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Demonstration of the Hydac 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 Hydac 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 (CBL/UMCES), U.S. Maritime Administration (MARAD), Smithsonian Environmental Research Center (SERC), and University of Maryland (UMD) to provide independent performance testing and to help facilitate the transition of new treatment technologies to shipboard implementation and operations.

The following report is a summary of an assessment of the Hydac AutoFilt ® RF3 automatic backflushing filter to remove ballast water organisms. Detailed protocols and formal MERC Test Plan can be downloaded at www.maritime-enviro.org.

2.0. Introduction to Hydac Technology

Hydac has been active in the field of fluid condition monitoring and filtration for over 30 years. This evaluation focused on the AutoFilt® RF3 automatic backflushing filter. AutoFilt® RF3 is a self-cleaning system for extracting particles from low-viscosity fluids. The principle application is the filtration of industrial water either as the main filter or as an offline filter. The conical slotted tube filter elements are stainless steel with the filter size ranging from 25 to 3,000 μm. The contamination condition of the elements is monitored by means of differential pressure measurement. When the filter reaches a certain pressure drop, automatic cleaning begins, during which all the filter elements in turn are back-flushed with a small volume of fluid without interrupting the flow of filtrate. The design system is currently used for continuous filtration of water in water plants, power plants and cooling towers.

3.0. Summary of Test Protocols

Sampling Design:

Six sequential trials were conducted: three in January/February, 2011 and three in May, 2011. Water was continuously pumped sea-to-sea, from Baltimore Harbor (Patapsco River, MD, in the mesohaline region of the Chesapeake Bay) into the US Maritime Administration vessel *MV Cape Washington* via the sea chest.

The duration of each trial (from 4 to 6 hours) was dependent upon a specific filtered amount of 1,000 m^3, pressure, and the flow rate. Water samples were collected before and after the Hydac filter, then analyzed for total suspended solids (TSS), particle size distribution (PSD), zooplankton, and phytoplankton (between 10 and 50 microns and between 5 and 10 microns).

Test Parameters:

Trial #1 – 3 sampling periods; high pressure 30 psi, 211 m^3/h flow; 6 back flushes; differential pressure ranged between 0.11 and 0.9 psi

Trial #2 – 3 sampling periods; high pressure 30 psi, 211 m^3/h flow; first back flush after 45 minutes from start time, additional back flushes approximately every 30 minutes over a 1h and 45min testing series; differential pressure ranged between 0.11 and 0.9 psi

Trial #3 – 3 sampling periods; high pressure 30 psi, 211 m^3/h flow, 5 back flushes – two after Sample 1, one after and one during Sample 2, and one after Sample 3; differential pressure ranged between 0.11 and 0.9 psi

Trial #4 – 6 sampling periods, high pressure 22 psi, 211 m^3/h flow for first three samples; changed to 29 psi at 216 m^3/h for remaining samples, 5 back flushes total – first back flush prior to Sample 3, four back flushes after Sample 3, 4, 5 and 6; differential pressure of 0.5 psi

Trial #5 – 6 sampling periods, Sample 1: 29 psi, 200 m^3/h flow; Sample 2: 27 psi, 256 m^3/h flow; Sample 3: 22.5 psi, 210 m^3/h flow; (Filter change prior to Sample 4) Sample 4: 22.9 psi, 200 m^3/h flow; Sample 5: 29 psi, 200 m^3/h flow; Sample 6: 29 psi, 265 m^3/h flow; 9 back flushes total – 1 prior to start, one each after Samples 1, 2, 3, 4, 5, and 6, two back flushes after filter change; differential pressure of 0.2 psi

Trial #6 – First three sampling periods at high pressure 22 psi, 200 m^3/h flow at 1400 filter differential pressure; remaining three sampling periods at high pressure 29 psi, 200 m^3/h flow at 1650 filter differential pressure; four back flushes after Sample 2 and one back flush after Sample 5

4.0. Trial Results

4.1. Water Quality – Physical Parameters

The parameters below were measured in the ambient water using a YSI 556 multi-parameter instrument.

Trial Number	Date	Temp (C°)	Salinity	DO (mg/l)	pH
Hydac-1	25 Jan 2011	1.5	15.1	14.3	7.4
Hydac-2	31 Jan 2011	1.5	13.5	16.6	6.9
Hydac-3	2 Feb 2011	1.3	11.4	N/A	6.9
Hydac-4	24 May 2011	21.2	1.9	7.9	N/A
Hydac-5	25 May 2011	22.4	1.8	8.7	N/A
Hydac-6	26 May 2011	23.8	1.7	9.1	N/A

4.2. Water Quality - Total Suspended Solids

The TSS samples for Hydac trials 1, 2, and 3 were collected after the Hydac filter for every major sample time point (T0, T1 and T2) in triplicate in order to obtain high-resolution TSS data. Back pressure and flow remained constant. Hydac trials 4, 5, and 6 focused on varying the pressure, flow and filter changes, sometimes between each time point; therefore, the sample regime changed to one ambient and one post filter sample per time point (with a total of 5 time points per trial).

Hydac-1 January 25, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0-Amb	Ambient	9:50	11.9	0.9
T0-1	Post 40 µm	9:50	9.8	0.0
T0-2	Post 40 µm	10:00	9.3	0.2
T0-3	Post 40 µm	10:10	7.0	0.1
T1-Amb	Ambient	12:00	9.6	1.4
T1-1	Post 40 µm	12:05	6.7	0.1
T1-2	Post 40 µm	12:15	6.3	0.0
T1-3	Post 40 µm	12:25	7.4	0.1
T2-Amb	Ambient	13:45	11.7	0.9
T2-1	Post 40 µm	13:45	6.8	0.1
T2-2	Post 40 µm	13:55	6.3	0.3
T2-3	Post 40 µm	14:05	7.2	0.6

Hydac-2 January 31, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0-Amb	Ambient	10:05	8.5	0.9
T0-1	Post 40 µm	10:05	6.7	0.2
T0-2	Post 40 µm	10:20	6.1	0.4
T0-3	Post 40 µm	10:30	5.3	0.2
T1-Amb	Ambient	12:20	7.0	0.1
T1-1	Post 40 µm	12:20	5.5	0.2
T1-2	Post 40 µm	12:30	5.0	0.4
T1-3	Post 40 µm	12:40	5.4	0.2
T2-Amb	Ambient	14:10	7.5	0.2
T2-1	Post 40 µm	14:10	5.1	0.1
T2-2	Post 40 µm	14:20	4.8	0.3
T2-3	Post 40 µm	14:33	4.8	0.5

Hydac-3 February 2, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0-Initial	Ambient	8:45	5.9	0.2
T0-1	Post 40 µm	8:45	4.2	0.3
T0-2	Post 40 µm	8:55	4.0	0.6
T0-3	Post 40 µm	9:05	4.1	0.1
T1-Mid	Ambient	10:55	4.6	0.8
T1-1	Post 40 µm	10:55	4.3	0.2
T1-2	Post 40 µm	11:10	4.0	0.4
T1-3	Post 40 µm	11:20	4.3	0.1
T2-Final	Ambient	12:30	5.8	0.3
T2-1	Post 40 µm	12:30	4.1	0.9
T2-2	Post 40 µm	12:40	3.6	0.0
T2-3	Post 40 µm	12:50	3.8	0.3

Hydac-4 May 24, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0	Ambient	9:40	9.4	0.0
	Post 40 µm	9:40	9.6	0.2
T1	Ambient	11:45	9.8	0.2
	Post 40 µm	11:45	10.1	0.2
T2	Ambient	12:00	9.0	0.2
	Post 40 µm	12:00	9.1	0.6
T3	Ambient	12:25	9.5	0.2
	Post 40 µm	12:25	9.9	0.4
T4	Ambient	12:55	9.6	0.4
	Post 40 µm	12:55	10.1	0.6
T5	Ambient	13:15	9.7	0.4
	Post 40 µm	13:15	9.8	0.2

Hydac-5 May 25, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0	Ambient	9:45	6.9	0.8
	Post 40 µm	9:45	7.2	0.4
T1	Ambient	10:15	7.3	0.5
	Post 40 µm	10:15	7.6	0.3
T2	Ambient	11:00	7.7	0.3
	Post 40 µm	11:00	7.7	0.2
T3	Ambient	13:20	9.5	0.4
	Post 40 µm	13:20	9.2	05
T4	Ambient	14:15	10.9	0.1
	Post 40 µm	14:15	10.9	0.5
T5	Ambient	14:50	11.2	0.2
	Post 40 µm	14:50	12.1	0.3

Hydac-6 May 26, 2011

Time point	Sample ID	Sample Time	TSS (mg/L) (Avg)	TSS (mg/L) (StDev)
T0	Ambient	8:40	8.6	0.6
	Post 40 µm	8:40	9.0	0.3
T1	Ambient	9:50	8.5	0.1
	Post 40 µm	9:50	9.2	0.4
T2	Ambient	10:10	8.3	1.0
	Post 40 µm	10:10	9.1	0.2
T3	Ambient	10:40	8.8	0.0
	Post 40 µm	10:40	9.0	0.6
T4	Ambient	11:55	9.0	0.4
	Post 40 µm	11:55	9.3	0.2
T5	Ambient	12:20	8.6	0.3
	Post 40 µm	12:20	8.8	0.2

4.3. Particle Size Distribution (PSD)

Water samples analyzed for particle size were drawn from ambient water, post-35-micron water and after each Hydac filter tested at each time point. Analysis was conducted at the Occoquan Watershed Monitoring Laboratory in Manassas, Virginia.

The EPA ASTM D4464 laser method was used in analysis. Due to low particle concentrations or counts, particles were only detected in the ambient samples. No detectable particles were found in the post-filter samples (below detection limits). Thus, the data below list only the challenge conditions for the Hydac filtration system.

Trial Number	Trial Date	Sample ID	PSD Mean (µm)
Hydac-1	25 Jan 2011	T0-Ambient	4.204
Hydac-2	31 Jan 2011	T0-Ambient	1.902
Hydac-3	2 Feb 2011	T0-Ambient	1.387

The 1-micron Laboratory Control Standard (LCS) samples ranged from 0.996 µm to 1.001 µm.

4.4. Zooplankton >50

The data below describes the numbers of zooplankton in both the ambient challenge water and the post Hydac filter water during all test 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.

<u>Hydac Trials 1, 2, and 3</u>

The zooplankton community was primarily composed of size class one organisms (>75µm to <120µm), such as rotifers, which typically passed the filter. The calanoid copepods, *Eurytemora affinis* and *Acartia sp.,* were also found in various life stages. Size-class one also contained copepod eggs and nauplii. While eggs were usually encountered singly, egg clusters, when present, were also counted as single objects. The size class two (around 1mm) was composed mainly of copepod adults. In addition, bivalve larvae and barnacle nauplii were present in lessor abundance.

<u>Hydac Trials 4, 5, and 6</u>

The zooplankton community was primarily composed of size class one organisms (>75µm to <120µm) such as rotifers. They were found in both ambient and post filter samples in near comparable numbers. The dominant species were identified as *Brachionus calyciflorus* and *Trichocercas rousseleti*. Although rotifers were still abundant after the filter, many experienced visible damage and may not have survived. Small nauplii of copepods were also found to be fairly abundant pre and post filter. Bivalve larvae were present in moderate numbers both pre and post filter. The filter generally stopped adult copepods (size class two), which were sparse in abundance.

Hydac-1 January 25, 2011

Time point		Size Class 1 >75 µm to <120µm	Size Class 2 ~ 1 mm	Total >50-µm
T-0 Initial	Ambient	53,750	12,000	65,750
	Post 40 µm	59,166	0	59,166
T-1 Mid	Ambient	59,000	14,000	73,000
	Post 40 µm	58,833	0	58,833
T-2 Final	Ambient	159,500	22,500	182,000
	Post 40 µm	140,666	500	141,166

Hydac-2 January 31, 2011

Time point		Size Class 1 >75 µm to <120µm	Size Class 2 ~ 1 mm	Total >50-µm
T-0 Initial	Ambient	119,000	5,500	124,500
	Post 40 µm	97,166	0	97,166
T-1 Mid	Ambient	60,500	13,500	74,000
	Post 40 µm	53,333	0	53,333
T-2 Final	Ambient	135,500	5,500	141,000
	Post 40 µm	108,166	0	108,166

Hydac-3 February 2, 2011

Time point		Size Class 1 >75 µm to <120µm	Size Class 2 ~ 1 mm	Total >50-µm
T-0 Initial	Ambient	60,500	1,500	62,000
	Post 40 µm	58,833	0	58,833
T-1 Mid	Ambient	74,000	6,000	80,000
	Post 40 µm	59,333	0	59,333
T-2 Final	Ambient	71,000	3,000	74,000
	Post 40 µm	46,500	0	46,500

Hydac-4 May 24, 2011

Time point		Size Class 1 >75 µm to <120µm	Size Class 2 ~ 1 mm	Total >50-µm
T-0 Initial	Ambient	241,000	4,000	245,000
	Post 40 µm	212,000	0	212,000
T-1	Ambient	202,000	7,000	209,000
	Post 40 µm	154,000	0	154,000
T-2	Ambient	155,000	11,000	166,000
	Post 40 µm	151,000	3,000	154,000
T-3	Ambient	162,000	8,000	170,000
	Post 40 µm	138,000	0	138,000
T-4	Ambient	237,000	9,000	246,000
	Post 40 µm	166,000	1,000	167,000
T-5 Final	Ambient	217,000	4,000	221,000
	Post 40 µm	173,000	1,000	174,000

Hydac-5 May 25, 2011

Time point		Size Class 1 >75 µm to <120µm	Size Class 2 ~ 1 mm	Total >50-µm
T-0 Initial	Ambient	227,000	6,000	233,000
	Post 40 µm	193,000	0	193,000
T-1	Ambient	271,000	5,000	276,000
	Post 40 µm	217,000	1,000	218,000
T-2	Ambient	288,000	4,000	292,000
	Post 40 µm	256,000	0	256,000
T-3	Ambient	287,000	2,000	289,000
	Post 40 µm	214,000	0	214,000
T-4	Ambient	392,000	1,000	393,000
	Post 40 µm	234,000	0	234,000
T-5 Final	Ambient	404,000	3,000	407,000
	Post 40 µm	278,000	0	278,000

Hydac-6 May 26, 2011

Time point		Size Class 1 >75 µm to <120µm	Size Class 2 ~ 1 mm	Total >50-µm
T-0 Initial	Ambient	193,000	4,000	197,000
	Post 40 µm	175,000	0	175,000
T-1	Ambient	213,000	3,000	216,000
	Post 40 µm	160,000	0	160,000
T-2	Ambient	335,000	2,000	337,000
	Post 40 µm	217,000	0	217,000
T-3	Ambient	278,000	2,000	280,000
	Post 40 µm	170,000	0	170,000
T-4	Ambient	258,000	1,000	259,000
	Post 40 µm	183,000	0	183,000
T-5 Final	Ambient	284,000	3,000	287,000
	Post 40 µm	177,000	0	177,000

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

The following two tables describe phytoplankton species composition during various trials in two different size classes.

Hydac 1, 2, and 3

Dominant Species	**Type**	**General Size**
Skeletonema costata	Diatom (chain forming)	Individual cells 9-10 µm but forms long chains, 100+µm long
Heterocapsa rotundatum	Dinoflagellate	5 – 6 µm
Other Noted Species (small #)		
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

Hydac 4, 5 and 6

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
Ceratulina pelagica	Diatom (chain forming)	100 x 24 µm (can form larger chains)
Cosinodiscus sp.	Diatom (centric)	Approx. 110 µm diameter
Gonyaulux sp.	Dinoflagellate	24 x 40 µm
Gyrodinium estruariale	Dinoflagellate	15 x 11 µm
Gymnodinium galiesianum	Dinoflagellate	15 x 18 µm
Heterocapsa rotundatum	Dinoflagellate	Approx. 5 – 6 µm
Heterocapsa triquerta	Dinoflagellate	24 x 16 µm
Rhizosolenia pungens	Diatom	Varies 4 – 12 µm 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 but forms long chains 100+ µm in length
Synedra 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	

The data below describes the numbers of phytoplankton in both the ambient challenge water and the post Hydac filter water during all test trials. Size-class distinctions or measures are determined by considering the greatest available measure among the x, y, and z axis. Total phytoplankton numbers are broken into two size classes.

Hydac-1 January 25, 2011

Time Point	Total Phyto 10-50 µm (#/ml) Ambient	Post 40 µm	Total Phyto 5-10 µm (#/ml) Ambient	Post 40 µm
T-0 Initial	10,507	5,515	15,752	18,119
T-1 Mid	12,090	10,870	18,756	29,288
T-2 Final	7,817	3,553	22,182	22,307

Hydac-2 January 31, 2011

Time Point	Total Phyto 10-50 µm (#/ml) Ambient	Post 40 µm	Total Phyto 5-10 µm (#/ml) Ambient	Post 40 µm
T-0 Initial	8,969	7,257	19,728	20,547
T-1 Mid	12,340	8,598	14,780	11,897
T-2 Final	10,052	2,235	17,755	13,172

Hydac-3 February 2, 2011

Time Point	Total Phyto 10-50 µm (#/ml) Ambient	Post 40 µm	Total Phyto 5-10 µm (#/ml) Ambient	Post 40 µm
T-0 Initial	12,567	3,674	24,280	14,963
T-1 Mid	10,128	2,606	23,370	11,047
T-2 Final	7,310	2,159	15,934	7,466

Hydac-4 May 24, 2011

Time Point	Total Phyto 10-50 µm (#/ml) Ambient	Post 40 µm	Total Phyto 5-10 µm (#/ml) Ambient	Post 40 µm
T-0 Initial	1,892	967	16,832	16,887
T-1	827	256	21,524	19,612
T-2	926	323	18,696	19,606
T-3	398	308	15,976	10,434
T-4	658	318	13,154	13,967
T-5 Final	733	191	14,495	10,034

Hydac-5 May 25, 2011

Time Point	Total Phyto 10-50 µm (#/ml) Ambient	Post 40 µm	Total Phyto 5-10 µm (#/ml) Ambient	Post 40 µm
T-0 Initial	320	426	17,045	12,462
T-1	371	130	10,586	8,012
T-2	570	147	18,374	10,283
T-3	444	158	22,611	13,069
T-4	615	200	27,078	19,048
T-5	603	73	23,946	11,387

Hydac-6 May 26, 2011

Time Point	Total Phyto 10-50 µm (#/ml) Ambient	Post 40 µm	Total Phyto 5-10 µm (#/ml) Ambient	Post 40 µm
T-0 Initial	488	173	22,131	28,177
T-1	624	97	20,541	15,187
T-2	482	203	27,534	23,673
T-3	933	130	36,384	20,517
T-4	1,197	315	45,076	34,793
T-5	1,242	133	36,044	18,951

5.0 Acknowledgments

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Appendix A. Vendor Comments