifetime), 4 – 10 (incl. pH compensation)</td>
</tr>
</tbody>
</table>
Questions when planning a monitoring and control system.

- What do I want to measure?
- Where do I want the sensor located?
- What type of communication signals and sensor outputs do I need?

6 x mA signal

- pH
- O₂
- TSS
- NH₄-N
- Turbidity
Requirements for automation of Process Control

• Instrumentation – sensors, analyzer, etc.
• Monitoring - data acquisition & reporting
• Control – how the plant is operated
• Commitment to continuous improvement
Basic Control Terminology

• Open Loop control (sequencing) – system where information about the controlled variable is not used (*no measurement*) to manipulate any of the process variables, e.g. operation based on timer.

• Closed Loop control (feedback) – system where the controlled variable (D.O.) is *measured* and the measurement used to manipulate one of the process variables (air flow).

• Feedforward control – system where the process variable (air flow) is manipulated in anticipation of a disturbance so that there is no change in the controlled variable. Requires *measurements* and a model.
Levels of Automation

• Level 1 – manual adjustment based on manual sampling.
• Level 2 – manual adjustment based on online measurements
• Level 3 – closed-loop control based on online measurements
• Level 4 – advanced, with feedforward control
Closed loop control – D.O. cascade control
Closed loop control – ammonium-based D.O. control

Example: if $\text{NH}_4\text{-N} < 1.5$ mg/L then D.O. setpoint = 0.5 mg/L

if $\text{NH}_4\text{-N} > 1.5$ mg/L then D.O. setpoint = 2.0 mg/L
Constraints

• Legislation – not adapted for dynamic requirements of receiving stream
• Training – Process vs. E,I,&C; Engineers vs. Operations.
• Economy – Automation only seen as a cost
• Measuring and actuating devices – reliability, economy, controllability
• Plant constraints – big safety margins built-in
• Software -
Robert C. Smith, P.E., BCEE, Ph.D.
Applications Engineer - Waste Water
1725 Brannum Ln.
Yellow Springs, OH 45387
O: 937.767.7241 x461
rsmith@ysi.com
www.ysi.com