Using an Imaging Particle Analyzer (FlowCAM®) to Detect, Identify, and Enumerate Taste & Odor and other Nuisance Algae

Harry Nelson
Fluid Imaging Technologies
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Outline

- Algae Tutorial
  - Algae – Good Algae Bad Algae
  - Types
  - Population Dynamics
- Taste & Odor in Drinking Water
  - What it is?
  - T&O Causing Plankton
- Monitoring Plankton & Controlling Blooms
  - AWWA Webcasts- Algae - Source to Treatment, Parts 1 & 2
- Automated Monitoring & Detection Method
  - Fluid Imaging Technologies & FlowCAM®
  - Case Study – Westminster, CO
  - AWWA TEC Taste & Odor Committee Study
- References & Resources
Photosynthesis
Extract & Sequester Carbon
“Primary Producers”
Base of Aquatic Food Web

- phytoplankton (dinoflagellates, diatoms)
- zooplankton (shrimp, copepods, pteropods)
- filterers (lantern fish, amonipods, ocean sunfish)
- predators (tuna, mackerel, lancet fish)
- smaller sharks
- large sharks
- top predators (a shark)

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Algae – So What?

- Produce Taste & Odors
- Blooms produce slime/mats, fouling screens, filters and pumps
- Can change aquatic system dynamics
  - Can alter pH, alkalinity, color, hardness, turbidity, TOC
Plankton (Algae)
Phytoplankton (Free Floating)

Ceratium

Microcystis

Dinobryon

Pediastrum

Anabaena

Synura
Major Phytoplankton Taxa

- **Chrysophytes** (Golden Brown Algae)
- **Chlorophytes** (Green algae)
- **Pyrrophytes** (Dinoflagellates)
- **Cyanophytes** (Blue-Green Algae)
- **Bacillariophytes** (Diatoms)
Zooplankton
Periphyton Plankton

Attached to Substrate
Taste & Odor Causing Algae...

Ceratium (U.S. EPA)

Tabellaria (Seattle Water Dist)

Aulacoseira (Waco Water Dist)

Anabaena (Lake Champlain)

Microcystis (Lake Champlain)

Mallomonas (Cravins Cove, VA)
...Taste & Odor Causing Algae

Asterionella  (San Francisco Public Utilities Commission)

Volvox (MWRA)

Pediastrum (Carvins Cove, VA)

Aphanizomenon  (Lake Champlain)
Filter Fouling Causing Algae

Deer Creek Reservoir (Utah)

Didymosphenia geminata (Chile)

Tabellaria (San Francisco PUC)

Melosira (Schuylkill)
Other Nuisance Algae

- Anacystis
- Staurastrum
- Uroglenopis
- Synedra
- Synura
- Pandorina
- Chlorella
- Hydrodictyon
- Oscillatoria
- Navicula
- Cytocella
- Trachelomonas
Taste & Odor

- Geosmin
  - Organic compound ("Earth smell")
- MIB (2-methylisoborneol)

Both produced by several classes of microbes either when living or when decomposing
Monitoring for T&O Algae

- Metabolite Testing
- Flavor Profile Analysis (FPA)
- Microscopy Enumeration

Limitations -
- Results after-the-fact
- Results not real-time
- Labor Intensive
  - Analyze few samples periodically
  - Inconsistent interpretation
Taste and Odor Production

- Presence of taste/odor compounds in drinking water leads to complaints and undermines consumer confidence

- Most common cyanobacterial T/O compounds include geosmin, MIB and sulfur compounds

- T/O compounds can be produced by planktonic and benthic species; can impart off-flavor to fish

- Removal of T/O compounds is expensive (ozone, granular activated carbon)
Biological Sources: Multiple

- Many species
- Different species produce different odour compounds
  - algae / cyanobacteria
  - bacteria, moulds/fungi, other
  - biofilms (substrates & plants; walls, filters, pipes etc.)
Cyanobacteria Blooms

- Aesthetically unpleasant; negative impact on recreation
- Reduced transparency may negatively impact submerged plants
- Impaired food web dynamics; decreased biodiversity
- Potential oxygen depletion that may result in fish kills
- Blooms in source water may result in filter clogging
Algae Dynamics

- Dynamic Growth
  - Highly dependent of local environmental conditions
    - Nutrient load, weather conditions, ambient light, temperature
  - Growth often predictable
    - Seasonal
    - Depending on conditions, can be exponential

![Graph showing algae growth phases](image.png)

*Figure 1. Algae Growth Phases*
Depth vs. Time Contours of Chlorophyll a at Intake Site

For water treatment plants that can alter the depth of the intake, provides real-time information about the “best” depth.
Characterize Algae to be Removed

- Identify algae type present in source
- Understand seasonal variations
- The more data collected the more accurate the picture
Value of Algal Quantitation: Operational Issues

- Early warning of T & O, turbidity
- Clogging of pipes, screens, filters
- Fluctuations in alkalinity, pH, DO
- Determining the algal removal efficiency of physical and chemical drinking water treatment processes
Develop Multi Barrier Approach

Establish Goals, Measure & Evaluate

- **Source/Res Mgmt**  
  Most Effective – Limit nutrients, etc.
- **Physical pretreatment**  
  Filters, River Bank Filtration…
- **Physical removal**  
  Coagulation, flocculation, lyse cells
- **Oxidation**  
  Potassium permaganate, ClO₂, Ozone
- **Biological treatment**  
  Activated Charcoal
- **Adsorption**  
  Powder Activated Carbon
Fluid Imaging Technologies

- Founded – 1999
- Maine, USA (BLOS)
- **Flow Cytometer And Microscope (FlowCAM)**
- 300+ FlowCAMs sold

**Product Development**

- Depth-of-Focus Technology
- VisualSpreadsheet 2.0, 2.4, 3.0
- Submersible FlowCAM

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An imaging-in-flow system for automated analysis of marine microplankton

Christian K. Sieracki*, Michael E. Sieracki, Charles S. Yentsch

Bieloff Laboratory for Ocean Sciences, PO Box 479 McKown Point, West Boothbay Harbor, Maine 04535, USA

ABSTRACT: Present automated systems for counting and measuring marine plankton include flow cytometers and in situ plankton video recorders. Neither of these approaches are optimized for the microplankton cells which range in size from 20 to 200 μm and can be less than 10 μm. We describe here an instrument designed for rapid counting, imaging and measuring of individual cells and particles in the microplankton size range from cultures and natural populations. It uses a unique optical system to extend the depth of focus of the imaging lens, allowing a sample strain flow rate of 1 ml min⁻¹. The instrument stores a digital image of each particle along with real-time fluorescence and size measurements. An interactive cytoplot links a dot plot of the size and fluorescence data to the stored cell images, allowing rapid characterisation of populations. We have tested the system on live phytoplankton cultures and standard nutrient solutions, proving the system counting and sizing accuracy and precision. The system provides images and size distributions for cultures or natural marine samples. It has been used successfully at sea to continuously monitor particles while underway. It may prove useful in studies of plankton community structure, ocean optics and monitoring for harmful algal species.

KEY WORDS: Imaging - Flow cytometer - Microplankton - Binary optical element - Cell counting - Cell sizing - Natural populations - High rate - Cultures
FlowCAM Models

Bench Top

Portable
FlowCAM Models

Submersible FlowCAM
FlowCAM “Standard” Architecture

- Sample
- Syringe Pump
- Computer
- Flow Chamber
- Flash LED
- Scatter detector
- Laser fan
- Objective
- Dichroic mirror
- Cylindrical lens
- Excitation filter
- Emission filter
- High resolution Firewire camera
- 575 nm band pass filter (exchangeable)
- 600 nm dichroic mirror
- 660 nm Longpass filter
- Fluorescence detector (PMT) 550-600 nm Channel 2
- Fluorescence detector (PMT) 600-700 nm Channel 1
FlowCAM Specifications

- **Particle sizes** –
  - Imaging – 3µm to 2mm

- **Objectives** – 20x, 10x, 4x, 2x

- **Flow Cell** – 50 µm to 2 mm

- **Processing Capability** –
  - Flow - .1 ml/min to 12 ml/min
  - Density - 500,000+ particles/ml (AutoImaging)
FlowCAM Features

- Continuous Imaging (1-20 frames/sec)
- Can be used in laboratory or *in-situ*
- Size *and* shape info for all particles/cells
- Wide particle size range (3 µm to 2 mm)
- Fluorescence/Scatter Detection/Auto Triggering
- Image Recognition
- Automated Identification & Classification
FlowCAM Uses

- Algae Counts
- Automatic Taxonomic Identification, Classification, Enumeration and Measurement
- Uses also in Wastewater Treatment
- Particle Removal Evaluation
- Training & Education
FlowCAM Users

- Mass Water Resource Auth (2)
- New York City DEP (2)
- Mohawk Valley Water Auth, NY
- Kansas City, MO
- Veolia Water (Indianapolis, IN)
- Colorado Springs, CO
- Westminster, CO
- Fort Collins, CO
- Fairfax, VA
- Tampa, FL
- Hartford, CT
- Fairfax, VA
- Bloomington, IN
- Tulsa, OK
- Cheyenne, WY
- U.S. EPA (2)
- Siemens (Australia)
- Singapore Public Utilities Board
- Institute of HydroEcology (China)
- Chongqing Inst Env Science, China (2)
FlowCAM Benefits

- Rapid algal/particle analysis
- For use in the field or the lab
- Objective analysis - *Not* dependent on skill set or experience of user
- Historical records of sample data *with* images
- Useful as a training tool

“With the automated instrumentation, a single technician can do in minutes what used to take days with a microscope. And we can be more confident in the data when taking action”

Betsy Reilly, MWRA
Early Warning Monitoring for T&O Algae

“BEST LOOKOUT WE’VE EVER HAD..!”

Kelly Kline, Water Quality Analyst, Westminster, CO
What we look at?

- Algae Count/Taste and Odor
- Algae/Biovolume
- Total Particle Count (5um-300um).
- Particles 5-25 um (small stuff; heterotrophic organisms like ciliates, protozoan, and autotrophs like algae).
- Particles 25um-300um (algae, ciliates and some zooplankton).
- Organisms >300um (zooplankton, algae).
What we do with the information?

Lake Report 4/11/11

- Increase in algae by 50% since last sampling.
- Increase in algae biovolume by 32%.
- Dinobryon population has declined by 24%.
- Zooplankton numbers, particularly large grazers have increase by 25%.

Algae is responding to precipitation event. No sign of harmful algae species.

- Bullet reports to stakeholders with algae and zooplankton abundance (< 24hrs).
- Data added to database for trending analysis, forecasting, and graphing.
- Archived (Historical perspectives).
Know Your Lake or Reservoir

• Trending analysis (Is this year better or worse than past years?)
• Cause and effects (If we get x-amount of rain, how does the algae respond)?
• Ecological Assessment (Are the zooplankton at a level that has controlled algae in the past? Or Why are all the zooplankton gone?)
• When is your lake the most vulnerable? (Different times of the year are more vulnerable to nutrient inputs than other times).
• Early detection sampling will alert you for when something is going wrong!
If you don’t measure it, you can’t manage it.
This study investigated the link between taste and odor producing organisms and the compounds they produce. We (Arizona State University) monitored three water systems over a two month period. The assessment of the samples collected included the examination of water samples to determine the density of filamentous cyanobacteria as well as the chemical analyses of samples to measure MIB and geosmin concentrations.

Salt River

Saguaro Lake Reservoir
Cyanobacteria filaments were quantified using two methods:

1) epifluorescence microscopy and
2) automated particle counting of water samples using a FlowCAM®

This side-by-side comparison was intended to assess how the availability of automated technologies may contribute to simplifying and speeding up the process of monitoring water supplies by agencies and utilities.
Our results indicate...a definable relationship between cyanobacteria and concentrations of these nuisance compounds. In two of the three primary sampling locations we noted that increases in MIB levels were observed after the cyanobacteria bloom began to decline. This suggests that the release of MIB may result from the stress and/or decomposition of these algal species.
Resources

- Control of Odorous Metabolites (AWWArf ID and AWWArf #2614)
- Feasibility Study for Early Warning Systems for Algae-induced Tastes & Odors (AWWA TEC Taste & Odor Committee)
- AWWA Webcasts
  - Algae - Source to Treatment, Parts 1 & 2
  - Impacts of Algae & Algal Toxins on Water Treatment Plants
  - Fluid Imaging Technologies, Booth 1349
- AWWA Bookstore
  - AWWA Manual – Algae: Source to Treatment (M57)
  - Practical T&O Methods for Routine Operations: Decision Tree
  - T&O: An Operator’s Toolbox
  - Algae Detection and Removal: Strategies for Drinking Water Plants
  - Early Warning Management of Surface Water T&O Events
  - Ozone-Enhanced Biofiltration for Geosmin and MIB Removal
  - Identification of Algae in Water Samples CD-ROM
References

- “Monitoring and Control of Nuisance Algae”
  Dr. Betsy Reilly, MWRA

- “Early Warning Monitoring for T&O Algae”
  Kelly Kline, Water Quality Analyst, Westminster, CO

- AWWA Webcasts - Algae - Source to Treatment, Parts 1 & 2

- *Opflow* Vol. 32, No. 6 June 2006 “Multiple Barriers for a Smelly Situation”

- *Opflow* Vol. 33, No. 4 April 2007 “Getting to Know Freshwater Algae”

Thank You!

Harry Nelson
harry@fluidimaging.com

Jonathan Dawson
jonathan.dawson@fluidimaging.com

207-846-6100