IMPROVING SINGLE PASS SOLIDS REMOVAL IN BEAD BIOCLARIFIERS BY OPTIMIZING MEDIA SIZE AND SHAPE

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There is a growing concern about the environmental impacts of aquaculture. In 1997, the Environmental Protection Agency (EPA) enumerated more than 5,000 aquaculture facilities nationwide with installations in every state and territory. Through the National Pollutant Discharge Elimination System (NPDES), the EPA has developed national effluent limitation guidelines and standards, to serve as a yardstick for environmental responsibility. The guidelines have emphasized solids control. Even prior to this thrust, aquacultural facilities were feeling pressure from state regulatory agencies that have virtually always included suspended solids as an element in their base effluent guidelines.

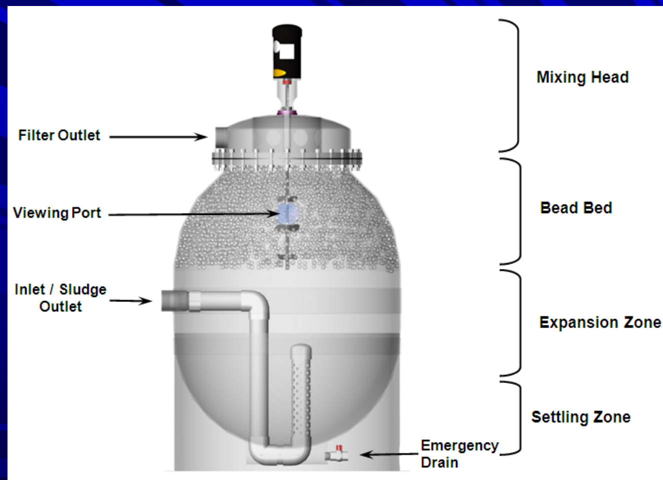
The successful use of floating bead filters (FBF) in recirculating aquaculture systems (RAS) for solids removal has created demand for similar devices to address other applications including agricultural and domestic wastewater treatment, potable water treatment, swimming pool filtration, industrial cooling water systems, and educational applications, e.g. zoos and aquaria. Floating bead filters capture solids through four mechanisms; include straining, settling, interception and adsorption. Until recently, high single-pass solids removal efficiency has rarely been an issue for bead filter applications, since the majority of research has focused, primarily, on biofiltration. The principal factor impeding the use of bead filters in solids removal applications is the bead filter's low single-pass efficiency in capturing particles with diameters less than 20 µm. Previous studies have shown that acclimated filters remove nearly 100% of the suspended particles larger than 50 µm in diameter on the first pass, but single-pass removal efficiency for unacclimated filters drops to about 20% for particles below 10 µm.

To address this issue, a Phase I Small Business Innovative Research (SBIR) grant was applied for and received in 2005. The research goal was to find a floating media that would allow floating bead filters to compete with sand filters, based on removing particles in the range of 5 µm – 10 µm. The specific objectives were to test floating bead media of differing sizes and shapes to identify a combination that provides the highest degree of fine solids removal, determine the effect of bead bed depth on particle size removal efficiency and determine if aggressive washing techniques could mitigate biofouling tendencies when the media is subjected to high organic loading.

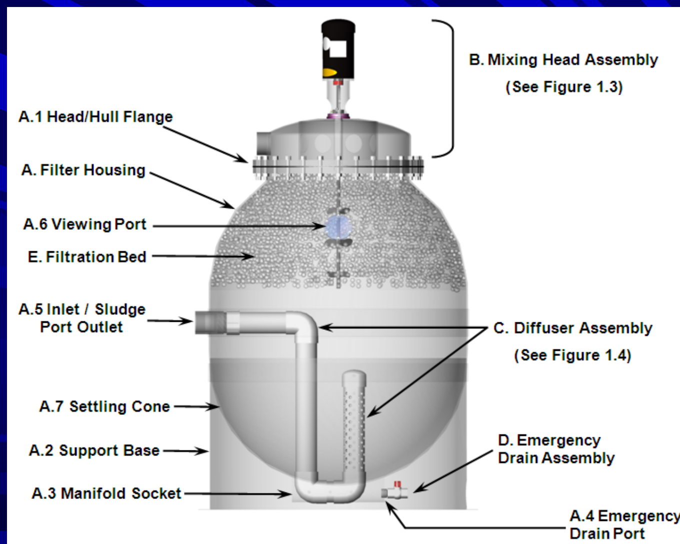
For this study, seventeen different beads were selected for analysis with varying size, shape, density and composition. The results of this study indicate that a floating bead filter containing spherical media with diameters ranging from 300 µm to 600 µm were capable of attaining 90% single pass mean removal efficiency, at a flux rate of 0.205 $m^3\ m^{-2}\ min^{-1}$ (5 gal $ft^{-2}\ min^{-1}$), for particles in the 5µm – 10 µm range. The proper choice of bead can achieve the same removal efficiency as sand filters while losing only a fraction of the water due to the backwash/cleaning process, comparatively. The combination of high single-pass removal efficiency and the low water loss associated with the use of floating bead filters may make the use of bead filters an attractive alternative to sand filtration in applications where there is a need for high single-pass removal efficiencies such as display aquaria, zoo applications and water treatment. In addition, the low water loss associated with the use of bead filters is of great benefit for facilities such as marine aquaria, where the cost of replacing salt in the display water is quite expensive.

Bead Filter: Operation

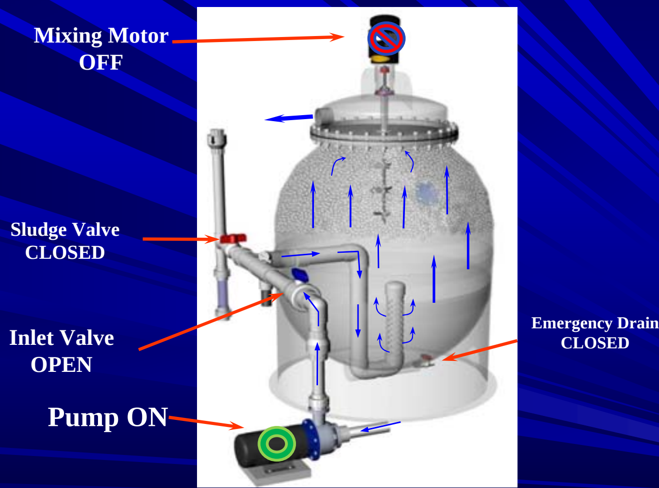
100 % Capture
~ 50 µm and above



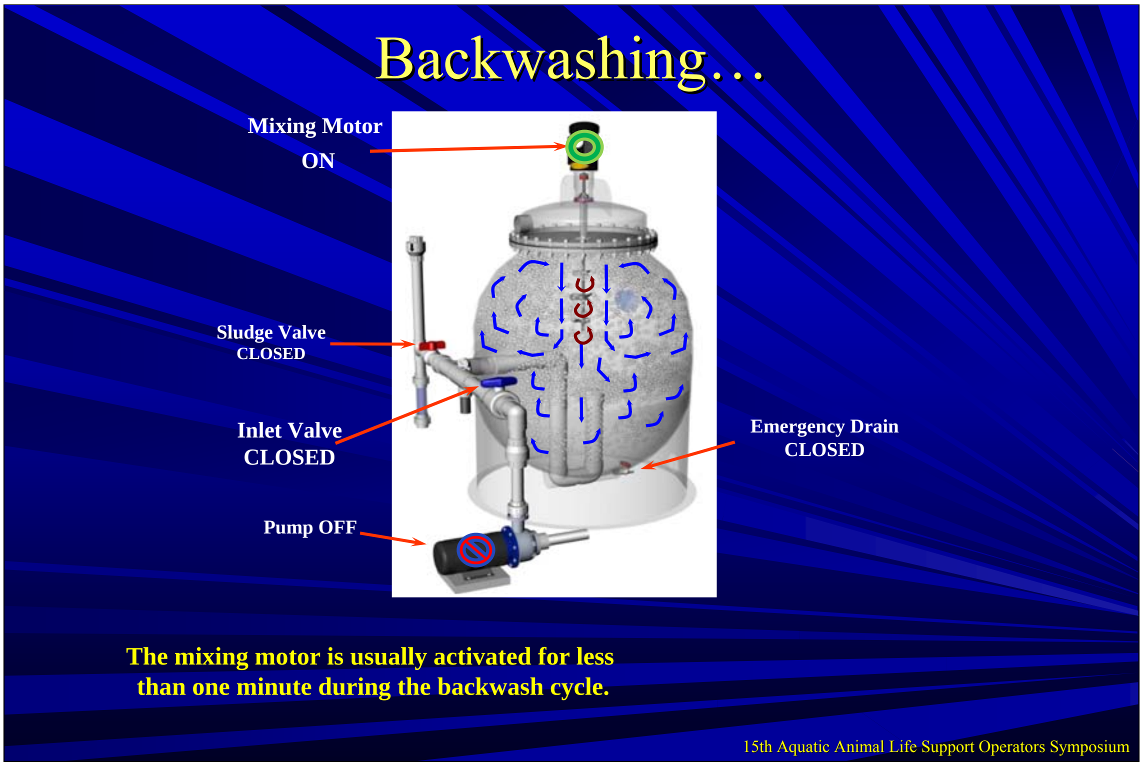
PBF Series Housing Configuration



Normal Operation



Most of the time the filter will operate in the filtration mode.


Backwashing…
Mixing Motor
ON
Sludge Valve
CLOSED
Inlet Valve
CLOSED
Pump OFF
Emergency Drain
CLOSED
The mixing motor is usually activated for less
than one minute during the backwash cycle.
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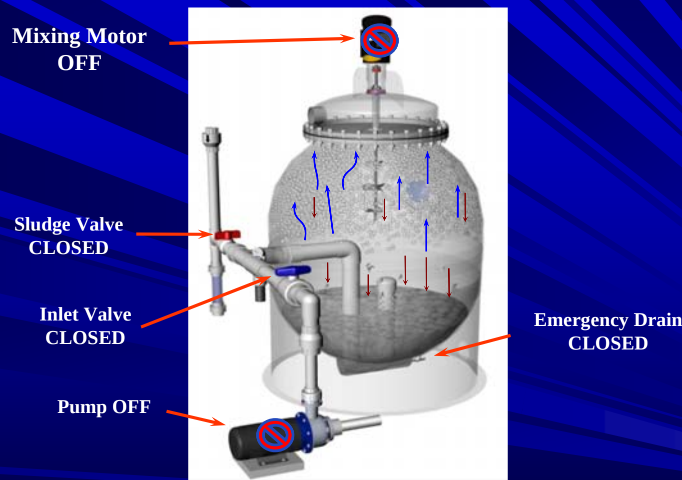
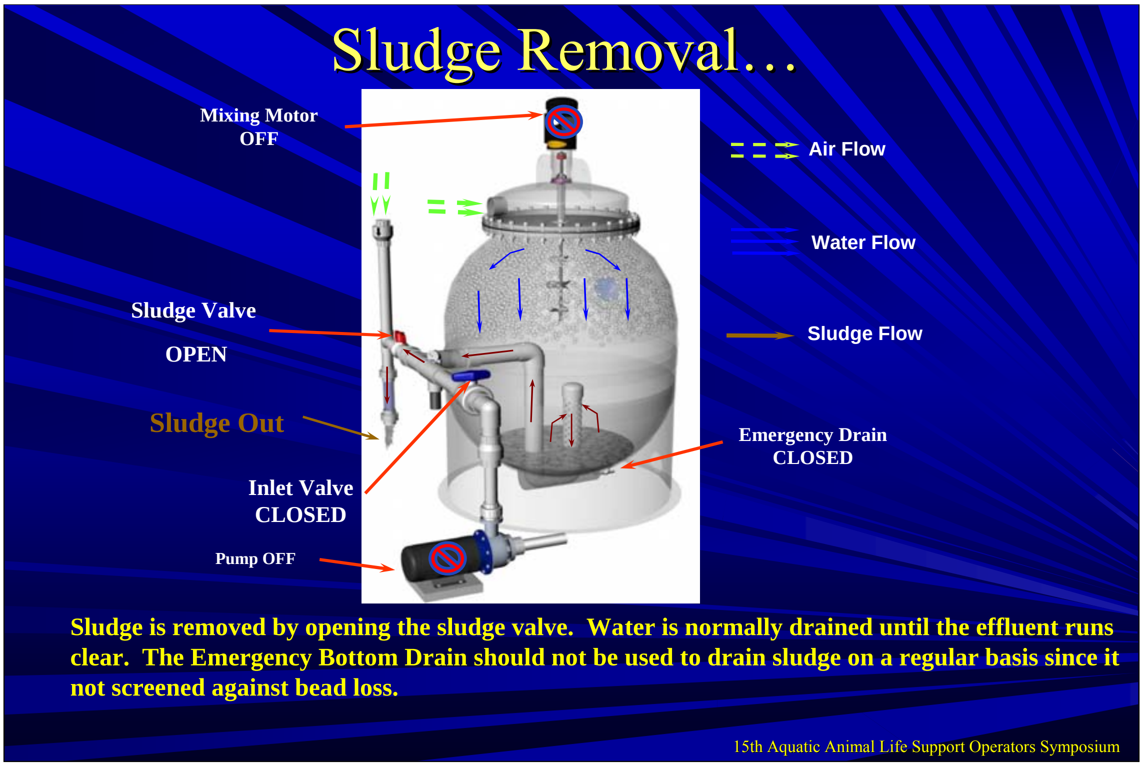
Settling…



During settling, the solids dislodged during mixing are allowed to settle for 10 minutes forming concentrated slurry, while the beads float back up re-forming the filtration bed.


Sludge Removal…
Mixing Motor
OFF
Air Flow
Water Flow
Sludge Flow
Sludge Valve
OPEN
Sludge Out
Emergency Drain
CLOSED
Inlet Valve
CLOSED
Pump OFF
Sludge is removed by opening the sludge valve. Water is normally drained until the effluent runs clear. The Emergency Bottom Drain should not be used to drain sludge on a regular basis since it not screened against bead loss.
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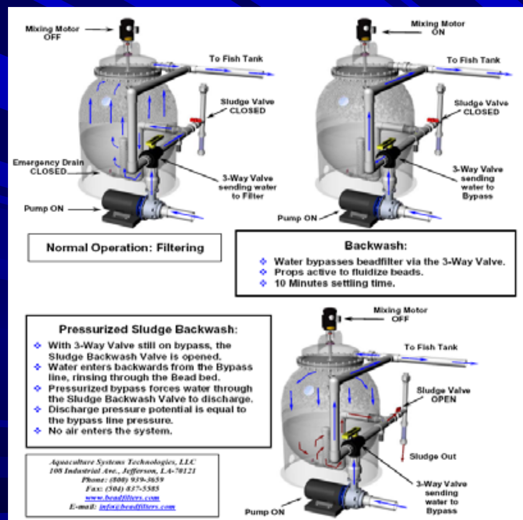
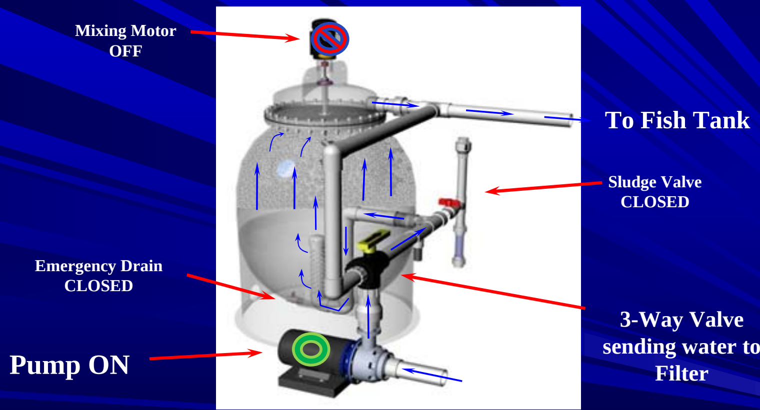
Pressurized Backwash Plumbing Scheme

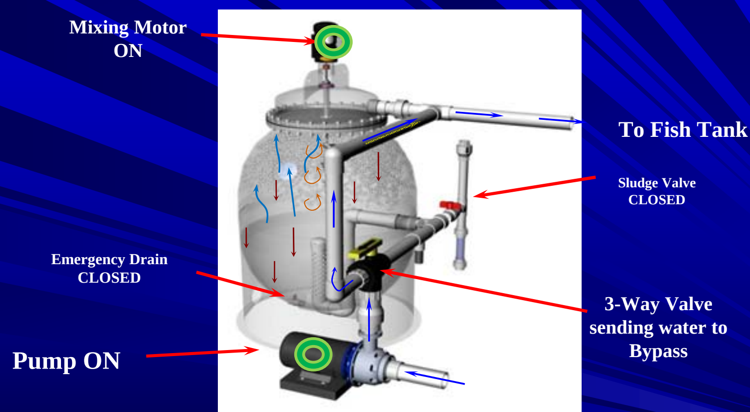


Pressurized Backwash Plumbing Scheme



Normal Operation: Filtering

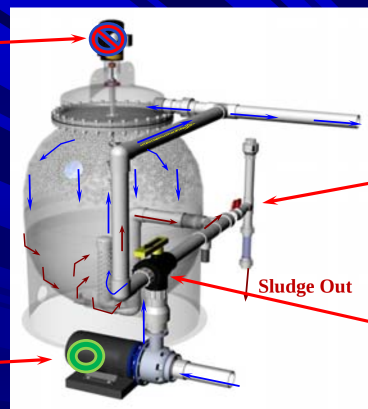
Pressurized Backwash Plumbing Scheme



Backwash Mixing Sequence:

- Water bypasses bead filter via the 3-Way Valve.
- Props active to fluidize beads.
- 10 Minutes settling time.

Pressurized Backwash Plumbing Scheme



Pressurized Sludge Backwash Sequence:

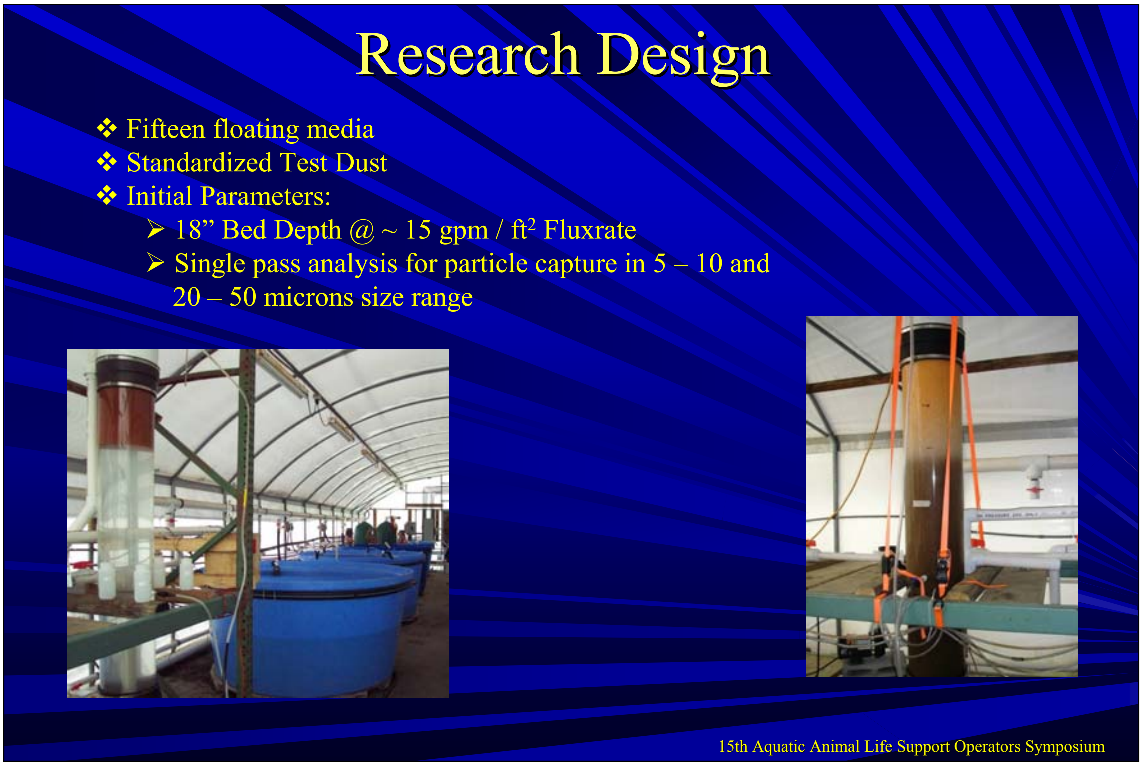
- **With 3-Way Valve still on bypass, the Sludge Backwash Valve is opened.**
- **Water enters backwards from the Bypass line, rinsing through the Bead bed.**
- **Pressurized bypass forces water through the Sludge Backwash Valve to discharge.**
- **Discharge pressure potential is equal to the bypass line pressure.**
- **No air enters the system.**

Research Objective

❖ **Improving Single-pass solids capture**

❖ **Focus on producing Display Quality Water for Zoos and Aquariums**

❖ Target: 5-10 µm



<u>PHASE I OBJECTIVES</u>:

The main objective of the Phase I effort was to characterize the single-pass solids capture ability of floating synthetic media of different shapes and sizes, as well as combinations thereof. The goal of this effort was to identify the defining characteristics of a medium that can best capture solids in the 5-10 μm size range. Additionally, the effects of bed depth, flux rates and biofouling on particle capture efficiency were investigated.

For these purposes, a standardized test dust was employed to simulate fish culture water. Use of this test dust, which contains known ratios of various particle size ranges, insured consistency in the test waters. The investigations were performed as a series of procedures of elimination in order to minimize the amount of tests required to obtain the media with the best capture characteristics. Since it was believed that the capture-performance of the media is governed by the interstitial space between particles, a certain trade-off between increased capture and associated pressure loss was expected.

The initial test procedures were aimed towards isolating the single medium that was best able to capture fine particulates for a given bed depth (18 inches) and flux rate (14.5 gpm/ft^2). These media were then investigated at the 36-in bed depth. Based on the results of those tests; three combinations of media were investigated at selected bed depths. Finally, we proposed to evaluate the best performing single-media and mixed media in terms of increased capture efficiency due to bio-fouling and compare clean-bed and acclimated bed performances.

Characteristics of Media Tested in this Study

Media Sample	Shape	Material	~ Diameter [mm]	~ Length [mm]
1	Cylindrical	Polyethylene	4.8	3.2
2	Grooved Cylindrical	Polyethylene	4.8	3.2
3	Crushed Cylinder	Polyethylene	-	8 – 11
4	Cylindrical	Polyethylene	3.2	3.2
5	Tube	Polyethylene	3.2	3.2
6	Pinched Oval	Polyethylene	3.2	-
7	Spoked Ring	Polyethylene	10.0	8.0
8	Tube	Inert Carbon-filler Plastic	3.5	4.5
9	Spherical	Polypropylene	0.5 – 3.5	-
10	Spherical	Polystyrene	1.5 – 2.5	-
11	Spherical	Polyethylene	0.3 – 2.0	-
12	Custom Shape #1: BUG	Polyethylene	3.2	4.8
13	Custom Shape #2: COG	Polyethylene	3.2	4.8
14	Custom Shape #3: Lizard	Polyethylene	3.2	4.8
15	Custom Shape #4: Modified BUG	Polyethylene	1.6	3.2

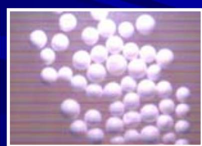
Eighteen commercially available floating media were selected (Figure 1) and four custom shaped floating media for in-line extrusions were designed. Initially, the most important characteristics for our custom media were determined to included size, shape and buoyancy. Size, which includes both the specific surface area, or area available for bacterial attachment, and the required screen mesh size for media retention and resulting headloss it attributes, was determined to be a critical factor in media design. Shape was determined to have an influence on specific surface area, porosity, packing (we wanted a large bead which when packed would mimic the characteristics of smaller beads), and internal and external protection of biofloc. Finally, buoyancy was a critical factor, since the media are required to float, even when fully coated with biofilm. We initially designed seven media, and then ranked them based on their optimal size, shape and buoyancy. We ultimately settled on four different custom shapes.

Illustrative Pictures of the Media

Graded Media :
Bead Sample 9 ~ 0.5 – 3.5 mm
Bead Sample 11 ~ 0.3 – 2.0 mm
C_u ~ 2.55

Illustrative Pictures of the Media





Custom Shapes:

(Φ 1/8”, 3/16” Length)

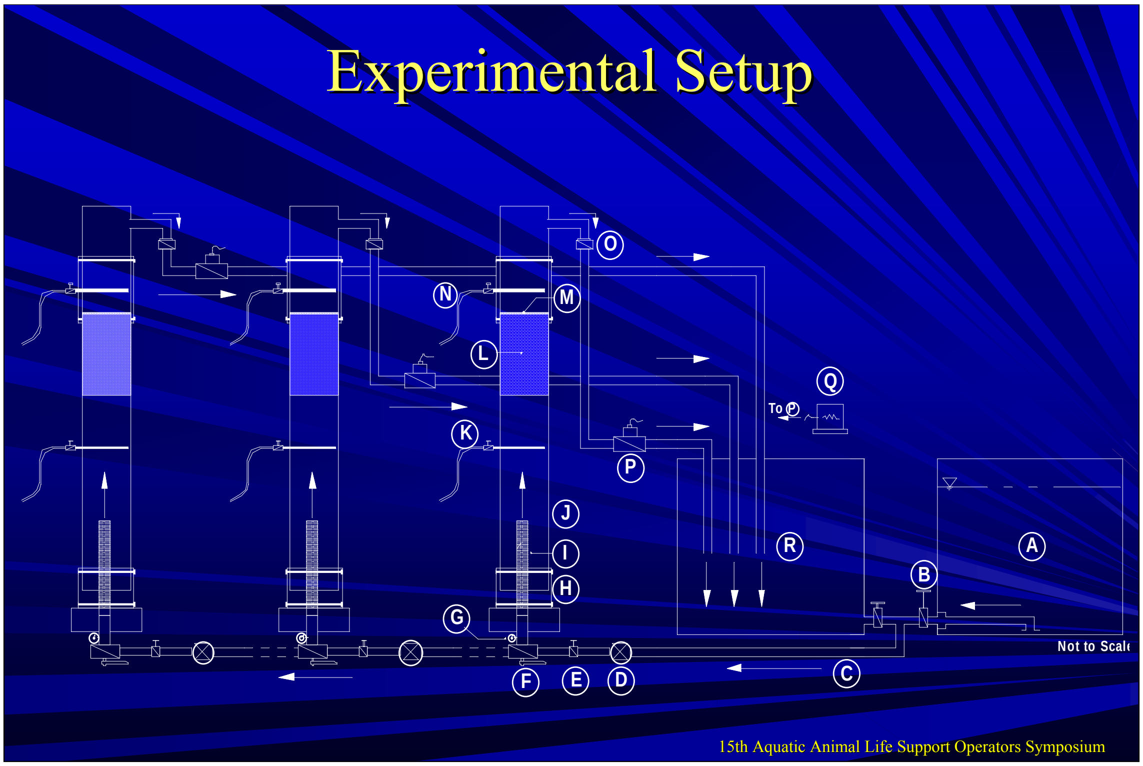
Bug

Cog

Lizard

(Φ 1/16”, 1/8” Length)

Modified Bug


Experimental Setup
O
N
M
L
Q
To P
K
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R
A
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H
G
Not to Scale
C
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D
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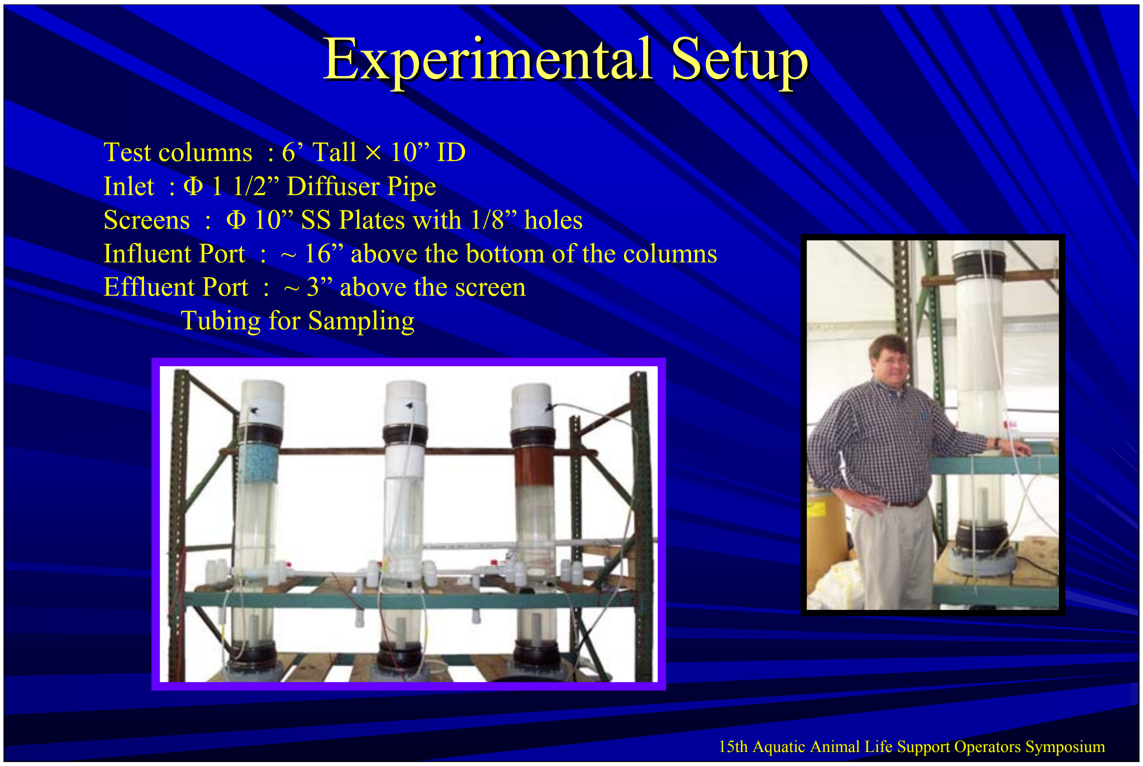


Figure 4: Experimental test apparatus including the three test columns, sampling outlets, test water, bead sample media and sampling bottles.

Three test columns were constructed from clear acrylic pipe (6' tall × 10" ID) (Figure 4). Since the outside diameter of the acrylic pipe is smaller than standard schedule 40 10" diameter PVC pipe, rubber couplings were used on the top and bottom of the acrylic column to allow the use of standard PVC fittings.

The inlet structure (Figure 5a) on each column consists of a 10" PVC flange to which is attached a 10" blind flange. The blind flange on each column was then tapped using a 2" npt tap. A 1.5" screen assembly manufactured from PVC pipe with 0.060" slots and a 2" × 1.5" threaded reducer bushing was screwed into the bottom of each column to act as a diffuser. A manual 3-way valve was attached to the diffuser using a 1.5" PVC close nipple. Water from the influent tank is pumped into one side of the 3-way valve, while the other side is plumbed to the drain.

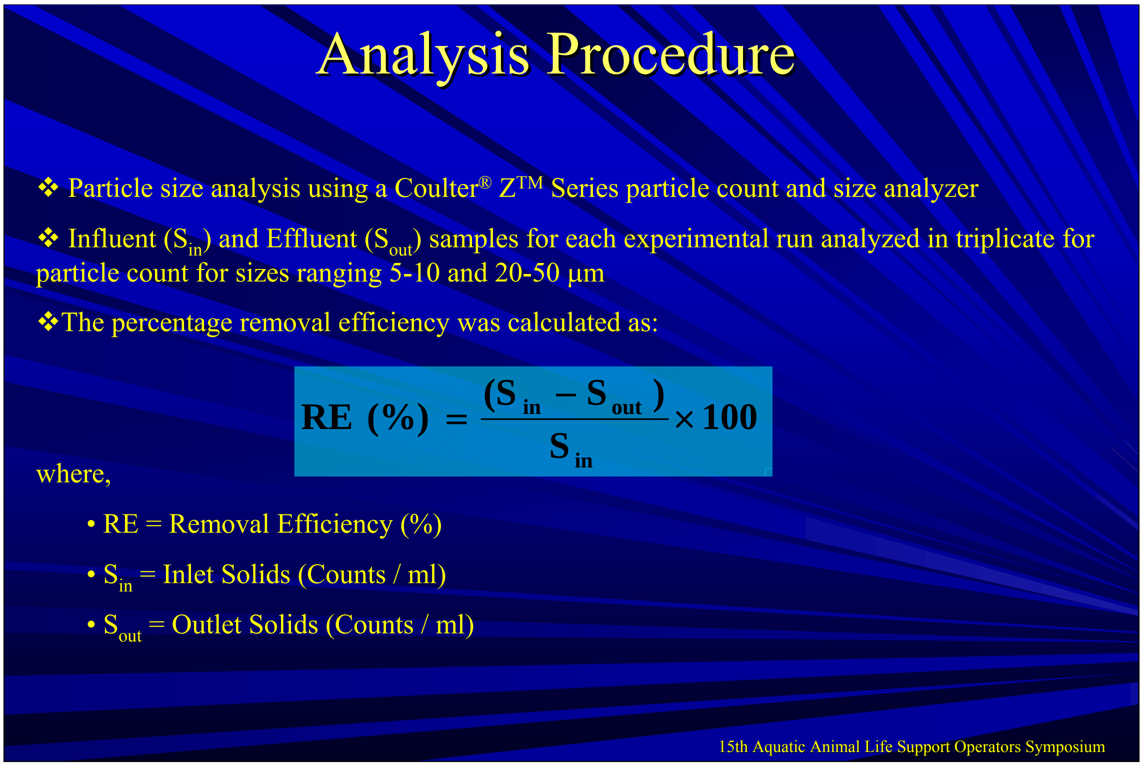
The outlet structure (Figure 5b) consists of a 10" PVC coupling which has a ¼" lip glued on the inside to support the bead retention screen. The bead retention screen is set on top of the 10" ID acrylic pipe, then the coupling in placed on top of it, sandwiching it in place. This whole assembly is then held in place by the 10" rubber coupling. A short piece of 10" PVC pipe was inserted into the 10" coupling to prevent accidental overflowing of the column. After passing upward through the screen, water exits the column via a 2" PVC Tee fitting welded into the 10" PVC pipe just above the coupling. Water then flows via gravity downward, and then turns and flows across a Rotor-X™ paddle-wheel flow sensor (Figure 6), before exiting into the effluent tank (Figure 7). Flow is measured using a pre-calibrated battery -powered digital flow rate monitor/totalizer and switch (Figure 8) to allow the same monitor to read paddle-wheel sensor from each of three columns.

Test Procedure

- ❖ Test water concentration: 100 mg/L
- ❖ Thorough mixing with the help of air-diffusers and a pump to recirculate/spin test-water to keep the particles in suspension
- ❖ Triplicate runs of samples drawn from the Influent and Effluent Ports at a 15 minute interval
- ❖ Backwashing between runs using fresh tap water from the top of the column

Test water is mixed in an 800 gallon Polytank (90" diameter x 38" depth) (Figure 9). The influent tank is kept thoroughly mixed using 10 9" ceramic air diffusers spaced evenly around the circumference of the tank and a 1/6 Hp centrifugal pump, which is used to recirculate/spin the water in tank to ensure thorough mixing. A 4" diameter PVC manifold leads from the influent tank to test columns. Water is drawn from the center of the influent tank (Figure 9)

Figure 9: Influent tank containing ceramic air diffusers and the PVC manifold
approximately 2" off the bottom.



Each sample was analyzed in triplicate for particle count for size ranging 5-10 and 20-50 µm. Particle size analyses were performed with a Coulter® Z™ Series particle count and size analyzer (Figure 13) on influent (S_{in}) and effluent (S_{out}) samples for each experimental run. Additionally, during the first run of three bead samples (# 1, 3 and 5), TSS (mg/L) was analyzed to quantify makeup of the test water. The AZ dust concentration in the test water was kept 100 mg/L to make sure the concentration is exceeding the quality of typical aquaculture recirculating water. The TSS analyses were performed in accordance with Standard Methods for the Examination of Water and Wastewater at the Water Quality Laboratory in the Department of Civil and Environmental Engineering at Louisiana State University.

The percentage removal efficiency was computed using Equation 1 below:

(Eq. 1)

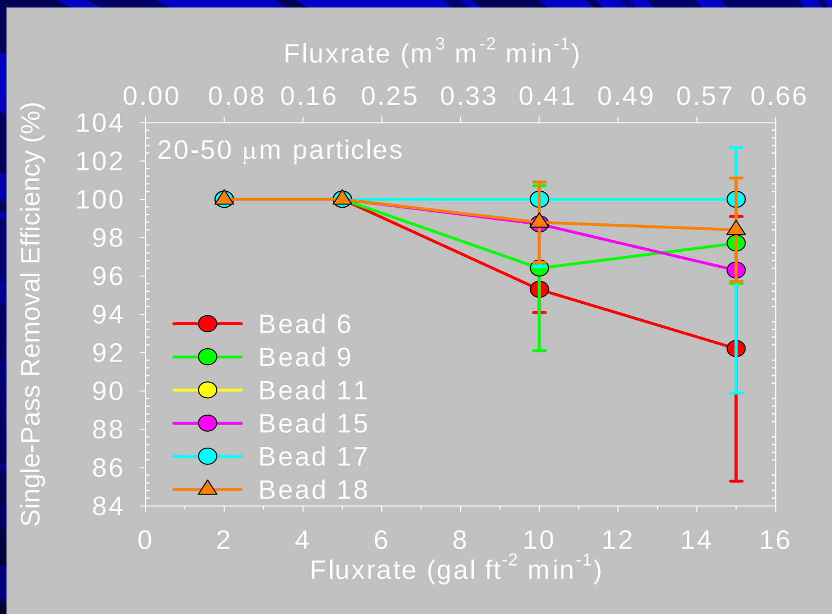
where,

RE = Removal Efficiency (%)

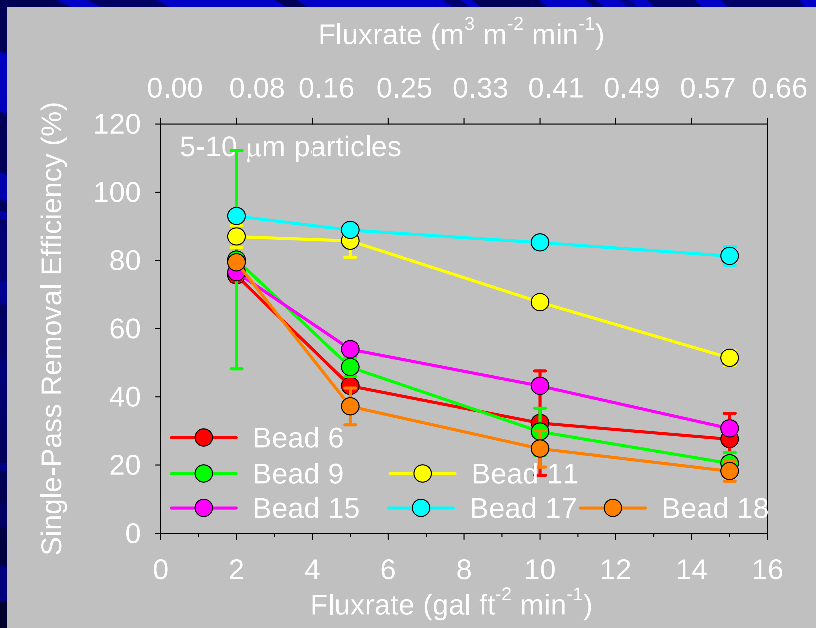
S_{in} = Inlet Solids (No.)

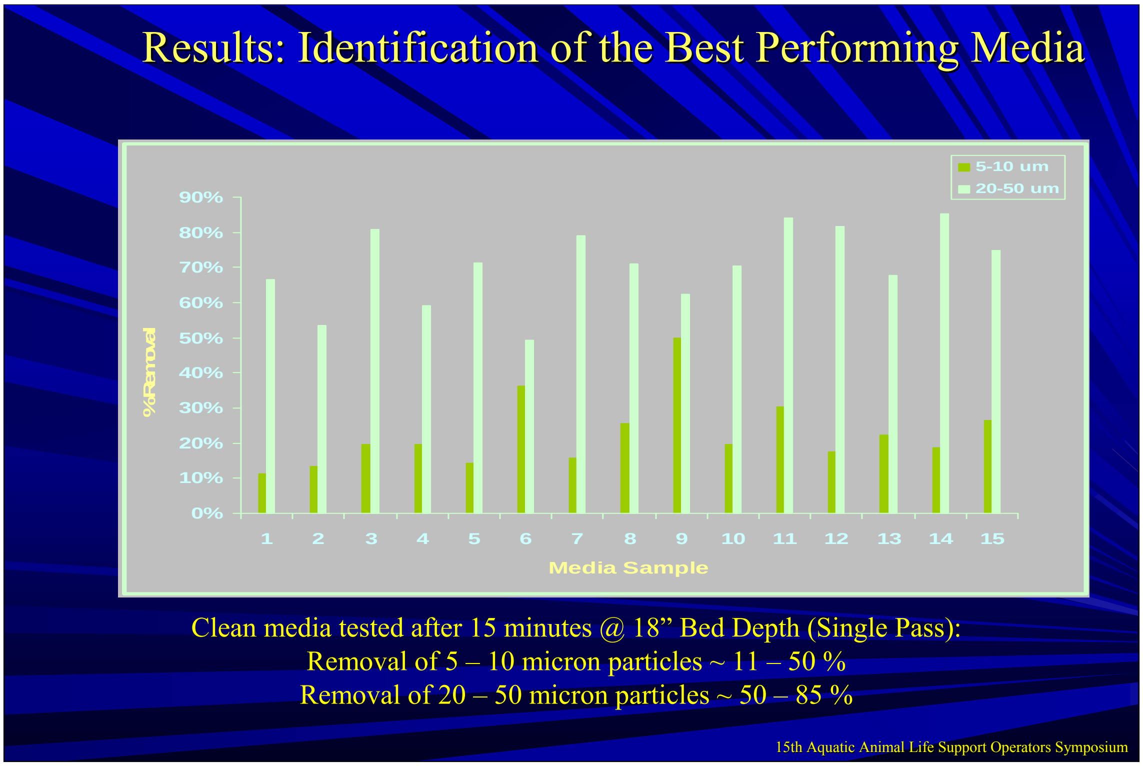
S_{out} = Outlet Solids (No.)

Fluxrate Study for Unacclimated Beads



Fluxrate Study for Unacclimated Beads



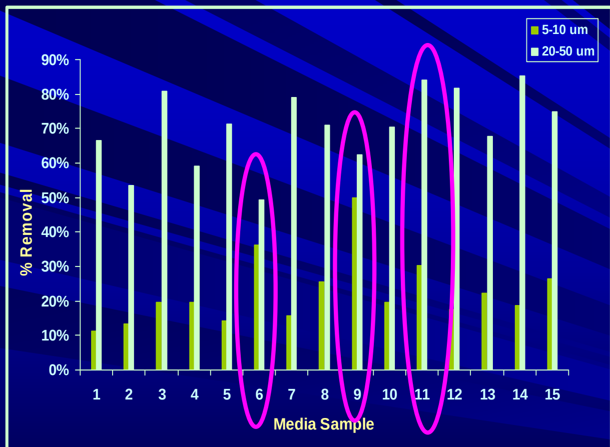


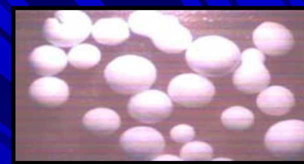
SINGLE-PASS REMOVAL EFFICIENCY FOR LARGE (20 µM – 50 µM) PARTICLES

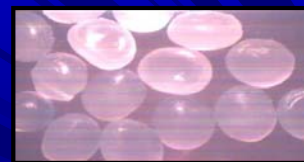
Although the goal of this research was to improve the single-pass removal efficiency of particles in the range of 5 µm to 10 µm, measurements were also performed in the 20 µm to 50 µm range in order to compare the results to existing knowledge. Figure 14 contains the mean removal efficiency measured for each of the six beads used in the study as a function of fluxrate. It was found that each of the six beads had mean removal efficiency in excess of 90% on a single-pass basis. This finding was consistent with other studies that found similar results (Ahmed 1996). Furthermore, there was no statistically significant difference in removal efficiency between the various beads at any of the measured flux rates for particles in the 20 µm to 50 µm range ($P > 0.05$).

The fifteen different media were tested in triplicate and found to have removals between 11 and 50% for particulates in the 5 – 10 micron size range when operated at an average flux rate of 14.5 gpm/ft^2 for a bed depth of 18 inches. Ability of the filter media to remove the finest solids tested did not necessarily correlate to high removal of particles in the 20-50 µm category. Percent removal within the different size categories has revealed single pass removals of up to 85% for the 20-50 µm particle size range at 15 minutes. Figure 2 illustrates the removal percentages for all tested media.

Results: Identification of the Best Performing Media

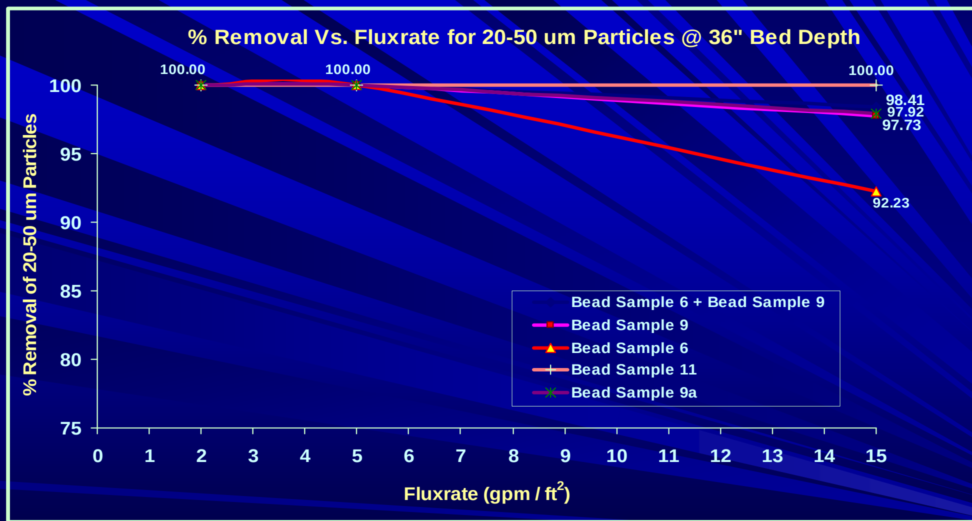






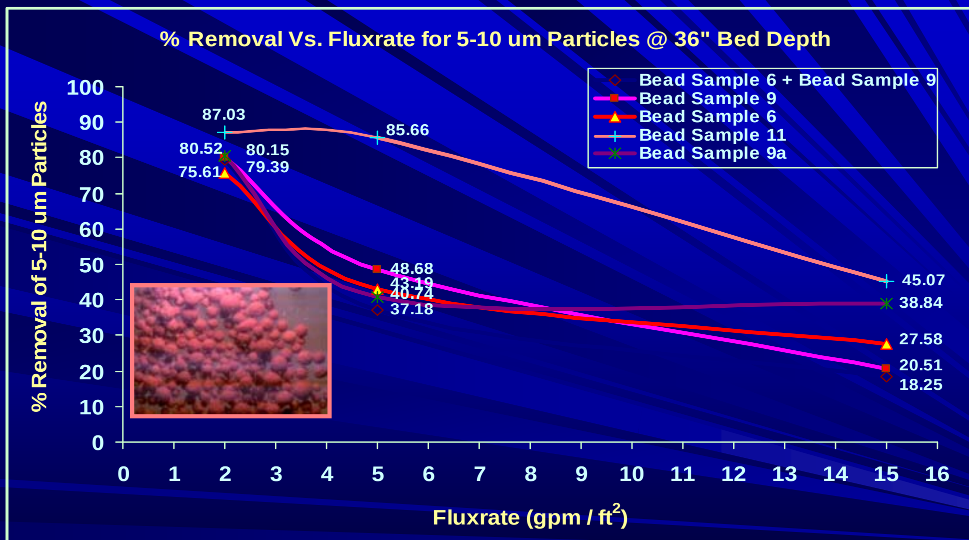
Clean media tested after 15 minutes @ 18" Bed Depth (Single Pass):
Removal of 5 – 10 micron particles ~ 11 – 50 %
Removal of 20 – 50 micron particles ~ 50 – 85 %

Results: Fluxrate Study



Effects of different Fluxrates @ 36" Bed Depth on particle capture in the 20 – 50 µm size range

Results: Flux Rate Study



Effects of different Fluxrates @ 36” Bed Depth on particle capture in the 5 – 10 µm size range

Conclusions

- ➢ Data collected to date will allow us to configure filters to optimize its performance or target specific size range of particles
- ➢ Fluxrate does impact the ability to capture fine particles:
  - ✓ Lower Fluxrate – Better Capture
- ➢ Increase in bed depth increased solids capture
- ➢ 1/8" Oval shaped media is competitive with other media
- ➢ Exception: Finer media showed substantially improved capture of fine particulates
- ➢ Spherically shaped, small graded media looks promising for increase in single pass removal of particles in the 5-10 µm range to produce display quality water

Ongoing Studies Phase II

- Evaluating effects of biological acclimation of media
    - Higher capture for fine particulates
    - Headloss through media beds
- Demonstrate robustness for mixing and cleaning finer media filtration bed

Phase II Research System

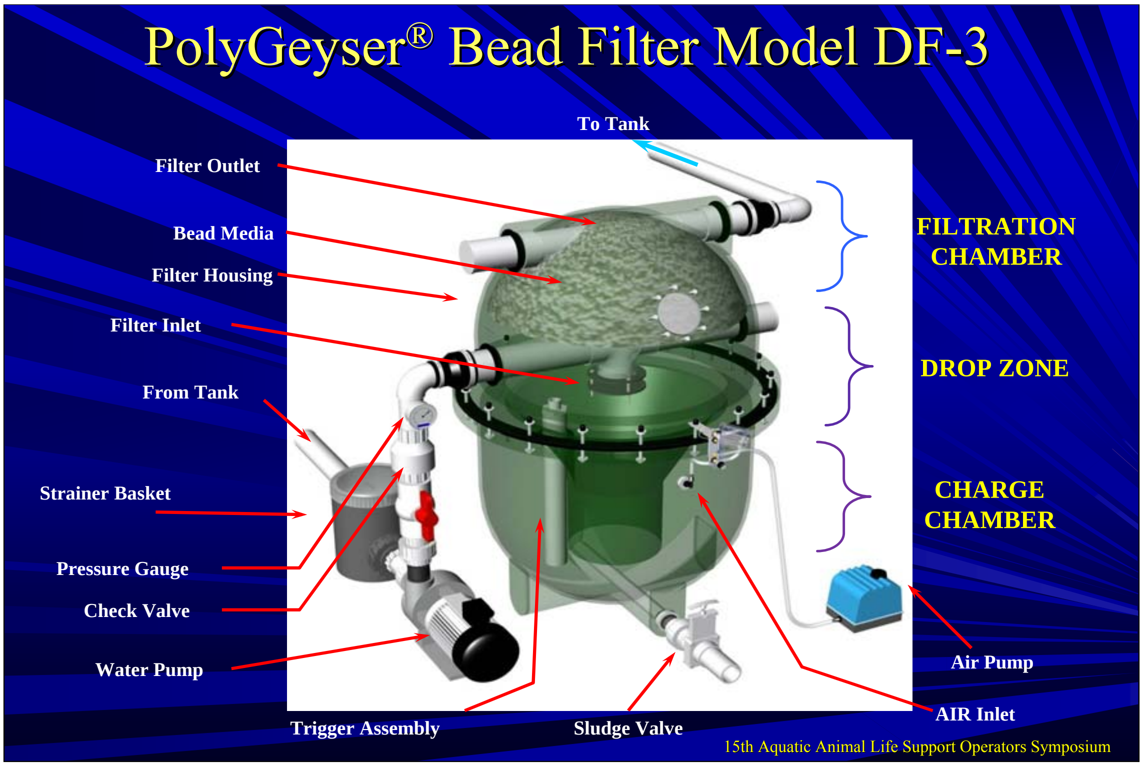
Control / Timer System

Flow Monitoring

Propeller Mixer

Phase II Research System

Solids Capture Propeller Mixing Settling


PolyGeyser® Bead Filter Model DF-3
To Tank
Filter Outlet
Bead Media
Filter Housing
Filter Inlet
From Tank
Strainer Basket
Pressure Gauge
Check Valve
Water Pump
Trigger Assembly
Sludge Valve
FILTRATION CHAMBER
DROP ZONE
CHARGE CHAMBER
Air Pump
AIR Inlet
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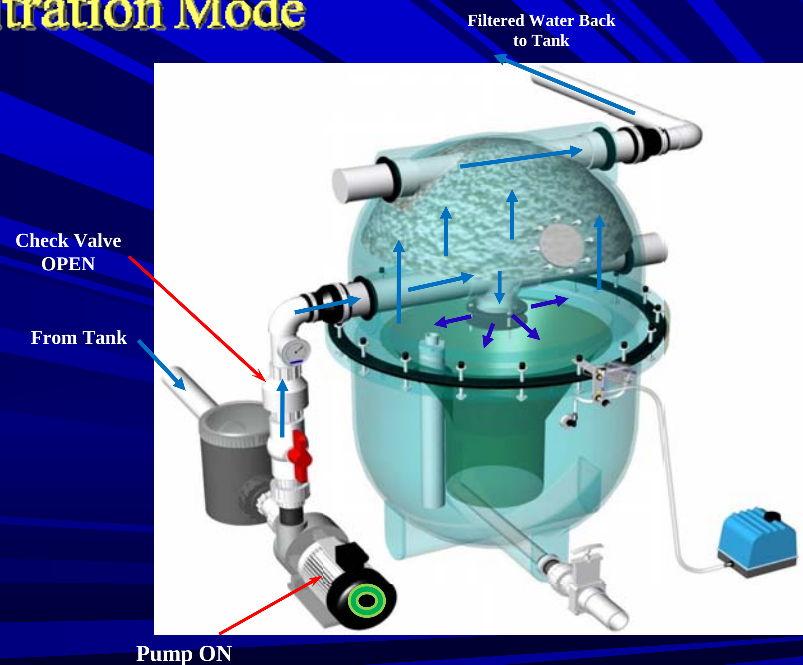
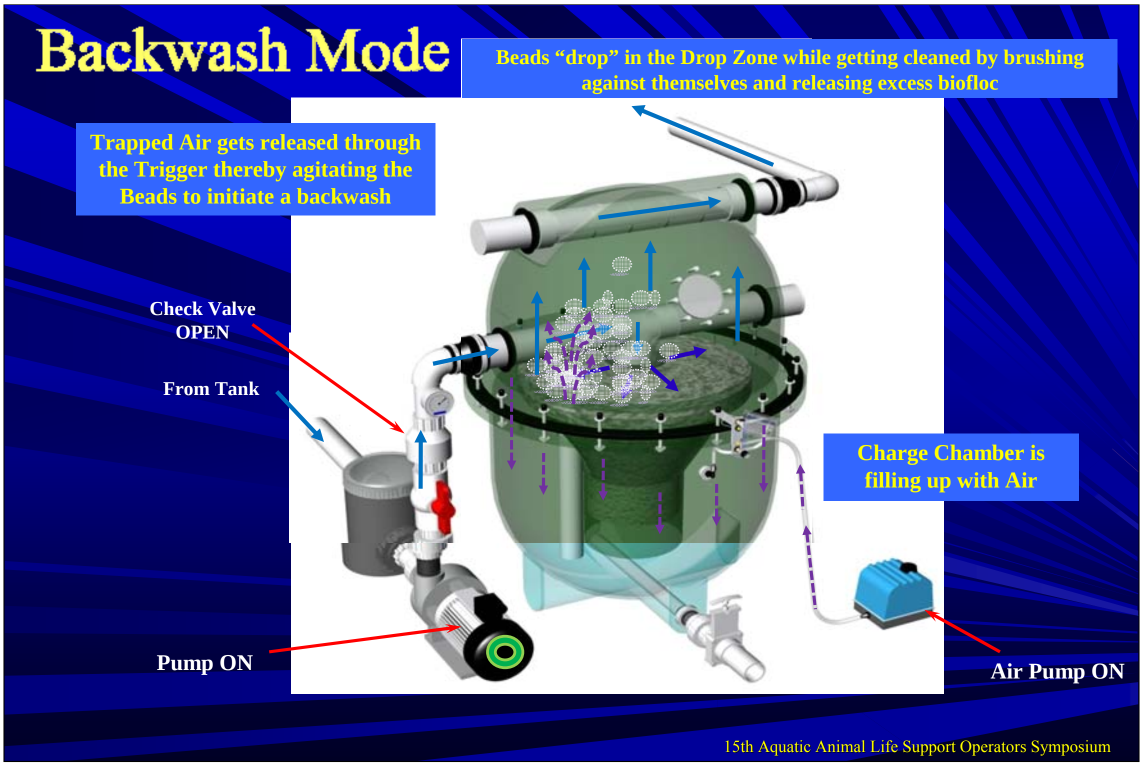
Filtration Mode





Backwash Mode
Beads "drop" in the Drop Zone while getting cleaned by brushing against themselves and releasing excess biofloc
Trapped Air gets released through the Trigger thereby agitating the Beads to initiate a backwash
Check Valve OPEN
From Tank
Charge Chamber is filling up with Air
Pump ON
Air Pump ON
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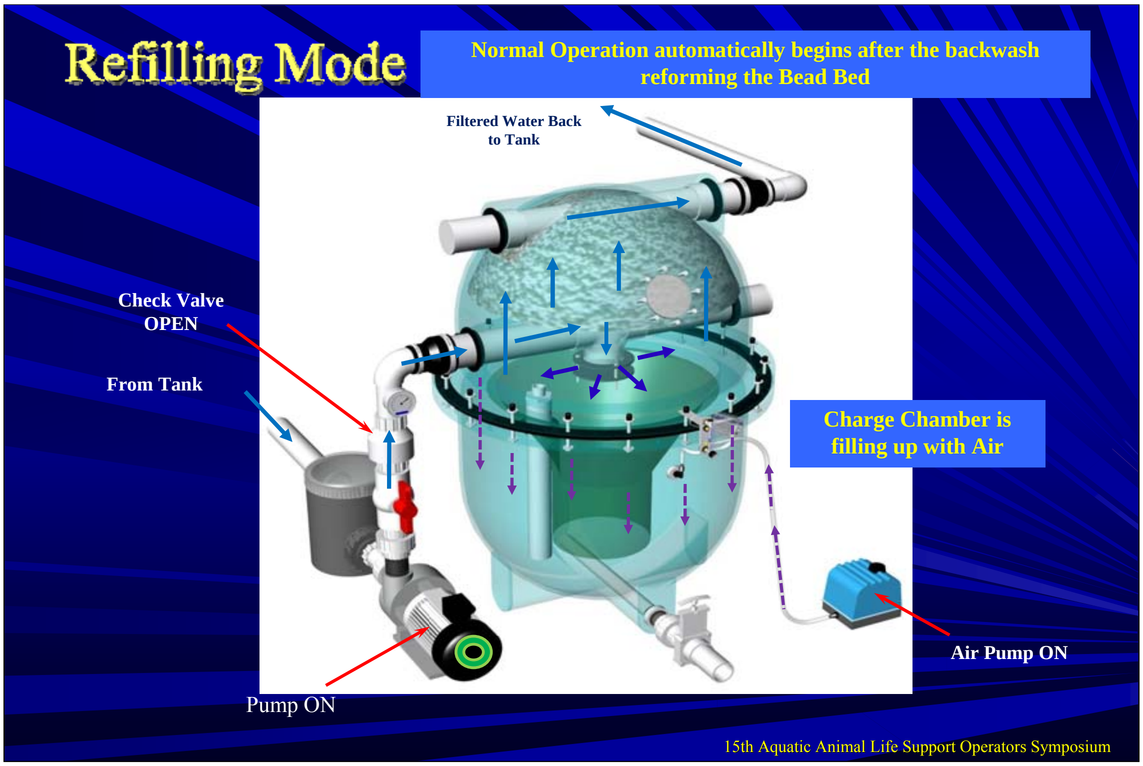

Refilling Mode
Normal Operation automatically begins after the backwash reforming the Bead Bed
Filtered Water Back to Tank
Check Valve OPEN
From Tank
Charge Chamber is filling up with Air
Air Pump ON
Pump ON
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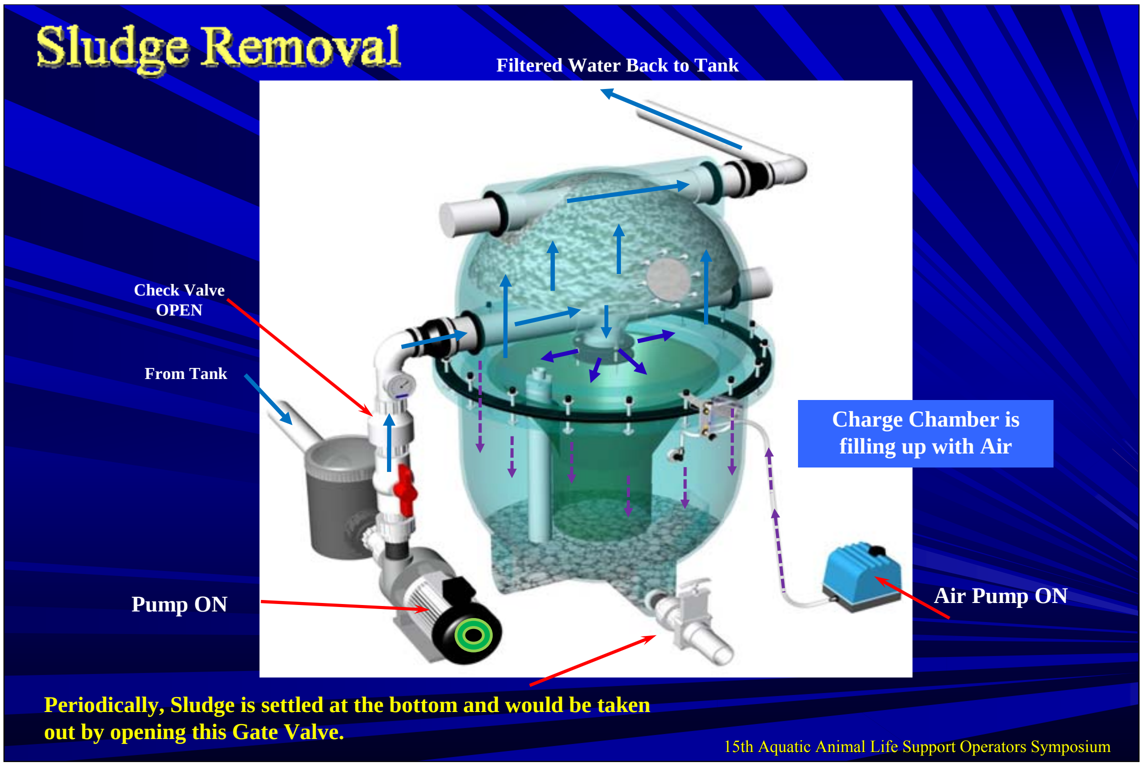
Sludge Removal
Filtered Water Back to Tank
Check Valve OPEN
From Tank
Charge Chamber is filling up with Air
Pump ON
Air Pump ON
Periodically, Sludge is settled at the bottom and would be taken out by opening this Gate Valve.
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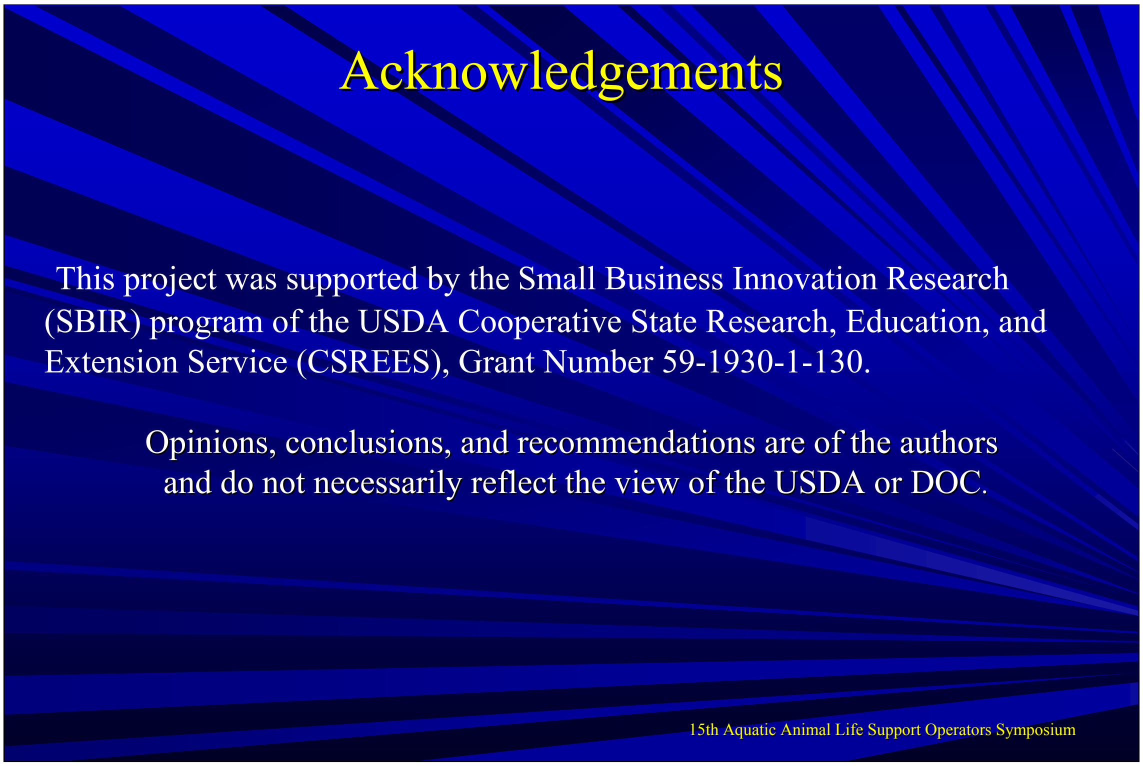
AST believes that the future for technologies that enhance overall water quality is bright. A wide variety of factors including issues as diverse as diminishing water supply, environmental regulations, coastal land development and concerns about exotic species introductions are driving the aquaculture industry towards better environmental stewardship. The propeller-washed bead filter with media selected for efficient single-pass effluent treatment had not been investigated prior to the Phase I project. The success for this project will be the development of reliable and cost effective units that, with simple modifications, can be applied to many different production schemes and/or be used for single pass treatment of a wide range of effluents.



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