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Demonstration of BOLLFILTER Corporation Filter System Efficacy on Ballast Water Plankton

Maritime Environmental Resource Center

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Notice

This evaluation was conducted under specific, predetermined, agreed-upon protocols, criteria, and quality assurance procedures to assess the treatment system's performance.

MERC does not label or list technologies as acceptable or unacceptable but will present the results in an objective way.

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This report has been reviewed by members of the MERC Advisory Board and provided to BOLLFILTER and MERC funding agencies prior to public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by MERC.

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1.0. MERC Background and Objectives

The Maritime Environmental Resource Center (MERC) is a State of Maryland initiative that provides test facilities, information, and decision tools to address key environmental issues facing the international maritime industry. The Center's primary focus is to evaluate the mechanical and biological efficacy, associated costs, and logistical aspects of ballast water treatment systems and the economic impacts of ballast water regulations and management approaches. A full description of MERC's structure, products, and services can be found at www.maritime-enviro.org.

To address the need for effective, safe, and reliable ballast water treatment systems to prevent the introduction of non-native species, MERC has developed as a partnership between the Maryland Port Administration (MPA), Chesapeake Biological Laboratory/ University of Maryland Center for Environmental Science (UMCES-CBL), U.S. Maritime Administration (MARAD), Smithsonian Environmental Research Center (SERC), and University of Maryland (UMCP, UMWREC) to provide independent performance testing and to help facilitate the transition of new treatment technologies to shipboard implementation and operations.

The following report describes the evaluation of filter performance for a proof-of-concept demonstration of the potential for the BOLL Automatic Filter Type 6.18.3 to remove ballast water organisms. Detailed protocols and formal MERC Test Plan can be downloaded at www.maritime-enviro.org.

2.0. Introduction to BOLLFILTER Technology

The BOLL Automatic Filter Type 6.18.3 system contains bipolar filter candles, which are open at both ends allowing water to flow through from either end during filtration. The filters utilized a 40-micron mesh and a large surface area with a flow capacity of 3,000 m^3 per hour. The system utilizes the bipolar filtration method in conjunction with bipolar backflushing. Rotating flushing arms are fitted both above and below the filter unit. The filter candles are cleaned alternately from above and below with the filtrate fluid without interrupting filtration. The filter housing is compact and made of carbon steel.

3.0. Summary of Test Protocols

Five trials were conducted, three in March 2011 and two in June 2011. Water was continuously pumped sea-to-sea, from Baltimore Harbor area (Patapsco River, MD, in the mesohaline region of the Chesapeake Bay) into the US Maritime Administration vessel *MV Cape Washington's* ballast system via the sea chest.

The duration of each trial (from 3 to 6 hours) depended upon a specific filtered volume of 1,000 m^3, pressure, and flow rate. Water samples were collected before (ambient) and after (post 40 µm) the BOLL filter, then analyzed for total suspended solids (TSS), particulate organic carbon (POC), zooplankton greater than 50 µm (microns), and phytoplankton (10 to 50 µm and 5 to 10 µm). Further details can be found in associated Test Plan.

3.1. Test Parameters

Each of the five trials consisted of three sampling periods labeled T-0, T-1 and T-2. Each sampling period was divided into thirds for more intensive sampling of some parameters, and labeled, for example, T0-1, T0-2 and T0-3.

Trial Number	Date	Ave. Back Pressure (psi)	Ave. Flow (m^3/hr)	Est. No. of Backflushes
BOLL-1	March 16, 2011	30	200	4
BOLL-2	March 17, 2011	30	200	5
BOLL-3	March 24, 2011	30	*200/210	5
BOLL-4	June 1, 2011	25	325	10
BOLL-5	June 2, 2011	24	375	7

* Flow was increased to 210 m^3/h prior to sample period T-1.

4.0. Trial Results

4.1. Water Quality – Physical Parameters

At the beginning of each trial, temperature, salinity and dissolved oxygen were measured in the ambient water using an YSI 556 multi-parameter instrument.

Trial Number	Date	Temp (C°)	Salinity	DO (mg/l)
BOLL-1	March 16, 2011	8.9	6.5	*12.19
BOLL-2	March 17, 2011	8.9	5.2	*11.1
BOLL-3	March 24, 2011	10.7	3.4	11.4
BOLL-4	June 1, 2011	27.7	1.5	6.8
BOLL-5	June 2, 2011	24.6	1.8	3.9

* These two D.O. readings were obtained from the MD DNR data monitoring program instrument deployed near the Cape Washington at 1 meter in depth.

4.2. Water Quality - Total Suspended Solids (TSS)

Ambient TSS samples were collected at the beginning of each major sampling period (T0, T1, T2). Post-filter TSS samples were collected for every time point (T0-1, T0-2, and T0-3, for example). TSS Mean Detection Limit (MDL) = 2.4 mg/L.

BOLL-1 March 16, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0-Amb	Ambient	9:40	5.9	0.3
T0-1	Post 40 µm	9:40	5.8	0.2
T0-2	Post 40 µm	10:05	6.1	0.7
T0-3	Post 40 µm	10:15	5.3	0.2
T1-Amb	Ambient	12:10	8.2	2.1
T1-1	Post 40 µm	12:10	6.0	0.2
T1-2	Post 40 µm	12:23	5.8	0.3
T1-3	Post 40 µm	12:35	6.0	0.1
T2-Amb	Ambient	14:00	5.7	0.0
T2-1	Post 40 µm	14:00	5.7	0.3
T2-2	Post 40 µm	14:10	5.8	NA
T2-3	Post 40 µm	14:20	5.9	0.4

BOLL-2 March 17, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0-Amb	Ambient	8:45	5.1	0.1
T0-1	Post 40 µm	8:45	4.4	0.1
T0-2	Post 40 µm	8:55	4.7	0.3
T0-3	Post 40 µm	9:05	4.5	0.2
T1-Amb	Ambient	10:47	4.1	0.6
T1-1	Post 40 µm	10:47	4.5	0.1
T1-2	Post 40 µm	10:56	5.0	0.1
T1-3	Post 40 µm	11:05	5.2	0.3
T2-Amb	Ambient	12:25	5.2	0.3
T2-1	Post 40 µm	12:25	5.2	0.6
T2-2	Post 40 µm	12:32	4.8	0.0
T2-3	Post 40 µm	12:42	5.5	0.6

BOLL-3 March 24, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0-Amb	Ambient	8:55	8.3	0.7
T0-1	Post 40 µm	8:55	8.6	0.3
T0-2	Post 40 µm	9:05	8.7	0.2
T0-3	Post 40 µm	9:15	9.8	1.6
T1-Amb	Ambient	11:10	8.8	0.1
T1-1	Post 40 µm	11:10	8.9	0.4
T1-2	Post 40 µm	11:20	8.7	0.1
T1-3	Post 40 µm	11:30	7.7	2.0
T2-Amb	Ambient	12:55	7.2	0.1
T2-1	Post 40 µm	12:55	7.6	2.1
T2-2	Post 40 µm	13:05	8.9	1.1
T2-3	Post 40 µm	13:15	8.8	0.2

BOLL-4 June 1, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0-Amb	Ambient	9:00	5.2	0.6
T0-1	Post 40 µm	9:00	5.2	0.2
T0-2	Post 40 µm	9:10	4.3	0.0
T0-3	Post 40 µm	9:25	4.2	0.1
T1-Amb	Ambient	10:35	3.9	0.1
T1-1	Post 40 µm	10:35	4.0	0.1
T1-2	Post 40 µm	10:40	4.0	0.4
T1-3	Post 40 µm	10:50	3.9	0.0
T2-Amb	Ambient	11:40	3.9	0.1
T2-1	Post 40 µm	11:40	3.9	0.3
T2-2	Post 40 µm	11:50	4.1	0.1
T2-3	Post 40 µm	12:00	3.8	0.2

BOLL-5 June 2, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0-Amb	Ambient	8:35	5.8	0.1
T0-1	Post 40 µm	8:35	5.8	0.1
T0-2	Post 40 µm	8:45	5.1	0.3
T0-3	Post 40 µm	8:55	5.4	0.2
T1-Amb	Ambient	9:50	5.8	0.6
T1-1	Post 40 µm	9:50	5.4	0.3
T1-2	Post 40 µm	10:00	5.6	0.0
T1-3	Post 40 µm	10:10	5.4	0.2
T2-Amb	Ambient	10:50	5.6	0.2
T2-1	Post 40 µm	10:50	5.3	0.2
T2-2	Post 40 µm	11:00	5.7	0.1
T2-3	Post 40 µm	11:10	5.9	0.0

4.3. Water Quality – Particulate Organic Carbon (POC)

Ambient POC samples were collected at the beginning of each major sampling period (T0, T1, T2). Post-filter POC samples were collected for every time point (T0-1, T0-2, and T0-3, for example). PC MDL = 0.0633 mg/L.

BOLL-1 March 16, 2011

Time point	Sample ID	Sample Time	POC (mg/L) (Avg)	POC(mg/L) (StDev)
T0-Amb	Ambient	9:40	0.759	0.056
T0-1	Post 40 µm	9:40	0.733	0.011
T0-2	Post 40 µm	10:05	0.691	0.019
T0-3	Post 40 µm	10:15	0.758	0.004
T1-Amb	Ambient	12:10	1.011	0.042
T1-1	Post 40 µm	12:10	0.955	0.004
T1-2	Post 40 µm	12:23	0.961	0.018
T1-3	Post 40 µm	12:35	1.008	0.032
T2-Amb	Ambient	14:00	0.923	0.010
T2-1	Post 40 µm	14:00	0.737	0.145
T2-2	Post 40 µm	14:10	0.868	0.006
T2-3	Post 40 µm	14:20	0.880	0.001

BOLL-2 March 17, 2011

Time point	Sample ID	Sample Time	POC (mg/L) (Avg)	POC(mg/L) (StDev)
T0-Amb	Ambient	8:45	0.874	0.150
T0-1	Post 40 µm	8:45	0.727	0.021
T0-2	Post 40 µm	8:55	0.729	0.007
T0-3	Post 40 µm	9:05	0.719	0.012
T1-Amb	Ambient	10:47	0.857	0.094
T1-1	Post 40 µm	10:47	0.794	0.012
T1-2	Post 40 µm	10:56	0.810	0.018
T1-3	Post 40 µm	11:05	0.825	0.002
T2-Amb	Ambient	12:25	0.837	0.180
T2-1	Post 40 µm	12:25	0.898	0.005
T2-2	Post 40 µm	12:32	0.882	0.008
T2-3	Post 40 µm	12:42	0.908	0.094

BOLL-3 March 24, 2011

Time point	Sample ID	Sample Time	POC (mg/L) (Avg)	POC(mg/L) (StDev)
T0-Amb	Ambient	8:55	1.270	0.198
T0-1	Post 40 µm	8:55	1.320	0.000
T0-2	Post 40 µm	9:05	1.360	0.014
T0-3	Post 40 µm	9:15	1.440	0.028
T1-Amb	Ambient	11:10	1.435	0.007
T1-1	Post 40 µm	11:10	1.415	0.007
T1-2	Post 40 µm	11:20	1.385	0.021
T1-3	Post 40 µm	11:30	1.405	0.021
T2-Amb	Ambient	12:55	1.285	0.049
T2-1	Post 40 µm	12:55	1.330	0.014
T2-2	Post 40 µm	13:05	1.310	0.000
T2-3	Post 40 µm	13:15	1.325	0.021

BOLL-4 June 1, 2011

Time point	Sample ID	Sample Time	POC (mg/L) (Avg)	POC(mg/L) (StDev)
T0-Amb	Ambient	9:00	1.120	0.000
T0-1	Post 40 µm	9:00	1.165	0.021
T0-2	Post 40 µm	9:10	1.070	0.042
T0-3	Post 40 µm	9:25	1.015	0.007
T1-Amb	Ambient	10:35	0.979	0.004
T1-1	Post 40 µm	10:35	0.935	0.033
T1-2	Post 40 µm	10:40	0.963	0.044
T1-3	Post 40 µm	10:50	0.944	0.030
T2-Amb	Ambient	11:40	0.966	0.013
T2-1	Post 40 µm	11:40	0.971	0.001
T2-2	Post 40 µm	11:50	0.998	0.001
T2-3	Post 40 µm	12:00	1.020	0.000

BOLL-5 June 2, 2011

Time point	Sample ID	Sample Time	POC (mg/L) (Avg)	POC(mg/L) (StDev)
T0-Amb	Ambient	8:35	0.787	0.007
T0-1	Post 40 µm	8:35	0.731	0.091
T0-2	Post 40 µm	8:45	0.734	0.034
T0-3	Post 40 µm	8:55	0.738	0.007
T1-Amb	Ambient	9:50	0.757	0.007
T1-1	Post 40 µm	9:50	0.750	0.024
T1-2	Post 40 µm	10:00	0.764	0.056
T1-3	Post 40 µm	10:10	0.735	0.009
T2-Amb	Ambient	10:50	0.750	0.008
T2-1	Post 40 µm	10:50	0.738	0.033
T2-2	Post 40 µm	11:00	0.761	0.013
T2-3	Post 40 µm	11:10	0.713	0.030

4.4. Zooplankton >50 µm

The data below describes the numbers of zooplankton in both the ambient challenge water and after the BOLL filter water during all trials. Size-class distinctions or measures are determined by considering the greatest available measure among the x, y, and z body axis, exclusive of appendages such as legs, swimming appendages, sensory apparatus, or other fine appendages.

The zooplankton communities found during trials 1, 2, and 3 were primarily composed of the calanoid copepod *Eurytemora affinis* in its various life stages. Size class one (>75µm to <120µm) contained the eggs and nauplii, which primarily passed through the filter. While eggs were usually encountered singly, egg clusters when present, were also counted as single objects. Size class two (around 1mm) organisms were largely adult *Eurytemora affinis*. The filter appeared to stop adult calanoid copepods effectively with the exception of run 3 when effectiveness dropped. In addition, barnacle nauplii, rotifers, and several other rare taxa were present in lessor abundance.

The zooplankton communities found during trials 4 and 5 were primarily size class one (>75µm to <120µm) organisms, which were found in both pre- and post-sieve samples in near equal numbers. The dominant species were primarily small rotifers identified as *Brachionus calyciflorus* and *Trichocercas rousseleti.* Although rotifers were nearly as abundant after the filter, many experienced visible damage and may not have survived. Small nauplii of copepods were also found to be abundant in both pre and post sieve samples, even though adult copepods were rare. Bivalve larvae were present in moderate numbers and often passed the filter. The filter generally stopped adult copepods, although some Harpacticoids (smaller than the Calanoids in our samples) were observed in the post filter samples.

BOLL-1 March 16, 2011

Time point		**Size Class 1 >75 µm to <120µm (#/m^3)**	**Size Class 2 Around 1 mm (#/m^3)**	**Total >50-µm (#/m^3)**
T-0 Initial	Ambient	143,000	12,000	155,000
	Post 40 µm	114,333	0	114,333
T-1 Mid	Ambient	201,000	8,000	209,000
	Post 40 µm	153,333	0	153,333
T-2 Final	Ambient	205,000	13,000	218,000
	Post 40 µm	132,000	333	132,333

BOLL-2 March 17, 2011

Time point		Size Class 1 >75 µm to <120µm (#/m^3)	Size Class 2 Around 1 mm (#/m^3)	Total >50-µm (#/m^3)
T-0 Initial	Ambient	215,000	17,000	232,000
	Post 40 µm	97,166	0	146,333
T-1 Mid	Ambient	174,000	19,000	193,000
	Post 40 µm	117,667	0	117,667
T-2 Final	Ambient	322,000	20,000	342,000
	Post 40 µm	205,000	333	205,333

BOLL-3 March 24, 2011

Time point		Size Class 1 >75 µm to <120µm (#/m^3)	Size Class 2 Around 1 mm (#/m^3)	Total >50-µm (#/m^3)
T-0 Initial	Ambient	415,000	24,000	439,000
	Post 40 µm	281,000	1,000	282,000
T-1 Mid	Ambient	513,000	14,000	527,000
	Post 40 µm	491,667	2,333	494,000
T-2 Final	Ambient	361,000	31,000	392,000
	Post 40 µm	322,333	2,667	325,000

BOLL-4 June 1, 2011

Time point		Size Class 1 >75 µm to <120µm (#/m^3)	Size Class 2 Around 1 mm (#/m^3)	Total >50-µm (#/m^3)
T-0 Initial	Ambient	285,500	2,500	288,000
	Post 40 µm	260,000	0	260,000
T-1 Mid	Ambient	391,100	2,900	394,000
	Post 40 µm	371,333	667	372,000
T-2 Final	Ambient	469,500	2,500	472,000
	Post 40 µm	416,000	0	416,000

BOLL-5 June 2, 2011

Time point		Size Class 1 >75 µm to <120µm (#/m^3)	Size Class 2 Around 1 mm (#/m^3)	Total >50-µm (#/m^3)
T-0 Initial	Ambient	188,000	14,000	202,000
	Post 40 µm	135,667	4,333	140,000
T-1 Mid	Ambient	195,500	16,500	212,000
	Post 40 µm	161,700	7,300	169,000
T-2 Final	Ambient	189,000	25,000	214,000
	Post 40 µm	187,667	3,333	191,000

4.5. Phytoplankton 10 – 50 µm and 5 – 10 µm

The following two tables describe phytoplankton species composition in both the ambient challenge water and after the BOLL filter water during all test trials.

BOLL Trials 1, 2, and 3

Dominant Species	**Type**	**General Size**
Skeletonema costata	Diatom (chain forming)	Individual cells 9 – 10 µm
Heterocapsa rotundatum	Dinoflagellate	Approx. 5 – 6 µm
Other Noted Species		
Prorocentrum minimum	Dinoflagellate	22 x 15 µm
Heterocapsa triquerta	Dinoflagellate	24 x 16 µm
Ceratulina pelagica	Diatom (chain forming)	100 x 24 µm (can form larger chains)
Gyrodinium estruariale	Dinoflagellate	15 x 11 µm

BOLL Trials 4 and 5

Dominant Species	**Type**	**General Size**
Thalassiosira sp.	Diatom (chain forming)	Individual cells 8 – 12 µm
Chaetoceros sp.	Diatom (chain forming)	Individual cells 7 – 15 µm
Other Noted Species (small #)		
Amphidinium sp.	Dinoflagellate	50 x 13 µm
Amphora sp.	Diatom	8 x 30 µm
Asterionella sp.	Diatom (forms star-shaped clusters)	40 x 11 µm
Gonyaulux sp.	Dinoflagellate	24 x 40 µm
Gyrodinium estruariale	Dinoflagellate	15 x 11 µm
Heterocapsa rotundatum	Dinoflagellate	Approx. 5 – 6 µm
Heterocapsa triquerta	Dinoflagellate	24 x 16 µm
Rhizosolenia pungens	Diatom	Varies 4 – 12 diameter; 100+ µm in length
Navicula sp.	Diatom	8 x 30 µm
Scrippsiella sp.	Dinoflagellate	23 x 36 µm
Skeletonema costata	Diatom (chain forming)	Individual cells 9 – 10 µm; can form chains 100+ µm in length
Syndedra sp.	Diatom	Varies 2 – 7 µm diameter 150 – 200 µm in length
Thalassionema sp.	Diatom	Varies 64 µm
Chlamydomonas sp.	Chlorophyceae	7 – 8 µm diameter
Pediastrum sp.	Chlorophyceae (forms star-shaped clusters)	5 – 6 µm
Agmenellum quadruplicatum	Cyanobacteriaceae	

Overall, phytoplankton conditions and cell densities were similar throughout trials 1, 2, and 3. The majority of the phytoplankton were in the 5 to <10 µm category. A strong winter bloom of *Skeletonema costata* and *Heterocapsa rotundatum* occurred during Trials 1, 2, and 3. Chains of *S. costata* were long and healthy; some were in the reproductive phase by presence of auxospores. *H. rotundatum* were also experiencing a winter bloom as noted by high density in the samples and distinctive color and odor of the water during sampling.

A very diverse population of phytoplankton was observed during trials 4 and 5. The dominant species were mostly chain-forming diatoms (*Thallassiosira* sp. *Chaetoceros* sp.). Many phytoplankton species were counted in small numbers along with a few larger dinoflagellates and diatoms. All samples contained large numbers of rotifers (see zooplankton analysis) found to be 3 distinct species.

BOLL-1 March 16, 2011

Time Point	Total Phyto 10-50 µm (#/ml)		Total Phyto 5-10 µm (#/ml)	
	Ambient	**Post 40 µm**	**Ambient**	**Post 40 µm**
T-0 Initial	3,636	697	11,169	5,554
T-1 Mid	4,651	424	16,784	5,736
T-2 Final	12,711	4,651	37,088	11,199

BOLL-2 March 17, 2011

Time Point	Total Phyto 10-50 µm (#/ml)		Total Phyto 5-10 µm (#/ml)	
	Ambient	**Post 40 µm**	**Ambient**	**Post 40 µm**
T-0 Initial	6,393	629	10,440	5,220
T-1 Mid	4,537	1,144	9,135	8,043
T-2 Final	2,757	606	8,164	6,647

BOLL-3 March 24, 2011

Time Point	Total Phyto 10-50 µm (#/ml)		Total Phyto 5-10 µm (#/ml)	
	Ambient	**Post 40 µm**	**Ambient**	**Post 40 µm**
T-0 Initial	1,318	136	19,788	10,865
T-1 Mid	2,992	1,712	15,903	7,223
T-2 Final	1,076	144	12,383	5,645

BOLL-4 June 1, 2011

Time Point	Total Phyto 10-50 µm (#/ml)		Total Phyto 5-10 µm (#/ml)	
	Ambient	Post 40 µm	Ambient	Post 40 µm
T-0 Initial	1,274	1,020	3,660	5,378
T-1 Mid	1,336	548	5,682	5,524
T-2 Final	1,038	427	2,999	2,568

BOLL-5 June 2, 2011

Time Point	Total Phyto 10-50 µm (#/ml)		Total Phyto 5-10 µm (#/ml)	
	Ambient	Post 40 µm	Ambient	Post 40 µm
T-0 Initial	1,671	461	11,709	5,864
T-1 Mid	794	397	10,252	6,616
T-2 Final	727	138	6,003	4,328

5.0 Acknowledgments

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Appendix A. Vendor Comments