Final Report for the Performance Evaluation of the FILTREX ACB Filter System

Maritime Environmental Resource Center

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Questions and comments should be directed to: Dr. Mario Tamburri
Maritime Environmental Resource Center
Chesapeake Biological Laboratory
University of Maryland Center for Environmental Science
PO Box 38 / 146 Williams Street
Solomons, Maryland 20688, USA
Email: tamburri@umces.edu

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1. Background and Objectives of MERC Technology Evaluations

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), University of Maryland (UMD), and Old Dominion University (ODU) to provide independent performance testing and to help facilitate the transition of new treatment technologies to shipboard implementation and operations.

MERC evaluated the performance characteristics of the Filtrex ACB Filtration System through objective and quality assured land-based testing. The goal of this specific evaluation was to provide information on the performance of the system under the conditions specified in the test plan. The data and information on performance characteristics cover legitimate information that users need and compare performance against the U.S. Coast Guard regulations for discharge of ballast water and similar International Maritime Organization (IMO) D-2 regulatory discharge standards.

MERC does not certify technologies nor guarantee that a treatment will always, or under circumstances other than those used in testing, operate at the levels verified. Treatment systems are not labeled or listed as acceptable or unacceptable. However, tests and results are in a format consistent with that requested by specific regulations (e.g., IMO D2, G8 and G9) so they can be used to determine compliance by Administrations and classification societies. Sampling and analytical procedures utilized by the MERC team also comply with the US Environmental Protection Agency ETV Protocols (2010) in anticipation of the publication of U.S. Federal Standards under the auspices of the U.S. Coast Guard. Final summary reports on technology performance will be reviewed by the members of the MERC Advisory Board and provided to FILTREX and the MERC funding agencies prior to public release. All specific terms of a testing program associated with a particular treatment system, including management of test findings, are outlined in a Participation Agreement executed between the treatment developer and MERC/University of Maryland Center for Environmental Science.

2. Introduction to Technology

Filtrex has developed its ACB filter as a tailored solution to fulfill the current and future water treatment requirements. Filtrex micronic self-cleaning technology was developed in the eighties for the filtration of lube oil and heavy fuel oil in marine applications for the military then for merchant ships. In the '90s the same technology was applied in the oil and gas market for process fluids filtration. In the last few years, the filter has been used for water treatment (marine, brackish and fresh water). Noble material, as bronze-aluminum alloy, was chosen to ensure durability, less maintenance and lower TCO (Total Cost of Ownership); maintaining at the same time a small size, being made of few parts, and with low levels of backwash fluid. The ACB filter flow rate range is from 6 to 3,000 m^3/h.

The filter works "on-condition", using the same filtered fluid for back washing. As more and more impurities build up on the cartridge surface, the differential pressure (dp) gradually increases, until it reaches the set-point value; at this set-point the cleaning phase starts. The cleaning operation is made by a nozzle rotating inside the filtering element basket. While all the filtering sectors of the filter element assure the filtration of the fluid, the sector in front of the nozzle is cleaned by a high-efficiency backwash flow. The cleaning time lasts for a few seconds.

3. Summary of USCG and IMO Standards

This report refers to, and incorporates specifics guidelines and requirements found in:

- International Maritime Organization (2008) Resolution MEPC.174 (58) Guidelines for Approval of Ballast Water Management Systems (G8); and
- ETV Generic Protocols for the Verification of Ballast Water Treatment Technologies, (2010) EPA/600/R-10/146.

USCG Regulations and the IMO Convention both include the following ballast discharge standards:

1) Less than 10 viable [live] organisms per m^3, greater than or equal to 50 μm in minimum dimension;

2) Less than 10 viable [live] organisms per ml, less than 50 μm in minimum dimension and greater than or equal to 10 μm in minimum dimension and

3) Less than the following concentrations of indicator microbes, as a human health standard:

1. Toxigenic *Vibrio cholerae* (serogroups O1 and O139), less than 1 colony forming unit (cfu) per 100 ml
2. *Escherichia coli,* less than 250 cfu per 100 ml;
3. Intestinal Enterococci, less than 100 cfu per 100 ml.

4. Summary of Test Protocols, Sampling Design, Hydraulics Testing

4.1. Test Protocols

This report presents the results for the MERC performance evaluation of the Filtrex ACB filter system. Details on program policies and testing approaches/methodologies can be found in the MERC Quality Management Plan (QMP), Quality Assurance Project Plan (QAPP) and various Standard Operating Procedures (SOPs) available upon request.

4.1.1. Commissioning

Prior to any formal testing, at least one mechanical commissioning run of each Filtrex system was provided to assure appropriate treatment operations (FXIT-[μm]-COMM). This run identified and corrected initial mechanical or operating issues. During the commissioning process, feed pump capacity was adjusted to the requested flow rate, the outlet throttling valve was adjusted, back wash delta pressure set point was determined; plus, the Filtrex instantaneous and accumulated data logging system was tested. Data collected during the commissioning was used for test preparations and is not provided in this final report.

After each treatment system commissioning was completed and accepted by Filtrex, MERC conducted biological efficacy trials on the MERC Mobile Test Platform (MTP) located in the Baltimore Harbor, MD.

4.1.2. Biological Efficacy Trials

MERC conducted a total of seven biological efficacy trials focused exclusively on live organisms ≥ 50 μm and ≥ 10 to < 50 μm in size. (See descriptions below and in MERC QAPP and SOPs). Each test was conducted using one track of the MERC barge piping system set in the sea-to-sea configuration. The paired tests included one trial of filter efficacy using natural ambient Baltimore Harbor water (FXIT-[μm]-NTL) and a second trial using augmented natural water to increase total suspended solids (TSS) and particulate organic carbon (POC) to ETV concentrations (FXIT- [μm]-AUG). Filtrex selected the flow rates (m^3/hr) and selected to use the flow meter located just prior to the Filtrex system. Filtrex also chose the backpressures (psi/bar) that the MERC system provided to the Filtrex system.

4.2. Sampling Design Overview

Statistically-validated (Miller et al., 2011), continuous, time-integrated samples were collected through sample ports located on the system pipes just prior to entry into the Filtrex filtration system and just after exit from the Filtrex filtration system. All sample ports include a valve and sample tube with a 90^o bend towards the direction of flow, placed in the center of the piping system (based on the design developed and validated by the US Naval Research Laboratory, Key West Florida; see ETV protocols). Summaries of the physical, chemical, and biological analyses for each sample are described below. Analyses details are found in the MERC SOPs.

Water for biological examination was split for sampling the ≥ 50μm size fraction (nominally zooplankton), ≥10 to <50 μm size fraction (nominally phytoplankton) and water quality analyses, including total suspended solids (TSS), particulate organic carbon (POC) and

chlorophyll (Chl). These analyses were carried out on representative samples collected from challenge water (upstream of the Filtrex system) and treated water (down stream of the Filtrex system). A hand-held multiparameter instrument measured temperature, salinity, and dissolved oxygen in the challenge (pre-filter) and treated (post-filter) water overflow drums at three time-points during each trial: beginning, middle and end. At the completion of each trial, the MERC piping system was immediately flushed with fresh municipal water. See MERC SOPs for additional details concerning operations and sampling.

4.3. Hydraulic tests

During the tests, Filtrex conducted independent hydraulic tests to add technological supporting data and study filter performance. A Filtrex engineer monitored the following parameters: instantaneous flow rate, daily accumulated flow, delta pressure on the filter, and number of back washes per working day.

5. Summary of Results

Note: key performance data is provided in sections 5 - 9. All raw data and complete datasets from this evaluation, including operational data, are available upon request.

MERC conducted seven land-based trials of the Filtrex ACB filtration system, under various conditions, during the fall of 2013 (Table 1). This performance evaluation was based on physical and biological characterization of challenge (pre-filter) water versus treated (post filter) water for two IMO D-2 and USCG regulated biological efficacy categories: ≥50 µm and ≥10 - <50 µm (Table 2). During the natural (NTL) water trials, *in situ* TSS and POC concentrations were not manipulated. During the augmented (AUG) trials, the target TSS concentration was ~ 50 mg/L and the target POC concentration was >5 mg/L. The augmentation trial for FXIT-30.1 µm was canceled due to inclement weather. A Filtrex 10 µm filter was also hydraulically tested; however, no biological efficacy trials were performed.

Table 1. Trial Summary

Trial ID	Trial Date	Filter Type	Water Type
FXIT-30-NTL	5 Nov 2013	Filtrex 30 µm filter	Natural
FXIT-30-AUG	7 Nov 2013	Filtrex 30 µm filter	Augmented
FXIT-20-NTL	13 Nov 2013	Filtrex 20 µm filter	Natural
FXIT-20-AUG	14 Nov 2013	Filtrex 20 µm filter	Augmented
FXIT-06-NTL	18 Nov 2013	Filtrex 6 µm filter	Natural
FXIT-06-AUG	20 Nov 2013	Filtrex 6 µm filter	Augmented
FXIT-30.1-NTL	9 Dec 2013	Filtrex 30 µm filter	Natural

Biological Efficacy:

Water quality conditions and planktonic communities during this evaluation were typical of fall in the upper Chesapeake Bay. Below (Table 2) is a summary of live organism concentrations found in the challenge water (pre-filter) and treated (post-filter) samples. More detailed datasets for each trial are provided in Sections 6 - 9.

Table 2. Summary of Live Organism Concentrations for all trials.

FXIT-30-NTL	**≥50 µm**		**≥10-<50 µm**	
Sample ID	**Ave (#/m^3)**	**SD**	**Ave (#/ml)**	**SD**
Challenge (pre-filter)	32,243	3,356	1,517	150
Treated (post-filter)	32,909	1,053	1,190	61

FXIT-30-AUG	**≥50 µm**		**≥10 - <50 µm**	
Sample ID	**Ave (#/m^3)**	**SD**	**Ave (#/ml)**	**SD**
Challenge (pre-filter)	66,782	3,383	1,260	62
Treated (post-filter)	62,517	1,216	947	161

FXIT-20-NTL	**≥50 µm**		**≥10 - <50 µm**	
Sample ID	**Ave (#/m^3)**	**SD**	**Ave (#/ml)**	**SD**
Challenge (pre-filter)	55,235	2,066	1,124	107
Treated (post-filter)	22,412	1,612	459	85

FXIT-20-AUG	**≥50 µm**		**≥10 - <50 µm**	
Sample ID	**Ave (#/m^3)**	**SD**	**Ave (#/ml)**	**SD**
Challenge (pre-filter)	53,984	2,361	1,864	292
Treated (post-filter)	24,823	2,174	1,185	121

FXIT-06-NTL	**≥50 µm**		**≥10 - <50 µm**	
Sample ID	**Ave (#/m^3)**	**SD**	**Ave (#/ml)**	**SD**
Challenge (pre-filter)	142,276	8,983	15,150	831
Treated (post-filter)	1,924	198	8,960	1,591

FXIT-06-AUG	**≥50 µm**		**≥10 - <50 µm**	
Sample ID	**Ave (#/m^3)**	**SD**	**Ave (#/ml)**	**SD**
Challenge (pre-filter)	102,869	4,500	9,097	967
Treated (post-filter)	300	55	3,273	290

FXIT-30.1-NTL	**≥50 µm**		**≥10 - <50 µm**	
Sample ID	**Ave (#/m^3)**	**SD**	**Ave (#/ml)**	**SD**
Challenge (pre-filter)	253,684	2,672	2,633	401
Treated (post-filter)	119,560	3,159	2,260	87

NTL = natural water
AUG = augmented water

6. FXIT-30

6.1. FXIT-30-COMM

Prior to any formal testing, a mechanical commissioning run of the Filtrex system using a 30 µm filtration mesh size was provided to assure appropriate treatment operations. This run was used to identify and correct initial mechanical or operating issues. During the commissioning process the feed pump capacity was adjusted to 250 m^3/hr, the outlet throttling valve was adjusted, the back wash delta pressure set point was established, and instantaneous and accumulated data logging was set up. Data collected during commissioning was only used for test preparations and is not provided in the final report.

After treatment system commissioning was completed and accepted by Filtrex, MERC conducted two trials to evaluate the 30-µm filtration mesh size for biological efficacy. The biological efficacy trials focused exclusively on live organisms ≥50 µm and ≥10 - <50 µm in size. Each test was conducted using the MERC barge piping system set in the sea-to-sea configuration. The two tests included one trial of filter efficacy with natural Baltimore Harbor water (FXIT-30-NTL) and a second trial with augmented natural water to increase TSS and POC (FXIT-30-AUG). Filtrex selected a flow rate of 250 m^3/hr and 1 bar of backpressure be provided to the Filtrex filter system.

6.2. FXIT-30-NTL (5 Nov 2013)

Natural harbor water.

NTL Physical Data

Measured in the challenge and treated overflow drums at three time points, using a multi-parameter instrument.

NTL Challenge (pre-filter)

Time Point	**Temp** (C)	**Salinity** (psu)	**Dissolved Oxygen** (mg/L)	**Dissolved Oxygen** (%)
TP1	14.1	11.6	8.0	83
TP2	14.5	11.8	7.9	83
TP3	14.6	11.9	7.6	79

NTL Treated (post-filter)

Time Point	**Temp** (C)	**Salinity** (psu)	**Dissolved Oxygen** (mg/L)	**Dissolved Oxygen** (%)
TP1	14.3	11.6	8.0	84
TP2	14.3	11.8	8.1	85
TP3	14.6	11.8	7.6	80

NTL Total Suspended Solids (TSS)
TSS values for this trial are not provided because they did not meet MERC data quality standards. However, there did not appear to be significant differences between challenge and treated TSS values, both between approximately 3 and 4 mg/L.

NTL Particulate Carbon Data
Samples from the time-integrated chambers.

Sample ID	Ave (mg/L)	SD
Challenge	1.09	0.02
Treated	1.09	0.02

NTL Live Organisms ≥50 µm
Samples from the 35 µm mesh nets.

Sample ID	Ave (#/m^3)	SD
Challenge	32,243	3,356
Treated	32,909	1,053

Zooplankton Taxa and Observations
Minimum dimensions measured.

Challenge (pre-filter)
1. Eleven (11) taxa or general categories were present in the challenge samples: Calanoida, Cyclopoida, Harpacticoida, bivalves, diatoms, copepod nauplii, polychaetes, barnacle nauplii, Nematoda, eggs, and Rotifera
2. Calanoida, Cyclopoida, Harpacticoida, (all adult-stage copepods), bivalves and diatoms, were in very low abundance.
3. The remaining taxa: copepod nauplii, polychaetes, barnacle nauplii, Nematoda, eggs, and Rotifera were similar to the treated sample in size and abundance.

Treated (post-filter)
1. Six (6) taxa or general categories remained in the treated sample: copepod nauplii, polychaetes, barnacle nauplii, Nematoda, eggs, and Rotifera.
2. Large abundances of copepod nauplii and rotifers were present in the 50-60 µm size class.
3. Polychaetes (soft-bodied) found were mainly in the 50-80 µm size class; however, two polychaetes measured about 110 µm.

NTL Live Organisms ≥10 - <50 µm
Samples from the time-integrated chambers.

Sample ID	Ave (#/ml)	SD
Challenge	1,517	150
Treated	1,190	61

Phytoplankton Observations

Challenge and Treated
The majority of cells in both challenge and treated samples were sized at 15 -25 µm. *Chaetoceros* (small chains - none longer than 3 cells) was the dominant species. One large unknown diatom species was noted in the challenge sample, but not present in the treated sample.

NTL Active Chlorophyll-a Data
Samples from the time-integrated chambers.

Sample ID	Ave (µg/L)	SD
Challenge	20.2	0.38
Treated	20.4	0.32

6.3. FXIT-30-AUG (7 Nov 2013)
Augmented harbor water.

AUG Physical Data
Measured in the challenge and treated overflow drums at three time points, using a multi-parameter instrument.

AUG Challenge (pre-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	14.7	11.1	9.3	96
TP2	14.8	11.1	8.9	93
TP3	14.7	11.1	9.3	98

AUG Treated (post-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	14.7	11.1	9.0	95
TP2	14.8	11.1	9.3	97
TP3	14.7	11.1	8.9	94

AUG Total Suspended Solids (TSS)
TSS values for this trial are not provided because they did not meet MERC data quality standards. However, there appeared to be clear decrease in TSS from approximately 50 mg/L in challenge water to approximately 40 mg/L in treated (post-filter) water.

AUG Particulate Carbon Data
Challenge and treated samples from the time-integrated chambers. Ambient sample was taken before augmentation.

Sample ID	Ave (mg/L)	SD
Ambient	1.11	0.02
Challenge	4.64	0.16
Treated	3.63	0.18

AUG Live Organisms ≥50 µm
Samples from the 35 µm mesh nets.

Sample ID	Ave (#/m^3)	SD
Challenge	66,782	3,383
Treated	62,517	1,216

Zooplankton Taxa and Observations

Minimum dimensions measured. The higher numbers on this date compared to FXIT-30-NTL, were due to an increased abundance of rotifers and copepod nauplii.

Challenge (pre-filter)
1. Eleven (11) taxa or general categories were present in the challenge sample: Calanoida, Cyclopoida, Harpacticoida, bivalves, diatoms, copepod nauplii, polychaetes, barnacle nauplii, Nematoda, Rotifera and eggs.
2. Calanoida, Cyclopoida, Harpacticoida (all adult-stage copepods), bivalves and diatoms were very low in abundance.
3. The remaining 6 taxa/general categories: copepod nauplii, polychaetes, barnacle nauplii, Nematoda, eggs and rotifers were similar in size and abundance to the treated samples.
4. Augmentation material was present in the samples.

Treated (post-filter)
1. Six (6) taxa/general categories remained in the treated samples: copepod nauplii, polychaetes, barnacle nauplii, Nematoda, eggs, and Rotifera.
2. Large abundances of copepod nauplii and rotifers were present in the 50-60 µm size class.
3. The majority of the polychaetes (soft-bodied) were in the 50-70 µm size class; however, one polychaete measured 90 µm.
4. Augmentation material was present in the samples.

AUG Live Organisms ≥10 - <50 µm
Samples from the time-integrated chambers.

Sample ID	Ave (#/ml)	SD
Challenge	1,260	62
Treated	947	161

Phytoplankton Observations

Challenge and Treated
The majority of cells in both challenge and treated samples were 15 -25 µm with nothing measuring greater than 30 µm. The dominant species in both the challenge and treated samples was *Chaetoceros* (small chains - none longer than 3 cells).

AUG Active Chlorophyll-a Data
Challenge and treated samples from the time-integrated chambers. Ambient sample was taken before augmentation.

Sample ID	Ave (µg/L)	SD
Ambient	16.44	0.29
Challenge	13.84	0.13
Treated	13.03	1.14

7. FXIT-20

7.1. FXIT-20-COMM

Prior to any formal testing, a mechanical commissioning run of the Filtrex system using a 20-µm filtration mesh size was provided to assure appropriate treatment operations. This run was used to identify and correct initial mechanical or operating issues. During the commissioning process the feed pump capacity was adjusted to 250 m^3/hr, the outlet throttling valve was adjusted, the back wash delta pressure set point was established, and instantaneous and accumulated data logging was set up. Data collected during commissioning was only used for test preparations and is not provided in the final report.

After treatment system commissioning was completed and accepted by Filtrex, MERC conducted two trials to evaluate the 20-µm filtration mesh size for biological efficacy. The biological efficacy trials focused exclusively on live organisms ≥ 50 µm and ≥10 - <50 µm in size. Each test was conducted using the MERC barge piping system set in the sea-to-sea configuration. The two tests included one trial of filter efficacy with natural Baltimore Harbor water (FXIT-20-NTL) and a second trial with augmented natural water to increase TSS and POC (FXIT-20-AUG). Filtrex selected a flow rate of 250 m^3/hr and 1.2 bar of backpressure be provided to the Filtrex filter system.

7.2. FXIT-20-NTL (13 Nov 2013)
Natural harbor water.

NTL Physical Data
Measured in the challenge and treated overflow drums at three time points using a multi-parameter instrument.

NTL Challenge (pre-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	12.6	11.8	7.8	77
TP2	12.8	11.9	7.8	77
TP3	13.0	12.0	7.3	74

NTL Treated (post-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	12.6	11.8	8.0	79
TP2	12.9	11.9	7.5	75
TP3	13.3	12.0	7.0	70

NTL Total Suspended Solids (TSS)
TSS samples at three time points taken from challenge and treated sampling hoses.
TSS MDL = 2.4 mg/L.

Sample ID	Sample Time	TSS AVE (mg/L)	TSS SD
Challenge 1	0906	2.5	0.3
Challenge 2	0933	2.1	0.2
Challenge 3	0956	1.9	0.2
Treated 1	0906	2.1	0.2
Treated 2	0933	1.8	0.1
Treated 3	0956	1.7	0.1

NTL Particulate Carbon Data
Samples from the time-integrated chambers.

Sample ID	Ave (mg/L)	SD
Challenge	0.44	0.01
Treated	0.38	0.01

NTL Live Organisms ≥50 µm
Samples from the 35 µm mesh nets.

Sample ID	Ave (#/m^3)	SD
Challenge	55,235	2,066
Treated	22,412	1,612

Zooplankton Taxa and Observations
Minimum dimensions measured.

Challenge (pre-filter)
1. Eleven (11) taxa or general categories were present in the challenge samples: copepod nauplii, Calanoida, Cyclopoida, Harpacticoida, Rotifera, Polychaeta, barnacle nauplii, diatoms, eggs, chaetognaths, and bivalves.
2. Copepod nauplii were the most abundant taxa.

Treated (post-filter)
1. Five (5) taxa or general categories, copepod nauplii, Polychaeta, Rotifera, eggs, and barnacle nauplii were present in the treated samples.
2. Six (6) taxa or general categories listed in the challenge sample were *absent* in the treated samples: Calanoida, Cyclopoida, Harpacticoida (all three are adult-stage copepods), diatoms, chaetognaths, and bivalves.
3. Fifty percent (50%) fewer copepod nauplii were found in the treated samples than in the challenge samples.
4. Copepod nauplii measured mainly in the 50-60 µm size class, with one measuring 85 µm.
5. Polychaetes, rotifers and eggs were similar in quantities in both challenge and treated samples.
6. Polychaetes measured mainly in the 50-80 µm size class, with two measuring 90 µm.

NTL Live Organisms ≥10 - <50 µm
Samples from the time-integrated chambers.

Sample ID	Ave (#/ml)	SD
Challenge	1,124	107
Treated	459	85

Phytoplankton Observations

Challenge and Treated
1. Majority of the species observed are diatoms, including *Skeletonema* and *Chaetoceros*. Most (at least three species) are short chain formers (8 cells or less). A few larger discoid and pennate diatom forms were noted.

Treated (post-filter)
1. Numbers were noticeably reduced in the treated samples.
2. Some larger diatoms and chains over 20 µm were observed.

NTL Active Chlorophyll-a Data
Samples from the time-integrated chambers.

Sample ID	Ave (µg/L)	SD
Challenge	2.80	0.06
Treated	2.77	0.02

7.3. FXIT-20-AUG (14 Nov 2013)
Augmented harbor water.

AUG Physical Data
Measured in the challenge and treated overflow drums at three time points using a multi-parameter instrument.

AUG Challenge (pre-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	12.3	11.8	8.5	84
TP2	12.4	11.9	8.3	82
TP3	12.3	11.9	8.5	84

AUG Treated (post-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	12.3	11.9	8.5	84
TP2	12.4	11.9	8.1	81
TP3	12.3	11.9	8.3	81

AUG Total Suspended Solids (TSS)
TSS samples at three time points taken from challenge and treated sampling hoses. Ambient sample was taken before augmentation. TSS MDL = 2.4 mg/L.

Sample ID	Sample Time	TSS AVE (mg/L)	TSS SD
Ambient	0900	2.3	0.1
Challenge 1	0926	47.6	0.7
Challenge 2	0950	42.7	0.9
Challenge 3	1016	40.9	0.6
Treated 1	0926	30.2	0.4
Treated 2	0950	33.6	0.4
Treated 3	1016	33.4	0.2

AUG Particulate Carbon Data
Challenge and treated samples from the time-integrated chambers. Ambient sample was taken before augmentation.

Sample ID	Ave (mg/L)	SD
Ambient	0.48	0.02
Challenge	3.57	0.03
Treated	2.82	0.08

AUG Live Organisms ≥50 µm
Samples from the 35 µm mesh nets.

Sample ID	Ave (#/m^3)	SD
Challenge	53,984	2,361
Treated	24,823	2,174

Zooplankton Taxa and Observations
Minimum dimensions measured.

Challenge (pre-filter)
1. Ten (10) taxa or general categories were present in the challenge samples: copepod nauplii, Calanoida, Polychaeta, Rotifera, diatoms, Harpacticoida, barnacle nauplii, eggs, bivalves, and Turbellaria
2. One quarter of the adult copepods (Calanoida and Harpacticoida) were damaged, possibly due to heavy grazing.
3. Augmentation material was present in the samples.

Treated (post filter)
1. Six (6) taxa or general categories were present in the challenge samples: copepod nauplii, Polychaeta, Rotifera, eggs, bivalves, and Calanoida .

2. Four (4) taxa or general categories listed in the challenge sample were *absent* in the treated samples: diatoms, Harpacticoida, barnacle nauplii, and Turbellaria
3. Fifty percent (50%) fewer copepod nauplii were found in the treated samples as in the challenge samples.
4. Polychaetes, rotifers and eggs were similar in quantities in both challenge and treated samples.
5. Copepod nauplii and rotifers in treated samples measured mainly in the 50-60 µm size class.
6. Polychaetes were in the 50-70 µm size class.
7. Bivalves averaged 60 µm in size.
8. Only one Calanoida measuring 64 µm was identified.
9. Augmentation material was present in the samples.

AUG Live Organisms ≥10 - <50 µm
Samples from the time-integrated chambers.

Sample ID	Ave (#/ml)	SD
Challenge	1,864	292
Treated	1,185	121

Phytoplankton Observations
Dominant species was the diatom *Skeletonema*.

Challenge and Treated
1. Larger number of long chains (10-12 cells), increasing the population density.
2. None of the three chain-forming species (*Skeletonema*, *Thalassiosira*, and *Chaetoceros*), observed were over 20 µm in their minimum dimension.
3. Augmentation material was observed in all samples.

Treated (post-filter)
1. Few observed in the treated samples were over 20 µm.
2. The larger plankton noted in the challenge samples were absent in the treated samples.

AUG Active Chlorophyll-a Data
Challenge and treated samples from the time-integrated chambers. Ambient sample was taken before augmentation.

Sample ID	Ave (µg/L)	SD
Ambient	6.31	0.32
Challenge	6.48	0.10
Treated	5.55	0.36

8. FXIT-06

8.1. FXIT-06-COMM

Prior to any formal testing, two mechanical commissioning runs of the Filtrex system using a 06 μm filtration mesh size were provided to assure appropriate treatment operations. This run was used to identify and correct initial mechanical or operating issues. During the commissioning process the feed pump capacity was adjusted several times to find the best speed for biological sampling, the outlet throttling valve was adjusted, the back wash delta pressure set point was established, and instantaneous and accumulated data logging was set up. Data collected during commissioning was only used for test preparations and is not provided in the final report.

After treatment system commissioning was completed and accepted by Filtrex, MERC conducted two trials to evaluate the 06-μm filtration mesh size for biological efficacy. The biological efficacy trials focused exclusively on live organisms ≥ 50 μm and ≥10 - <50 μm in size. Each test was conducted using the MERC barge piping system set in the sea-to-sea configuration. The two tests included one trial of filter efficacy with natural Baltimore Harbor water (FXIT-06-NTL) and a second trial with augmented natural water to increase TSS and POC (FXIT-06-AUG). Filtrex selected a flow rate of 108 m^3/hr and 1.2-1.5 bar of backpressure be provided to the Filtrex filter system.

8.2. FXIT-06-NTL (18 Nov 0613)

Natural harbor water.

NTL Physical Data - *Note: plankton blooms in progress.*
Measured in the challenge and treated overflow drums at three time points using a multi-parameter instrument.

NTL Challenge (pre-filter)

Time Point	**Temp** (C)	**Salinity** (psu)	**Dissolved Oxygen** (mg/L)	**Dissolved Oxygen** (%)
TP1	11.3	9.3	14.2	137
TP2	11.2	9.7	13.6	132
TP3	11.3	9.8	13.2	129

NTL Treated (post-filter)

Time Point	**Temp** (C)	**Salinity** (psu)	**Dissolved Oxygen** (mg/L)	**Dissolved Oxygen** (%)
TP1	11.3	9.3	13.5	131
TP2	11.2	9.7	13.0	126
TP3	11.3	9.8	13.2	124

NTL Total Suspended Solids (TSS)
TSS samples at three time points taken from challenge and treated sampling hoses.
TSS MDL = 2.4 mg/L.

Sample ID	Sample Time	TSS AVE (mg/L)	TSS SD
Challenge 1	1143	5.8	0.3
Challenge 2	1207	4.9	0.1
Challenge 3	1234	5.0	0.1
Treated 1	1143	5.4	0.4
Treated 2	1207	4.7	0.4
Treated 3	1234	4.2	0.3

NTL Particulate Carbon Data
Samples from the time-integrated chambers.

Sample ID	Ave (mg/L)	SD
Challenge	2.13	0.01
Treated	1.84	0.00

NTL Live Organisms ≥50 µm
Samples from the 35 µm mesh nets.

Sample ID	Ave (#/m3)	SD
Challenge	142,276	8,983
Treated	1,924	198

Zooplankton Taxa and Observations
Minimum dimensions measured.

Challenge (pre-filter)
1. Eleven (11) taxa or general categories were present in the challenge samples: copepod nauplii, Rotifera, bivalves, Polychaeta, diatoms, Calanoida, barnacle nauplii, eggs, harpacticoid, tintinnids, and Nematoda.
2. Copepod nauplii were the most abundant taxa.

Treated (post-filter)
1. Four (4) of the eleven taxa or general categories remained in the treated samples: Rotifera, copepod nauplii, eggs, and Polychaeta.
2. Copepod nauplii were in the 50-60 µm size class but fewer were found in the treated samples than in the challenge samples. The removal of live organisms > 50 µm was 98.6%
3. Polychaetes found were mainly in the 50-70 µm size class.

NTL Live Organisms ≥10 - <50 µm
Samples from the time-integrated chambers.

Sample ID	Ave (#/ml)	SD
Challenge	15,150	831
Treated	8,960	1,591

Phytoplankton Observations

Challenge and Treated
1. A very diverse population was observed containing the 17 species already noted.
2. The dominant species was the diatom *Skeletonema* with long chains of 14-16 cells.
3. *Prorocentrum*, the dominant dinoflagellate, caused a brown coloration in the water.

Treated (post-filter)
1. Numbers were noticeably reduced in the treated samples.
2. Although the majority of the larger species were removed, many in the 30 µm range were noted in the treated sample.

NTL Active Chlorophyll-a Data
Samples from the time-integrated chambers.

Sample ID	Ave (µg/L)	SD
Challenge	35.8	1.5
Treated	34.4	0.6

8.3. FXIT-06-AUG (20 Nov 2013)
Augmented harbor water.

AUG Physical Data
Measured in the challenge and treated overflow drums at three time points using a multi-parameter instrument.

AUG Challenge (pre-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	10.2	11.0	10.5	97
TP2	10.1	11.1	10.0	94
TP3	10.4	11.2	10.2	96

AUG Treated (post-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	10.3	11.1	10.0	94
TP2	10.4	11.2	10.0	94
TP3	10.5	11.2	10.0	94

AUG Total Suspended Solids (TSS)

TSS samples at three time points taken from Challenge and treated sampling hoses. Ambient sample was taken before augmentation. TSS MDL = 2.4 mg/L.

Sample ID	Sample Time	TSS AVE (mg/L)	TSS SD
Ambient	1000	3.9	0.6
Challenge 1	0946	30.4	0.4
Challenge 2	1007	44.1	0.6
Challenge 3	1034	55.2	1.1
Treated 1	0946	18.3	0.3
Treated 2	1007	21.4	0.0
Treated 3	1034	21.8	0.2

AUG Particulate Carbon Data

Challenge and treated samples from the time-integrated chambers. Ambient sample was taken before augmentation.

Sample ID	Ave (mg/L)	SD
Ambient	1.01	0.01
Challenge	4.10	0.03
Treated	2.14	0.02

AUG Live Organisms ≥50 µm

Samples from the 35 µm mesh nets.

Sample ID	Ave (#/m3)	SD
Challenge	102,869	4,500
Treated	300	55

Zooplankton Taxa and Observations
Minimum dimensions measured.

Challenge (pre-filter)
1. Nine taxa or general categories were present in the challenge samples: copepod nauplii, Rotifera, Polychaeta, bivalves, eggs, Calanoida, barnacle nauplii, diatoms, and tintinnids.
2. Augmentation material was present in the samples.

Treated (post-filter)
1. Six (6) taxa or general categories remained in the treated samples: Rotifera, copepod nauplii, tintinnid, eggs, Bivalves, and Polychaeta.
2. Copepod nauplii were in the 50-60 µm size class but fewer were found in the treated samples than in the challenge samples. The removal of live organisms > 50 µm was 99.7%

3. Polychaetes measured 60 µm.
4. Augmentation material was present in the samples.

AUG Live Organisms ≥10 - <50 µm
Samples from the time-integrated chambers.

Sample ID	Ave (#/ml)	SD
Challenge	9,097	967
Treated	3,273	290

Phytoplankton Observations

Challenge and Treated
1. Very high species diversity noted.
2. The dominant species was the diatom *Skeletonema.*

Treated (post-filter)
1. Numbers were noticeably reduced in the treated samples.
2. Although the majority of the larger species were removed, many in the > 30 µm range were noted in the treated sample, especially chain-formers.

AUG Active Chlorophyll-a Data
challenge and treated samples from the time-integrated chambers. Ambient sample was taken before augmentation.

Sample ID	Ave (µg/L)	SD
Ambient	17.6	1.7
Challenge	18.5	0.9
Treated	14.8	1.2

9. FXIT-30.1

9.1. FXIT 30.1 COMM

Prior to any formal testing, a mechanical commissioning run of the Filtrex system using a 30 μm filtration mesh size was provided to assure appropriate treatment operations. This run was used to identify and correct initial mechanical or operating issues. During the commissioning process the feed pump capacity was adjusted at 310 m^3/hr, the outlet throttling valve was adjusted, the back wash delta pressure set point was established, and instantaneous and accumulated data logging was set up. Data collected during commissioning was only used for test preparations and is not provided in the final report.

After treatment system commissioning was completed and accepted by Filtrex, MERC conducted a third trial to evaluate the 30-μm filtration mesh size for biological efficacy (FXIT-30.1-NTL). The MERC barge piping system was set in the sea-to-sea configuration using natural Baltimore Harbor water. The biological efficacy trials focused exclusively on live organisms ≥50 μm and ≥10 - <50 μm in size.

Note that for this trial, Filtrex requested a flow of 340-360 m^3/hr (28-29 Nov emails). However, the specific configuration of the MERC test facility did not allow for flow greater than 310 m^3/hr for this series of filter tests. Filtrex requested (and was provided) 1.3 to 1.6 bar of backpressure to the Filtrex filter system.

9.2. FXIT-30.1-NTL (9 Dec 2013)

Natural harbor water.

NTL Physical Data

Measured in the challenge and treated overflow drums at three time points using a multi-parameter instrument.

NTL Challenge (pre-filter)

Time Point	**Temp** (C)	**Salinity** (psu)	**Dissolved Oxygen** (mg/L)	**Dissolved Oxygen** (%)
TP1	6.2	10.1	11.4	97
TP2	6.3	10.3	11.7	100
TP3	6.1	10.2	11.8	100

NTL Treated (post-filter)

Time Point	Temp (C)	Salinity (psu)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)
TP1	6.1	10.2	11.5	98
TP2	6.3	10.3	11.3	97
TP3	6.1	10.3	11.6	99

NTL Total Suspended Solids (TSS)
TSS samples at three time points taken from challenge and treated sampling hoses.
TSS MDL = 2.4 mg/L.

Sample ID	Sample Time	TSS AVE (mg/L)	TSS SD
Challenge 1	1147	2.7	0.0
Challenge 2	1213	2.7	0.2
Challenge 3	1239	3.0	0.1
Treated 1	1147	2.4	0.1
Treated 2	1213	2.8	0.1
Treated 3	1239	2.6	0.0

NTL Particulate Carbon Data
Samples from the time-integrated chambers.

Sample ID	Ave (mg/L)	SD
Challenge	0.67	0.06
Treated	0.65	0.04

NTL Live Organisms ≥50 µm
Samples from the 35 µm mesh nets.

Sample ID	Ave (#/m3)	SD
Challenge	253,684	2,672
Treated	119,560	3,159

Zooplankton Taxa and Observations
Minimum dimensions measured.

Challenge (pre-filter)

1. Nine (9) taxa or general categories were present in the challenge samples. Rotifera, Polychaeta, copepod nauplii, bivalves, Calanoida, eggs, diatoms, tintinnids, and barnacle nauplii.
2. Rotifera were the most abundant.

Treated (post-filter)
1. Seven (7) taxa or general categories remained in the treated sample: Rotifera, copepod nauplii, bivalves, barnacle nauplii, Polychaeta, tintinnids, and eggs.
2. Copepod nauplii and Rotifera measured in the 50-60 µm size class with a substantial reduction of both, ~50%, from challenge.
3. Polychaetes (soft-bodied) found were mainly in the 50-70 µm size class; however, one polychaete measured 90 µm.

NTL Live Organisms ≥10 - <50 µm
Samples from the time-integrated chambers.

Sample ID	Ave (#/ml)	SD
Challenge	2,633	401
Treated	2,260	87

Phytoplankton Observations

Challenge and Treated
1. Most cells measured between 10 and 30 µm.
2. The majority were smaller species (*Eutreptia* and *Amphidium*) over 10 µm.
3. Very few chain-formers; those observed (*Skeletonema*) were very short chains composed of mostly empty skeletal remains plus 1-2 living cells.
4. *P. minimum* was observed, but mainly empty skeletal remains plus a few living cells.
5. No large cells, such as the diatom, *Cosinodiscus* were observed in the treatment samples.

NTL Active Chlorophyll-a Data
Samples from the time-integrated chambers.

Sample ID	Ave (µg/L)	SD
Challenge	3.9	0.01
Treated	3.7	1.11

FXIT-30.1-AUG was canceled due to inclement weather.

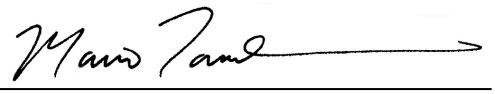
10. Quality Assurance and Quality Control

Quality Assurance and Quality Control policies and procedures, data recording processing and storage, and detailed roles and responsibilities are found in the MERC QMP, QAPP and SOPs. These documents are available upon request.

11. Acknowledgements and Approvals

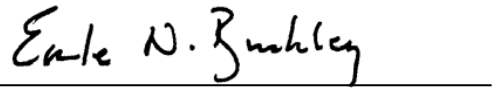
The MERC Testing Team for the Filtrex trials included: E. Bailey, J. Barnes, M. Carroll, K. Holzer, T. Mullady, G. Ruiz, G. Smith, D. Sparks, M. Tamburri, and K. Ziombra. MERC thanks the Maryland Port Administration and U.S. Maritime Administration for funding and supporting this performance evaluation.

March 7, 2014
Date



Approved By: Dr. Mario Tamburri
MERC Director

March 7, 2014
Date



Approved By: Dr. Earle Buckley
MERC QA Manager

Sede: 20134 Milano
via Rubattino, 94/B
tel. (02) 75.33.841 ric.aut.

r.e.a. mi 1130092
trib. milano 223935
c.f. partita i.v.a. 06954820152
telefax (02) 75.31.383
e-mail: info@filtrex.it
web: www.filtrex.it

stabilimento:
20060 vignate (mi)
via g.di vittorio, 2

Cert Nr. LRC 110960
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automatici

Messrs

Maritime Environmental Resource Center (MERC)
P.O. box 38, Solomons, Maryland 20688
U.S.A.
K. A. Mr. Mario Tamburri

ns ref :
our ref : **Letter 6371/14/OR/ap** *Milan, 6th of March, 2014*

vs ref :
your ref : Final Report for the Performance Evaluation of the FILTREX ACB Filter System

oggetto :
subject : **Filtrex comments to the Report**

Dear Sirs,

After having completed the ACB filter tests at MERC facilities, we would like to thank Mr. Mario Tamburri and all his staff for the assistance and the very cooperative attitude they have been keeping with Filtrex and for having sometimes worked in quite heavy environmental conditions.

With regard to the tests results, two main aspects merit to be remarked:

1. Due to the anomalous results recorded on the first trial (FXIT-30-NTL/AUG), we decided to run again the 30 µm, obtaining results (FXIT-30.1-NTL) more consistent with the other trials. Unfortunately the weather conditions did not allow the second run with augmented TSS and POC.
Since the number of trials was limited to 8 (eight), we had to renounce to trials with the 10 µm mesh.

2. In such challenging water condition, we deem it is remarkable that the ACB filter practically stopped the zooplankton and reached a high phytoplankton removal efficiency without interruption of operations; this in both natural (NTL) and augmented (AUG) water conditions.

It has been quite a learning experience, in which Filtrex accumulated useful data for the ACB filter further design development in the lower end of the filtration degrees.

Thanks again to MERC staff.

Yours Sincerely

FILTREX S.r.l.
Luigi RIOLO
(C.E.O. & President)