Ballast Water Treatment through Filtration using Modified Graded Sand-filters

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Abstract

Marine bio-invasion through ballast water exchange is one of the major threats to the marine environment. Various methods based on physical, chemical, biological and engineering principles are being tried to address this issue. Filtration through modified graded sand medium based on computer modeled packing analysis is attempted in this study and its efficiency in comparison with mixed sand filtration medium is presented. A laboratory filtration model was constructed and evaluated for its efficacy in filtration and yield. The results indicated efficient removal of organism even to the extent of bacteria.

KEYWORDS
Alien species, bio-invasion, ballast water, sand-filtration

Introduction

Possibility of bulk transportation at considerably cheaper cost by sea transport resulted in the tremendous growth of the marine navigation since the beginning of 20th century. Navigable vessels carry ballast water for their stable operations. Practices of ballasting and de-ballasting of navigable vessels followed so far have been causing transportation of marine organism in considerable quantity from one region to another. In the modern scenario, approximately 2 to 3 billion tons of sea water as ballast is transferred from one location to another globally (Oyvind et al, 2003). The transportation and introduction of non-indigenous species or "alien species", by navigable vessels' ballast water has created substantial economic and environmental impact throughout the world as the forced migration of non-indigenous species poses major threat to the native species. Recent estimates reveal that bio-invasion has cost millions of dollars in remedial actions.

Environmental degradation due to bio-invasion has reached to such an extent that world scientific community has seriously started working towards understanding the issue through multidisciplinary research approach. At the same time various technological firms around the world are working in tandem with aims and guidelines of International Maritime Organization (IMO) in coming out with tangible solutions satisfying technical and commercial aspects of ballast water treatment and management. Accordingly, there are various innovative methods being tried all over the world to address this issue based on physical, chemical, biological and engineering principles either individually or in suitable combinations of above (http://www.uspto.gov/, http://espacenet.com/). Still none of the solutions offer complete satisfaction for the commercial viability of the treatment and management of ballast water due to inherent complexities involved in the processes.

Current practices of ballast water management include open sea ballast water exchange. When practiced, though the number of organisms is substantially reduced, there may still be significant risks associated with discharge of residual organisms in some case and the risk may even be increased in some other (Alan et al, 2001). Hence, this exchange method is not viewed as the final solution due to the safety issues associated with the exchange in the open ocean as well as other environmental concerns. Given proper incentives and flexibilities for development, alternative management methods will be identified that will permit treatment of ballast water either onboard or ashore and will prove more effective and far safer than physical exchange methods. There are various ship/vessel based ballast water treatment systems being tried all over the world (http://globallast.imo.org/index.asp?page=ballastw_treatm.htm, http://globallast.imo.org/abstract%20Book.pdf).

With flow rates as high as 2000 cubic meter per hour, the treatment technology has to be robust.

Sand bed filtration is one of the common and old practices in water filtration. Conventional sand filters provide ample contact opportunities for the removal of all particles applied to them. When such filters are not producing efficient removal, the chemistry of the system should be changed (Kuan-Mu et al, 1971). It is beneficial to utilize sand particles in a deep sand bed in which particles size are normally below 0.2mm but above 0.05mm. Even after all the research has been performed it is still unknown as to what the actual ideal sand size is, however the majority of aquarists who run a deep sand bed in their aquarium utilize one which actually feels like silt when touched. There are other aquarists who utilize sand which feels more like mud to the touch.

In this study, the treatment of ballast water by micro filtration through modified graded sand medium is being explored and its efficiency is presented. To remove micro fractions in the order of 2 microns or even lesser, a micro filtering graded sand medium through computer modeled packing analysis is designed and used in this present work. Thus, a laboratory filtration model was constructed, using such graded layered sand bed and evaluated for its efficacy with respect to both the filtration as well as the yield. The micro filtering medium made of sub-rounded to rounded well graded sand layers performed better in filtration efficiency and yield compared to angular sand particles. The results were encouraging as the efficiency is arrived consistently.

METHODOLOGY

Laboratory model of filtration chamber (Fig. 1) consisting different graded layers (3) of sand was constructed in a glass tank (1) for finding out efficiency of filtration and yield of the system. Natural seawater entering (6) the filtration chamber gets filtered through vertical and horizontal graded sand layers and leaves through outlet (5) of the system. 6.5 cm diameter PVC pipe (2) is the filtered water collection pipe. On the wall of the collection pipe, 0.5 cm diameter holes (4) were made at the bottom 20 cm length of 65 cm long pipe with 0.5 cm spacing between adjacent holes. The perforated portion was covered with mesh of aperture 0.075 mm to prevent the entry of sand inside the pipe from inner most graded filtration layer.

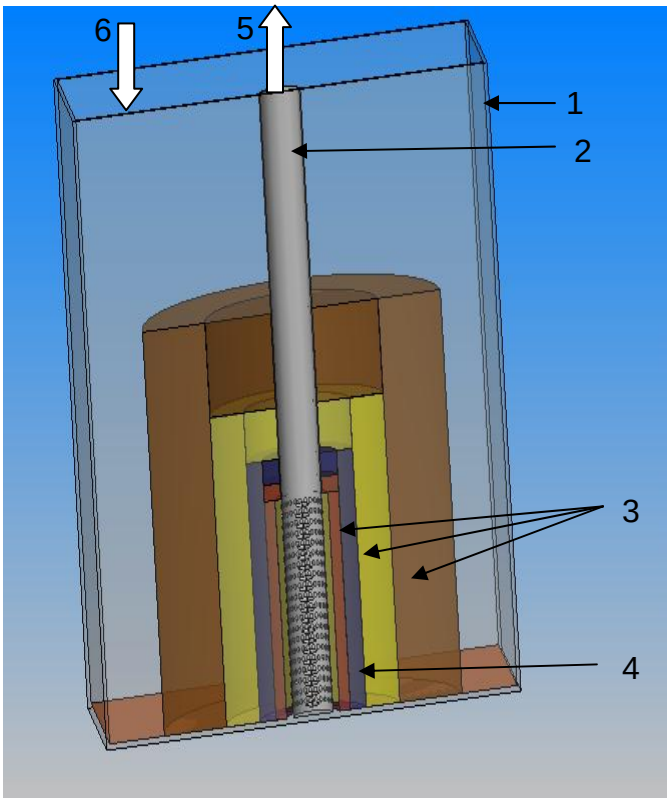

Fig. 1. Cross sectional details of layered graded sand filtration chamber (Laboratory model)

Graded layers in both the vertical and horizontal direction help in increasing yield of the system while not sacrificing the quality of filtration. Every layer thickness is as per their equivalent thickness to give same rate of permeability, which was arrived based on constant head permeability test. The graded filtration layers from outer to inner were classified based on particle size fractions in the order of 1-0.5mm, 0.5-0.3mm, 0.3-0.212mm, 0.212-0.125mm and 0.125-0.075mm.

In addition, each graded layer is mixed with suitable quantity of finer size sand fraction to fill the voids in the sand particles packing so that passage size for micro organisms is restricted gradually as per the required control. This particle packing analysis is achieved through computer modeling assuming

every sand particle is of spherical in shape. The operating pressure used in the laboratory study is 0.05 kg per square centimeter. The optimum back wash system is considered in this study as the performance of rapid sand filtration plants is believed to be dependent on backwash and start-up regimes (Jason et al, 1996). Laboratory scale model experiments using variable head permeability tests were made to find out the yield potential between layered and mixed sand filtration medium keeping the volume and thickness of the sand filter medium constant.

RESULTS AND DISCUSSIONS

The maximum yield arrived through graded layered sand filtration medium at very minimum operating pressure of 0.05 kg/cm^2 is 288 liters per hour. The system of same foot print can yield close to 300m^3/hour under 5 kg/cm^2 operating pressure without sacrificing quality of filtration. This capacity can further be enhanced by increasing filtering surface by multi-folded collection chamber inside the filtration medium. Hence, these results are in the positive side of the feasibility of this filtration system for the sea water filtration as the system is scalable as per requirement.

The micro filtering medium made of sub-rounded to rounded sand particle layers performed better in efficiency and yield compared to such layers made of angular sand particles. This may be due to the fact that compact packing efficiency is more in the case of former than the later. Also water flow between sand particles is smoother in case of rounded to sub-rounded sand particle packing than the angular sand particle packing.

Variable head permeability tests performed on both the above conditions revealed that yield of layered system is better with 80ml/sec discharge than mixed filtration medium where the discharge is 70ml/sec at the hydraulic head of 50cm (Fig. 2 & 3). In the layered filtration system, coarser fractions of micro-organisms are filtered by the outer layer and finer fractions are filtered by subsequent inner layers. By this stepped filtration process, the filtration load is shared by all the layers and duration for chocking of pores by organism increases. This helps in decreasing back wash frequency. Also, size wise stepped down filtration by layers in this system enhances easy and faster removal of clogged organisms during the back wash.

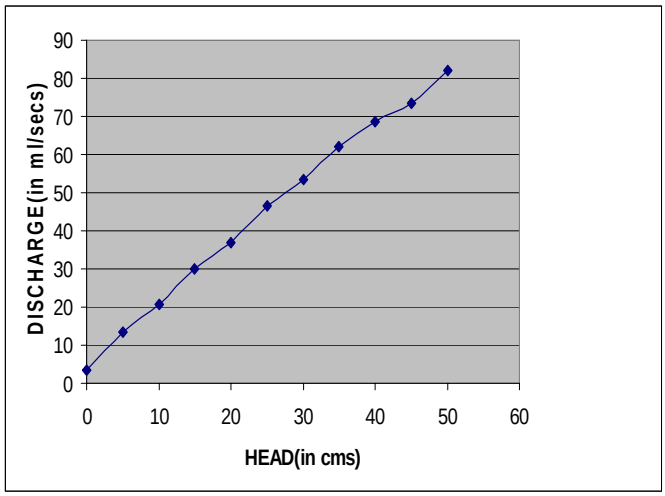

Fig. 2. Discharge Vs hydraulic head for the layered filtration medium

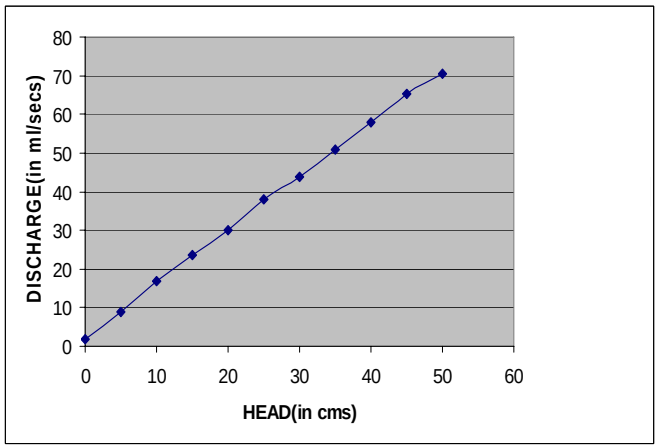

Fig. 3. Discharge Vs hydraulic head for the mixed sand filtration medium

Though the quality of filtered seawater with respect to zooplankton is same (Table1 & 2) with both the layered and mixed sand filter medium, former gives better efficiency (92-95%) in the removal of bacteria than the later (50-73%), (Table 3 & 4), which gives enough confidence towards preferring the layered filtration medium.

Table 1. Removal of Zooplankton (Layered sand filter)

Species Name	Pre-filtered		Filtered		Removal %
	Live Nos/ml	Dead Nos/ml	Live Nos/ml	Dead Nos/ml	
Copepod	5	1	0	0	100
Copepod Nauplii	2	0	0	0	100
Cirriped &Nauplii	1	0	0	0	100
Gastropods	-	-	-	-	-
Bivalve	-	-	-	-	-

Table 2. Removal of Zooplankton (Mixed sand filter)

Species Name	Pre-filtered		Filtered		Removal %
	Live Nos/ml	Dead Nos/ml	Live Nos/ml	Dead Nos/ml	
Copepod	3	23	0	0	100
Copepod Nauplii	3	0	0	0	100
Cirriped &Nauplii	2	2	0	0	100
Gastropods	3	2	0	0	100
Bivalve	1	0	0	0	100

Table 3. Removal of colony forming units, cfu. (Layered sand filter)

Set No.	Counts (cfu/ml)		Reduction %
	Pre-filtered	Filtered	
1	5.72×10^6	0.26×10^6	95.45
2	4.18×10^6	0.33×10^6	92.04

Table 4. Removal of colony forming units, cfu. (Mixed sand filter)

Set No.	Counts (cfu/ml)		Reduction %
	Pre-filtered	Filtered	
1	3.75×10^6	0.99×10^6	73.6
2	3.56×10^6	1.76×10^6	50.6

CONCLUSIONS

The layered graded sand filtration medium performs better to mixed sand filtration medium with respect to yield potential and filtration quality. Yield of layered sand filter medium is better with 80ml/sec discharge than mixed sand filtration medium where the discharge is 70ml/sec at the hydraulic head of 50cm. The system of same foot print can give filtration yield close to $300m^3$/hour under 5 kg/m^2 operating pressure. The micro filtering medium made of sub-rounded to rounded sand particle layers performed better in efficiency and yield compared to such layers made of angular sand particles. Size wise stepped down filtration by layers in this system decreases frequency of back wash as well as enhances easy and faster removal of clogged organisms during the back wash.

Though the quality of filtered seawater with respect to zooplankton is same (100% removal) with both the layered and mixed sand filter medium, former gives better efficiency in the removal of bacteria (92-95% removal) than the later (50-73%), which gives enough confidence towards preferring the modified layered graded filtration medium. The system is scalable, rechargeable for maintaining the efficiency. These results are in the positive side of the feasibility of this filtration system for the sea water filtration. after further refinement and modification for handling large quantity seawater with minimum maintenance and cleaning processes.

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