New alternatives to online DPD for TRO measurement in ballast water.

WHITE PAPER · BALLAST WATER

How direct pipe insertion amperometric sensors eliminate compliance risks, reagent costs, and sampling delays in Ballast Water Management Systems — with third-party ACT evaluation data and 2,000+ vessel installations since 2014.

AUTHOR Michael Silveri
Founder, Halogen Systems, Inc.

APPLICATION Ballast Water Management Systems (BWMS)

PUBLISHED April 2026

REV 2.0

EXECUTIVE SUMMARY

Direct measurement. No reagents. No sampling lines.

The DPI (Direct Pipe Insertion) Amperometric sensor is a new alternative to online DPD instruments for TRO measurement in Ballast Water Management Systems. It eliminates sampling lines, reagents, filters, and pumps — while providing faster response, superior performance in muddy ports, and proven reliability across 2,000+ vessel installations. Third-party ACT evaluation confirmed performance comparable to or better than DPD instruments, with ±4% precision versus ±15–32% for the DPD units tested.

±4%

Precision in ACT third-party evaluation — vs. ±15% and ±32% for the two DPD instruments tested

2,000+

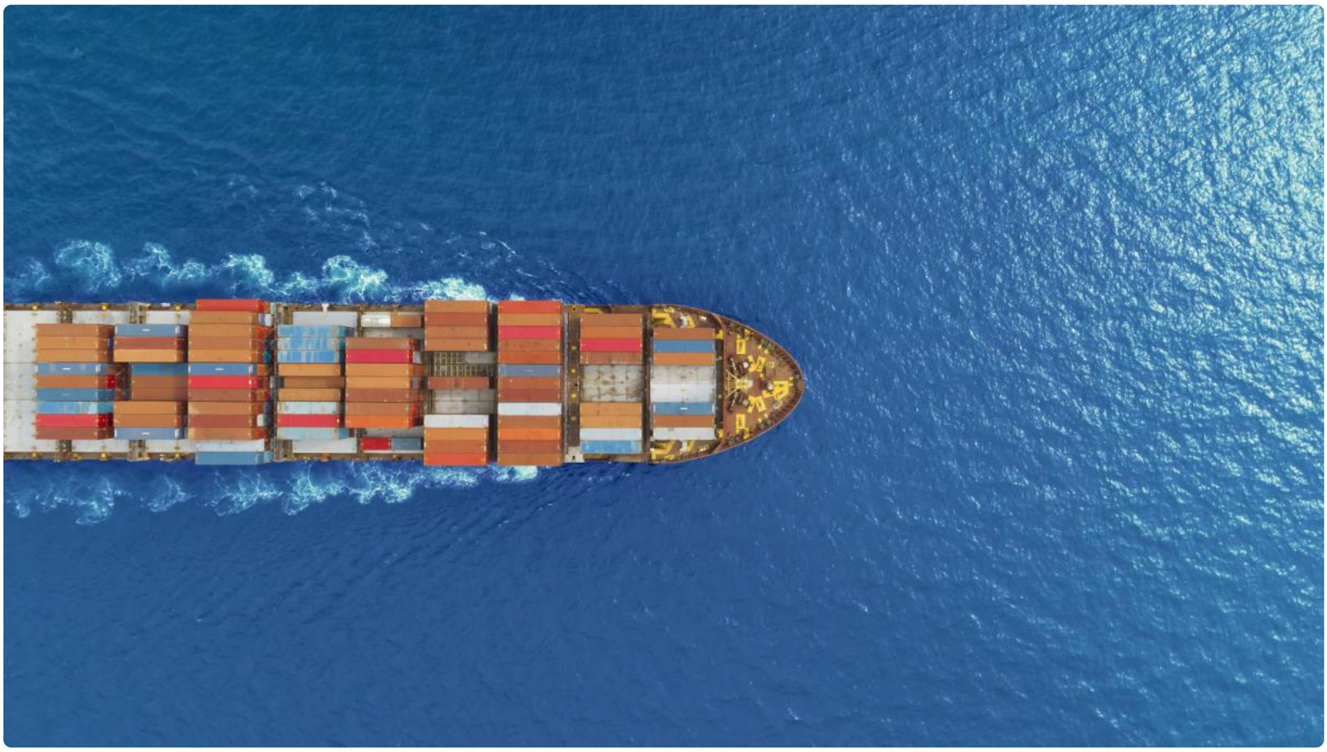
Sensors installed on vessels in BWMS applications since 2014, with DNV Type Approvals issued

<45 sec

Response time from direct pipe installation — vs. 3–8 minute delays through DPD sampling lines

15 months

Equivalent maintenance-free operation demonstrated in ISO 15839 accelerated field test



Ballast water treatment systems on large vessels require reliable, reagent-free TRO measurement for IMO compliance.

THIRD-PARTY EVALUATION

ACT performance verification

The Alliance for Coastal Technologies (ACT) conducted an independent evaluation of ballast water TRO instruments. While ACT did not directly compare sensors, the results reveal significant performance differences. In the precision test, brand-new DPD instruments installed by factory personnel were both outside their ±5% specification: DPD1 achieved ±15% accuracy while DPD2 was ±32%. The Halogen sensor was well within specification at ±4%, with a coefficient of variation (2.5%) better than the DPD reference method itself (2.6%).

In the accuracy tests across multiple salinities (0.2, 15, and 30 PSU), one DPD instrument failed to operate during two tests and could not produce data. For tests where all instruments operated, the Halogen sensor performed comparably to or better than both DPD instruments.

THIRD-PARTY DATA

ACT evaluation results

Table 1: Comparison of Precision — Three Instruments Evaluated by ACT

SAMPLE	REFERENCE METHOD	DPD2	DPD1	HSI
1	3.55	2.30	3.02	3.45
2	3.56	2.41	3.10	3.45
3	3.48	2.39	3.01	3.40
4	3.53	2.39	3.01	3.34
5	3.49	2.29	3.05	3.34
6	3.50	2.30	2.93	3.35
7	3.47	2.31	2.92	3.33
8	3.41	2.33	2.91	3.28
9	3.38	2.32	2.85	3.27
10	3.45	2.30	2.83	3.24
11	3.33	2.32	2.79	3.22
12	3.27	2.27	2.68	3.20
Average	**3.45**	**2.33**	**2.93**	**3.32**
Std Dev	**0.09**	**0.04**	**0.12**	**0.08**
CV (%)	**2.60%**	**1.90%**	**4.20%**	**2.50%**
Rel. % Accuracy	**—**	**–32%**	**–15%**	**4%**

Table 2: Linear Regression Slopes Reported by ACT

Values closer to 1.00 indicate better agreement with the reference method. A dash indicates the instrument did not operate during that test.

PSU SALINITY	HSI	DPD1	DPD2
0.2	0.809	0.829	1.072
0.2	0.962	0.879	0.728
0.2	0.814	0.924	0.777

PSU SALINITY	HSI	DPD1	DPD2
15	0.779	—	0.762
15	0.825	0.783	0.458
15	0.793	0.859	0.635
30	0.756	—	0.746
30	0.818	0.747	0.456
30	0.717	0.787	0.603
15	Not Tested	0.814	0.585
16	0.778	0.794	0.665

F A S T   R E S P O N S E

Direct pipe installation eliminates sampling delays

The sensor installs directly in the ballast pipe, delivering TRO readings in under 45 seconds. Online DPD instruments fed by long sampling lines introduce 3 to 8 minutes of delay before the BWMS receives an updated reading. This delayed process loop causes problems with accurate chlorine control, resulting in oscillation between over-chlorination and under-chlorination. Long sampling lines are also frequently responsible for sample contamination.

M U D D Y   P O R T S

Robust operation at 40× the TSS challenge level

BWMS systems are evaluated at 50 ppm Total Suspended Solids (TSS). However, many ports have much higher suspended solids, and water can appear visibly muddy. Silt remaining in ballast tank bottoms creates similar conditions during deballasting.

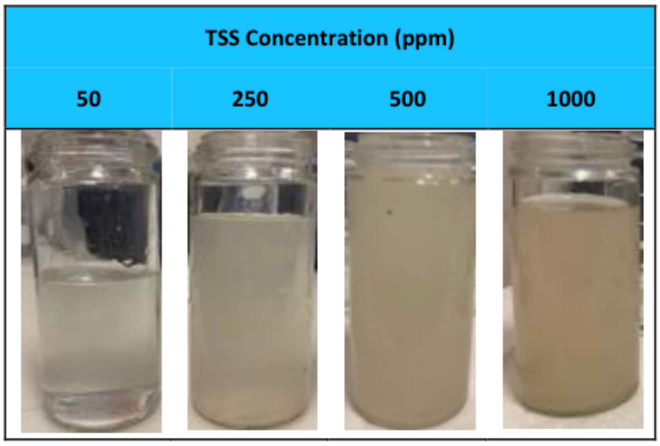


Figure 1. Unfiltered water samples at TSS concentrations from 50 to 1,000 ppm.

The Halogen sensor was evaluated at 2,000 ppm TSS — 40 times the required challenge level. At these high TSS levels, the DPD spectrophotometric method produced lower measurements due to interference with the optical measurement. To obtain accurate DPD readings, samples required reagent reaction, 5-micron filtration to remove TSS, then measurement. The amperometric sensor was unaffected by TSS levels up to 2,000 ppm.

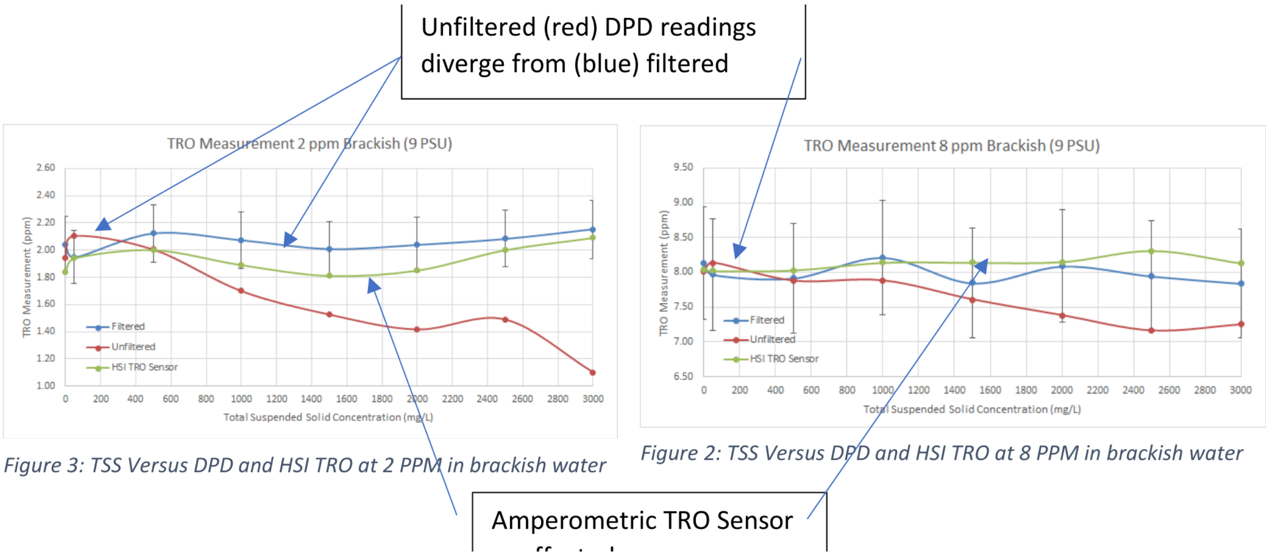


Figure 3: TSS Versus DPD and HSI TRO at 2 PPM in brackish water

Figure 2: TSS Versus DPD and HSI TRO at 8 PPM in brackish water

Figures 2 & 3. TSS versus DPD and HSI TRO at 2 ppm (left) and 8 ppm (right) in brackish water. Unfiltered DPD readings diverge from filtered at high TSS. The amperometric TRO sensor remains unaffected.

F L O W   I N D E P E N D E N C E

Accurate across all ballast flow conditions

Other amperometric sensors are extremely sensitive to flow changes. The Halogen sensor was tested across flow velocities from 0 to 1.93 m/s to 3.73 m/s. Accuracy remained within ±6% of the Hach DPD reference at all flow rates, with most readings within ±2–3%. Flow conditions have negligible effect on measurement accuracy.

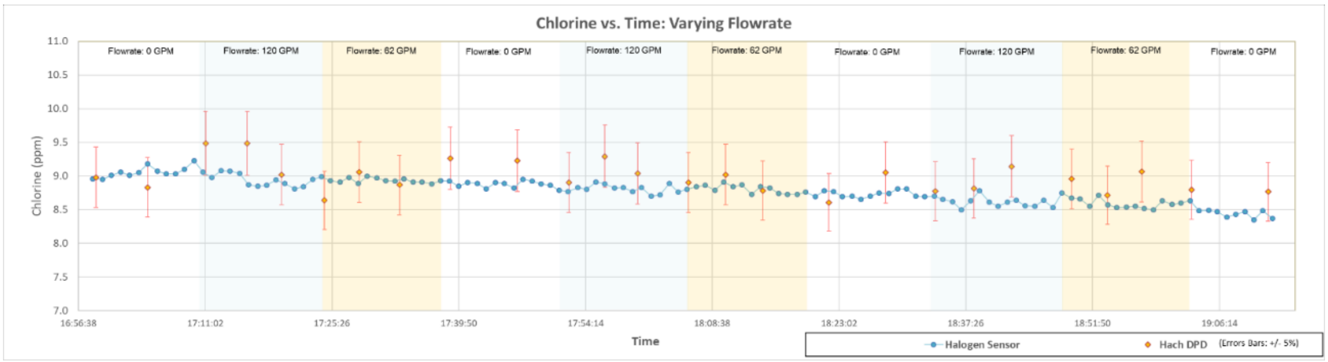


Figure 4. Chlorine vs. time at varying flow rates (0, 62, and 120 GPM). The Halogen sensor (blue dots) maintains consistent readings across all flow conditions, closely tracking the Hach DPD reference (orange diamonds, ±5% error bars).

Table 3: Flow Test — Hach DPD values with corresponding Halogen sensor measurements

The accuracy of the Halogen sensor as compared to the Hach DPD value is given in the last column.

FLOW (GPM)	HACH DPD (PPM)	HALOGEN (PPM)	ACCURACY	FLOW (GPM)	HACH DPD (PPM)	HALOGEN (PPM)	ACCURACY
0	8.98	8.96	0%	62 (1.93 m/s)	8.90	8.80	−1%
	8.83	9.05	2%		9.02	8.91	−1%
120 (3.73 m/s)	9.49	9.06	−4%		8.78	8.84	1%
	9.48	9.04	−5%	0	8.61	8.78	2%
	9.02	8.94	−1%		9.05	8.75	−3%
62 (1.93 m/s)	8.64	8.99	4%	120 (3.73 m/s)	8.77	8.70	−1%
	9.06	8.89	−2%		8.82	8.63	−2%
	8.87	8.92	1%		9.14	8.61	−6%
0	9.26	8.92	−4%	62 (1.93 m/s)	8.96	8.67	−3%

FLOW (GPM)	HACH DPD (PPM)	HALOGEN (PPM)	ACCURACY	FLOW (GPM)	HACH DPD (PPM)	HALOGEN (PPM)	ACCURACY
	9.23	8.82	−4%		8.71	8.71	0%
120 (3.73 m/s)	8.90	8.77	−1%		9.07	8.55	−6%
	9.29	8.91	−4%	0	8.80	8.63	−2%
	9.04	8.77	−3%		8.77	8.48	−3%

COMPLIANCE ADVANTAGE

Direct pipe installation means no sampling lines that can introduce contamination or delay. No reagents means no risk of running out during a voyage. No filters means no clogging in muddy ports. These operational advantages translate directly to compliance reliability — the sensor works when you need it, in the conditions you encounter.

OPERATIONAL COSTS

Lower installation, lower maintenance, lower cost

ITEM	DPD INSTRUMENT	HALOGEN AMPEROMETRIC
Reagents	Every 30–60 days of operation	**None**
Wear parts replacement	N/A	**Every 24 months**
Annual consumable cost	~$600	**$120**
Pump overhaul	Annually (seawater corrosion)	**N/A**
T-strainer cleaning	Monthly	**N/A**
Check valve/tubing	Quarterly	**N/A**
Solenoid valve cleaning	Semi-annually	**N/A**

Installation cost savings

The Halogen sensor requires no skid mounting, sampling lines, filters, pumps, waste lines, or remote valves. Installation requires only a hot tap valve and remover tool (~$450) compared to an estimated $2,672 in additional components for a DPD instrument installation — a savings of over $2,200 per instrument.

MAINTENANCE INTERVAL

15 months of equivalent operation without service

Following ISO 15839 methodology, the sensor operated 24 hours per day for 80 days across 33 ballast/deballast cycles — requiring no maintenance or calibration. Based on typical two-week voyage patterns with approximately 8 hours of sensor operation per cycle, this corresponds to 66 weeks (15 months) of shipboard operation and over 792 hours of actual sensor runtime.

During each deballast cycle, sodium sulfite was used to lower TRO levels to approximately 0.1 ppm (the Maximum Allowable Discharge Concentration), and the sensor accurately measured at this critical threshold throughout the test period.

SENSOR MODELS

Hazardous and non-hazardous configurations

Four sensor models are available in both hazardous (Zone 1, Group IIC) and non-hazardous configurations with three mounting options: in-pipe (hot tap), side stream, and open deck. The sensor's compact size makes it practical to carry as a spare on board, reducing potential downtime.

The sensor's compact size makes it practical to carry as an onboard spare, reducing potential downtime. The sensor is easily separated from the junction box for quick replacement or service.

Figure 10. The compact size of the Halogen sensor makes it suitable to carry as an onboard spare.

Table 7: Fast Sensor Removal System

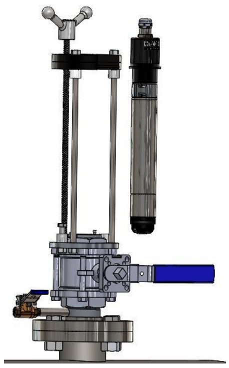
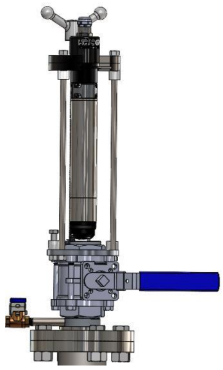
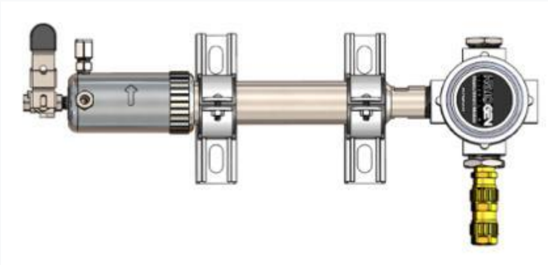
FIG. 6: SENSOR INSTALLED	FIG. 7: REMOVER INSTALLED	FIG. 8: SLIDE SENSOR OUT	FIG. 9: REMOVE SADDLE CLAMPS
			

Table 8: Halogen Sensor Models

MODELS	IN PIPE (HOT TAP)	SIDE STREAM
Non-Hazardous		Side stream chamber with sampling port

MODELS	IN PIPE (HOT TAP)	SIDE STREAM
		
Hazardous Zone 1, Group IIC	 IECEx Sensor	Side stream chamber with IECEx sensor with sampling port

The side stream version does not require pressure or flow regulation. Customers have installed this version without a sampling pump by using pressure differential in the ballast pipe to circulate water through the chamber. Models can also be installed on Open Deck.

Self-cleaning technology

The sensor (covered by seven U.S. patents and five foreign patents) incorporates an integrated pump that increases velocity across sensor electrode surfaces, improving signal-to-noise ratio. Cleaning beads captured within the sensor continuously abrade the electrodes during operation. This mechanical cleaning, combined with electrochemical cleaning cycles, keeps the sensor accurate without manual intervention. In addition to TRO, the sensor measures salinity, temperature, ORP, and pH — with three parameters used to compensate for signal changes across fresh and brackish water.

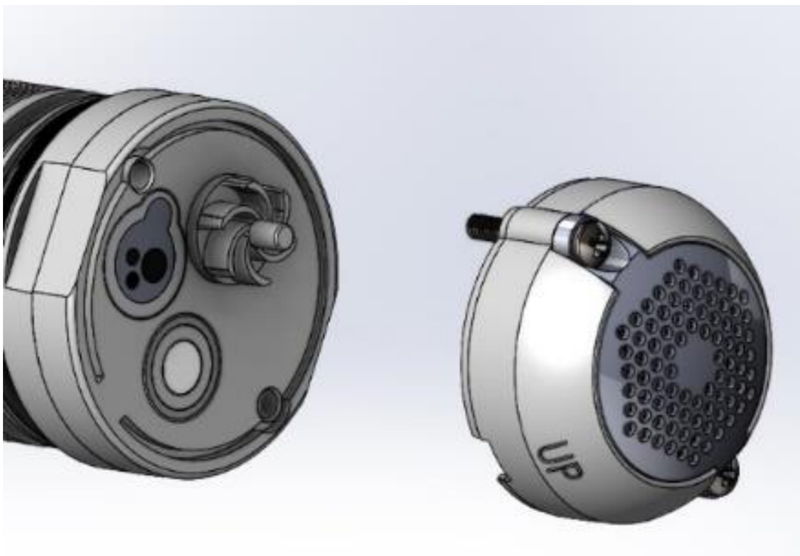


Figure 7. Sensor detail: back view showing connector and cable gland (left) and front view showing the self-cleaning electrode mesh (right).

Integrated salinity sensor

All models include an integrated salinity sensor, potentially eliminating the need for a separate instrument (savings of over $3,000). This function enables automatic signal compensation when operating in freshwater ports.

C O N C L U S I O N

Purpose-built for ballast water compliance

As noted in a 2014 research publication: "Amperometric sensors are not commonly used in BWMS but offer potential advantages over other instruments. If applied to BWMS, they would allow direct immersion in a sampling inlet, ending the need for sampling pumps and reagents associated with DPD online analyzers."

The Halogen DPI amperometric sensor was designed specifically for this application. With over 2,000 installations on vessels since 2014, DNV Type Approvals, ACT third-party verification, and proven operation in conditions that challenge or defeat DPD instruments — muddy ports, flow variations, extended voyages — it represents a cost-effective, compliance-reliable alternative to reagent-based TRO monitoring.

R E F E R E N C E S

References

1. Alliance for Coastal Technologies (2020). Performance Verification Statements for TRO Instruments. Baltimore, MD: ACT. http://www.act-us.info/evaluations.php
2. Tamburri, Z.-F.A. (2014). "Evaluation of approaches to quantify total residual oxidants in ballast water management systems." Water Science and Technology, 1585–1593.
3. EPA (2010). Generic Protocol for the Verification of Ballast Water Technology. United States Coast Guard.
4. ISO 15839:2003. Water Quality — Online Sensors/Analysing Equipment for Water — Specifications. Geneva: ISO.
5. Halogen Systems Inc. (2020). White Papers: Amperometric Sensor Turbidity Performance (WP03), ISO 15839 Field Test (WP04), Flow Test Report (WP06).
6. Korean Register of Shipping (KRS). BWMS Technical Information for Shipowners and Inspectors.
7. DoD (2020). SBIR-STTR Success: Halogen Systems, Inc. https://www.sbir.gov/node/1704083

A B O U T   T H E   A U T H O R

Michael Silveri

Michael Silveri is the founder of Halogen Systems, Inc. and inventor of the company's amperometric sensor technology. With over two decades of experience in electrochemical water quality measurement, he has led the development of reagent-free chlorine analyzers deployed across municipal water treatment plants, ballast water management systems, and industrial applications worldwide. The Halogen sensor platform was funded in part by SBIR contracts from the U.S. Office of Naval Research.