Innovative Sensor Design for Prevention of Bio-fouling

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***Abstract*— Sensors used for in-situ water monitoring are subject to biological fouling, siltation, and scaling [3]. Fouling causes inaccurate measurements. Sensor maintenance is resource intensive. Techniques that lengthen the maintenance interval will improve measurements and conserve resources.**

Materials, mechanical apparatus and biocides were evaluated to determine effectiveness in improving measurements and reducing maintenance. Test panels were placed in various locations and evaluated.

Mechanical wipers and shutters were designed and tested. Photographs taken at intervals were used to estimate stages of fouling and the effectiveness of various preventive techniques. Campbell Scientific has developed a new sensor design incorporating several features that improve on conventional designs.

Keywords-turbidity; fouling; biocide

I. Introduction

Fouling of water quality sensors is a primary cause of measurement error. Biological fouling, siltation, and scaling are the principal causes of fouling. Manual sensor maintenance at a frequency required for accurate measurement is prohibitive in many installations, particularly in the marine environment. Several mechanical and chemical schemes have been proposed to discourage biological agents from establishing in sensors. Until recently, effective uses of these schemes in an integrated sensor have been lacking. Mechanical means of wiping sensing elements clean of silt and scaling have met with limited success.

II. Bio-fouling Test Panels

Test panels featuring samples of various materials were placed in coastal waters in Washington State and Florida, and fresh water at a catfish farm in Mississippi.

A. *Washington State Test Panel Results*

Tables I through III list images and comments concerning several bio-deterrent materials that were tested in the coastal waters of Washington State.

TABLE I. Polymer Deterrents, Washington State

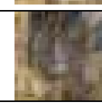
Polymer	Before	After 120 days	Effectiveness
Anti-microbial delrin			Moderate
Delrin (acetal copolymer)			Poor

TABLE II. Metallic Deterrents, Washington State

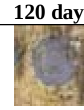
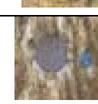
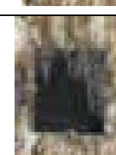
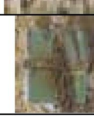
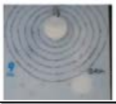
Metal	Before	After 120 days	Effectiveness
Sterling Silver (92.5% Ag / 7.5% Cu)			Moderate
1954 silver coin (% Ag / Cu)			Good
Silver (99.99% Ag)			Moderate
90/10 Copper (90% Cu / 10% Ni)			Good
Free Machining Brass			Moderate

TABLE III. CHEMICAL DETERRENTS, WASHINGTON STATE

Chemical	Before	After 120 days	Effectiveness
Bromide biocide			Good
Cayenne pepper biocide			Moderate

B. *Florida Test Panel Results*

Tables IV through VI list images and comments concerning several bio-deterrent materials that were tested in the coastal waters of Florida.

TABLE IV. POLYMER DETERRENTS, FLORIDA

Polymer	Before	After 56 days	Effectiveness
Anti-microbial delrin			Poor
Delrin (acetal copolymer)			Poor

TABLE V. METALLIC DETERRENTS, FLORIDA

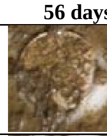
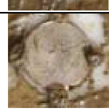
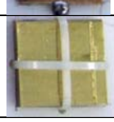
Metal	Before	After 56 days	Effectiveness
Sterling Silver (92.5% Ag / 7.5% Cu)			Poor
1907 silver coin (90% Ag / 10 Cu)			Good
Titanium Commercial pure grade 2			Poor
90/10 Copper (90% Cu / 10% Ni)			Good
Machining brass			Moderate

TABLE VI. CHEMICAL DETERRENTS, FLORIDA

Chemical	Before	After 120 days	Effectiveness
Bromide biocide			Good
Cayenne pepper biocide			Poor

C. *Mississippi Test Panel Results*

Tables VII through IX list images and comments concerning several bio-deterrent materials that were tested in a fresh water catfish aquaculture installation in Mississippi.

TABLE VII. POLYMER DETERRENTS, MISSISSIPPI

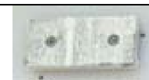
Polymer	Before	After 86 days	Effectiveness
Anti-microbial delrin			Poor
Delrin (acetal copolymer)			Poor

TABLE VIII. METALLIC DETERRENTS, MISSISSIPPI

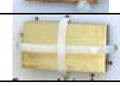
Metal	Before	After 86 days	Effectiveness
Sterling Silver (92.5% Ag / 7.5% Cu)			Poor
Silver coin (90% Ag / 10%Cu)			Moderate
Silver (99.99% Ag)			Poor
90/10 Copper (90% Cu / 10% Ni)			Good
Free Machining Brass			Moderate

TABLE IX. CHEMICAL DETERRENTS, MISSISSIPPI

Chemical	Before	After 86 days	Effectiveness
Bromide biocide			Poor
Cayenne pepper biocide			Poor

III. PROTOTYPE SENSOR

A prototype optical turbidity sensor was chosen to test a new bio-resistive design as this measurement is particularly susceptible to bio-fouling. Based on the test panels and a search of the literature, a prototype was designed that incorporates new shutter and wiper designs, biocides, and removable sleeves.

Figure 1. Prototype sensor design

A. Shutter

The shutter shown in Fig. 2 reduces biological activity by limiting biological organisms and sunlight from reaching critical sensors surfaces [1]. The shutter resting upon the sensor surface leaves no space for growth.

Figure 2. Shutter closed over sensor optics

B. Wiper

The wiper shown in Fig. 3 is able to displace biological or other material that starts to form under a shutter [2].

Figure 3. Wiper displaces fouling as it pushes across optics

C. Biocide

A chemical biocide slowly leaching over the sensor surface prevents attachment of organisms [1]. Unabated, these organisms lead to more biological growth on the sensor. The refillable chamber shown in Fig. 4 allows for a biocide such as bromide, cayenne pepper, or copper braid to be placed in the prototype.

Figure 4. Refillable biocide chamber

D. Bio-deterent Metals

Materials such as copper and "coin" silver are known biocides [4][5]. Use of these materials in the sensor body will slow biological growth.

Figure 5. Copper sleeve to prevent fouling of sensor body

E. Removable Disposable Sleeves

Shown in Fig. 6, easily removable disposable sleeves allow for quick cleaning of the sensor body at calibration checks. Beyond keeping the sensor optics clean, as the sensor body becomes overgrown with biological activity, the sensor is negatively influenced.

Figure 6. Plastic sleeve provides easy cleaning

IV. FIELD TESTING

A. Baseline Sensor

A commercially established back scatter sensor with no anti-fouling design was deployed alongside the prototype to provide a baseline comparison. The prototype received no maintenance. The baseline sensor was cleaned at regular intervals to provided data showing that cleaned baseline sensors come back into agreement with the prototype. Figs. 7 and 8 show the before and after effects of sensor cleaning.

Figure 7. Baseline sensor, day 36 before cleaning

Figure 8. Baseline sensor, day 36 after manual cleaning

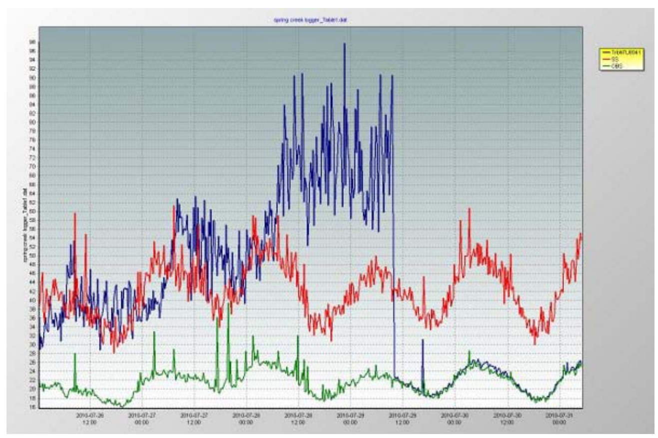


Figure 9. Baseline sensor back and side scatter

Fig. 9 shows the baseline sensor (blue) drifting higher as fouling increases. The baseline sensor was cleaned on July 29th, at which time its measurements again agreed with the measurements of the prototype sensor.

B. Locations of Field Tests

Tests were conducted in the coastal waters of Georgia's Skidaway Island and the fresh waters of Utah's Cache Valley under a variety of environmental conditions. Corroborating results were obtained from installations in Australia and Brazil.

1) Skidaway Island, GA

Skidaway Island experiences a semidiurnal tide. Figs. 10 through Fig. 15 show the progression of biological growth on the prototype, but the sensing element remains free of fouling.

Figure 10. Day 13, shutter open (GA)

Figure 11. Day 36, shutter open (GA)

Figure 12. Day 103, shutter open (GA)

Figure 13. Day 103, shutter closed (GA)

Figure 14. Day 119, shutter open (GA)

Figure 15. Day 119, shutter closed (GA)

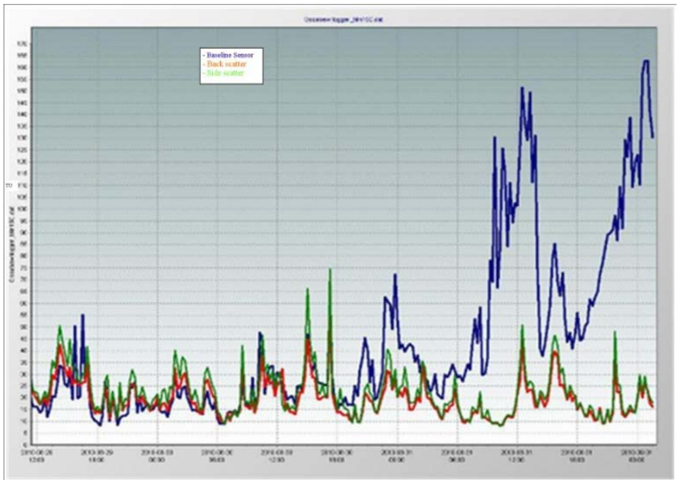


Figure 16. Effects of Bio-fouling on Backscatter Turbidity Sensors (GA)

Fig. 16 shows the baseline sensor without anti-fouling technology (blue) drifting higher after several days. After manually cleaning, the baseline sensor again tracks with the prototype sensors.

2) Cache Valley, UT

Spring Creek is a mountain valley stream in Cache Valley with heavy agricultural runoff.

TABLE X. PROGRESSION OF BIO-FOULING ON PROTOTYPE SENSOR (UT)

Days since deployment	Prototype appearance
18	
32	
47	
55	

TABLE XI. BIO-FOULING ON BASELINE SENSOR AS A FUNCTION OF WATER TEMPERATURE (UT)

Days since cleaning	Average water temperature, °C	Baseline sensor appearance
11	13.5°	
7	20.5°	
8	21°	
11	19.5°	

Table X shows that essentially no bio-fouling occurred at the sensing element during its 6+ month maintenance free deployment. Table XI shows bio-fouling on the baseline sensor despite regular cleaning. The baseline sensor actually began showing effects of bio-fouling only three days after deployment.

V. REMOVABLE SLEEVES

The problem of cleaning the sensor body after long periods of deployment was addressed by deploying removable sleeves.

A. Plastic Sleeves

Figure 17. Process of removing a disposable plastic sleeve

Fig. 17 is a series of photos illustrating quick and easy removal of a disposable plastic sleeve at a Savannah, GA site. Where water quality measurements are made in open waters, the existence of an active biological community near the sensor has been observed to degrade measurements, even if sensor windows are clean. Keeping clean sleeves on the sensor at some regular maintenance interval will likely help measurements be more representative of the natural environment.

B. Copper sleeves

As an option to the disposable plastic sleeve, a copper sleeve was tested to see if maintenance visits could be further reduced.

Figure 18. Removable copper sleeve

Figure 19. Copper sleeve after 137 days at Skidaway Georgia site

Figure 20. Plastic sleeve after 137 days at Skidaway

Fig. 18 shows a copper sleeve. Fig. 19 shows a copper sleeve 137 days after deployment. Fig. 20 shows significantly more biological growth on a plastic sleeve after 137 days.

VI. SHUTTER/WIPER MATERIAL

The shutter/wiper is critical to the design of the anti-fouling system. Copper does not have suitable machining properties, so Delran polymer and brass sliders were tested.

Figure 21. Delrin after 137 days at Skidaway

Figure 22. Brass after 137 days at Skidaway

The Delrin shutter/wiper has growth on the tip (Fig. 21), whereas the brass remains relatively clean (Fig. 22). The growth on the Delrin shutter hung in the view of the back scatter optics resulting in measurement error. A sensor with a brass shutter performed significantly better.

VII. OPTICS SCRATCHING

The prototype sensor uses sapphire windows to limit scratching of the optics in installations where sand and grit may become trapped under the wiper as it moves across the windows. In laboratory testing, a prototype sensor was cycled over 621,000 times (17+ years equivalent at 4 cycles/hr) with 500 mg/l of Kaolinite, 500 mg/l of silica powder, and 4 g/l of 0.005 to 0.008 Anna Maria Island (FL) sand. After cycling, no scratches were visible on the prisms.

VIII. CONCLUSIONS

A combination of anti-fouling techniques used in a new sensor design increased the quality of turbidity data in long term deployments. Data show drift in an older sensor design not equipped with anti-fouling features. Data confirm that the new design delivers quality data over the long term without maintenance. The new sensor design significantly reduces the effects of biological fouling, siltation, and scaling. The time interval between maintenance visits was significantly increased, which will result in decreased maintenance costs in these types of deployments.

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